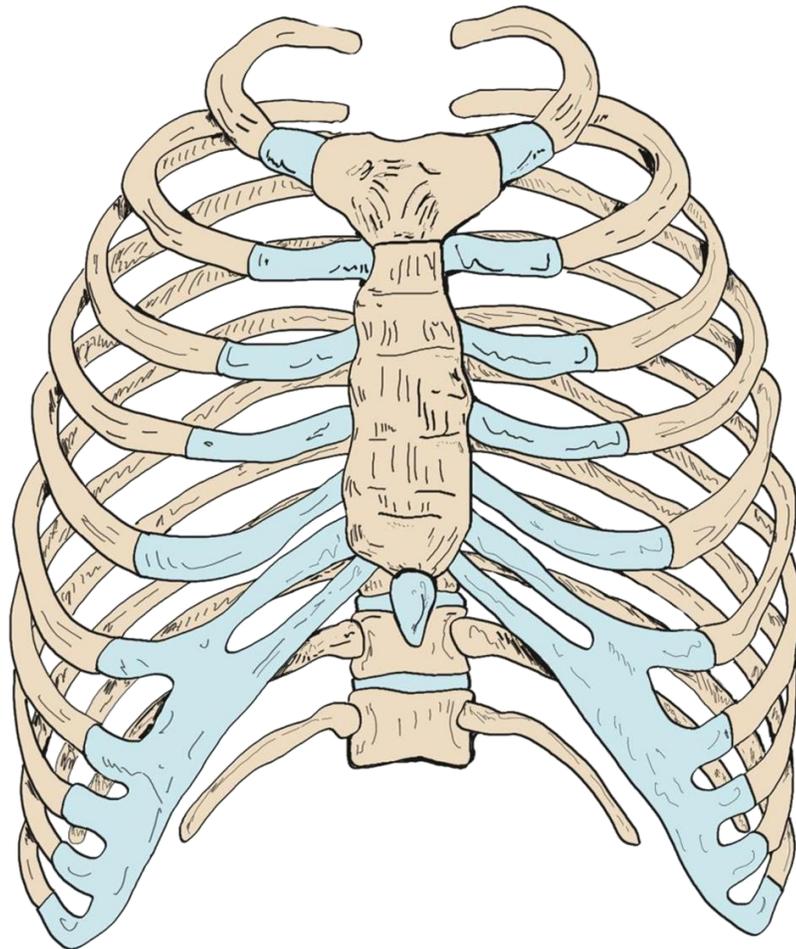


# Principles of **Anatomy & Physiology**

Second edition

Part 1 – Course Companion



**Peter Reuter ♦ Valerie Weiss ♦ Nicola Khalaf ♦ Jason Craddock**

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# **Principles of Anatomy & Physiology**

**Second Edition**

## **Part 1 Course Companion**

**Peter Reuter**

**Valerie Weiss**

**Nicola Khalaf**

**Jason Craddock**

Department of Rehabilitation Sciences  
Marieb College of Health & Human Services  
Florida Gulf Coast University

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Reuter Academic Publishing  
12721 Dresden Court  
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USA  
Email: reutermedical@comcast.net



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## About the Authors

### **Peter Reuter, MD, PhD**

Dr. Reuter received his medical degree and his research doctorate from Johannes Gutenberg University in Mainz/Germany. After publishing his first book in early 1989, Dr. Reuter focused on compiling medical, dental, and scientific dictionaries and databases for print and digital publications. In 1998, he moved to Florida and founded Reuter Medical Inc., a medical and scientific reference publishing company. Overall, he has authored or contributed to more than 100 dictionaries and textbooks as well as other publications published in six languages and nineteen countries.

In 2010, Dr. Reuter set out to fulfill his life-long ambition to teach at a university and to help students achieve their dream of becoming health professionals. He loves teaching undergraduate and graduate courses and tries to inspire students to push themselves to success when courses become challenging.

Outside of teaching, Dr. Reuter enjoys yoga, cycling, pickleball, and traveling as well as spending time with his growing family.

### **Valerie Weiss, MD, MS**

Dr. Weiss received her BA in visual arts from Brown University, including a year of study at the Rhode Island School of Design. She then earned an MD from Brown University Medical School followed by an MS in Medical Illustration from the Medical College of Georgia, where she further studied Anatomy and Physiology while learning to draw the human body.

Prior to becoming a professor, Dr. Weiss had her own business as a medical illustrator, providing medical illustrations to physicians, attorneys, educators, and other professionals. Her illustrations have been published in various books. Additionally, she has lectured to public and business groups about the connection between art and anatomy.

Dr. Weiss has been teaching at the University level since 2005. She previously taught at Hodges University from 2005 to 2012, culminating in being named Hodges University's Professor of the Year. In 2012, Dr. Weiss was excited about the opportunity to teach at Florida Gulf Coast University. She enjoys getting to know her students and challenging them to reach their potential.

Along with spending time with her family, Dr. Weiss enjoys running, swimming, and practicing yoga.

**Nicola Khalaf, PT, DPT, MSPT, MBA**

Dr. Khalaf completed her undergraduate degree at the University of California, Davis with a major in Nutrition and Physiology. After receiving her MS in Physical Therapy from the University of Miami, FL, she joined the rehabilitation team at Orlando Regional Medical center where she explored the vast specialties in the field of physical therapy. Dr. Khalaf then earned her DPT from the University of St. Augustine followed by an MBA from Florida Gulf Coast University.

Prior to starting her teaching career at Florida Gulf Coast University, Dr. Khalaf owned an outpatient physical therapy clinic, serving the rehabilitation needs of her community. Additionally, she merged her love for horses and her passion for her profession by becoming an Equine Rehabilitation Therapist. Additionally, she remains very active within her professional organization by providing seminars and continuing education to her peers.

Since starting at Florida Gulf Coast University in 2017, Dr. Khalaf has shown an interest in examining factors that lead to student success. Her teaching philosophy, therefore, is that every student is capable of learning and has the potential to succeed in reaching their goals provided the right environment, tools, and access and when held accountable for playing an active role in their learning process. She is currently enrolled in the EdD program in order to enhance her skills and competencies in education.

When she is not teaching or working on patients, Dr. Khalaf enjoys martial arts and horse-back riding.

**Jason Craddock, EdD, LAT, ATC, CSCS**

Dr. Craddock earned his Bachelor of Science in Sports Medicine with an emphasis in athletic training from Free Will Baptist Bible College, a Master of Science from Middle Tennessee State University, and his EdD from University of Central Florida.

Dr. Craddock is a Certified Athletic Trainer through the National Athletic Trainer's Association Board of Certification.

Before his appointment at Florida Gulf Coast University, Dr. Craddock worked in outpatient rehabilitation settings, secondary and intercollegiate athletic programs as well as club and professional athletic teams. He is also a Certified Strength and Conditioning Specialist through the National Strength and Conditioning Association and has served as the Strength and Conditioning Coordinator.

## Preface

Since the publication of the first edition of *Principles of Anatomy & Physiology* in 2019, many things have happened. We lived through a pandemic none of us saw coming and, undoubtedly, nobody had hoped for. Nevertheless, even the darkest of clouds usually has a silver lining and for us the challenges posed by pandemic-related restrictions pushed us to explore new ways of teaching our students the basics of Anatomy & Physiology online and in-person. Many of the lessons learned found their way into the changes and revisions we made for this second edition.

Most important, however, was the addition of new instructors to our teaching team and as co-authors to our writing team. Together we developed an improved content outline for *Part 1 Course Companion* and completely redesigned and rewrote *Part 2 Course Companion*.

Both parts are again organized into corresponding chapters. The chapters in *Part 1 Course Companion* introduce students to the chapter topic; the chapters in *Part 2 Lab Workbook* are designed for active learning in the lab and in study groups. The lab sessions of our courses are built around the book chapters, incorporating group learning and integrated lab activities.

One of the more significant features for students is the integration of medical terminology throughout *Part 1 Course Companion*. Students learn about word roots and commonly used prefixes and suffixes, and how to analyze or build new medical terms. Throughout the chapters, the roots of terms are explained to help students understand how medical terminology works in all areas of healthcare in addition to increasing their knowledge and understanding of the material discussed.

In another important change, we increased the *Test Your Knowledge* sections at the end of each chapter in *Part 1 Course Companion* by adding new elements, such as *Matching Word Parts*, *True/False*, and *Matching*, enhancing the sections' utility for self-study or study groups.

As always, we are aware that despite all our efforts this edition still contains errors and omissions, and we encourage readers to give critical feedback so we can improve the book in future editions.



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## Chapter 1 Introduction into Medical Terminology

### 1.1 Chapter Outline

Becoming a knowledgeable healthcare provider is much easier once students understand how word parts work together to form medical terms. We will look at the different word parts and at how to breakdown (analyze) medical terms as well as how to create new ones.

### 1.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Identify the roles of the word parts in forming medical terms.
- Demonstrate the ability to comprehend a new medical term knowing commonly used prefixes, word roots, and suffixes introduced in this chapter and the appendix of this book.
- Recognize the importance of spelling in using medical terminology.
- Define commonly used prefixes, word roots, and suffixes.
- Describe the standard anatomical position and name the three principal body planes.
- Explain the difference between directional and regional terms.
- Create medical terms related to Health Sciences by combining prefixes, word roots, and suffixes.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 1.3 Introduction

The vocabulary of the Health Sciences contains words from many fields (for example, Anatomy, Physiology, Pathology, Pharmacology, and Psychology) that have roots in a number of languages. However, the two most common languages from which terms are traditionally derived are Latin and Greek. Latin was the predominant language for written communication for more than a thousand years, especially during the foundation of modern sciences, including medicine. Even now, newly discovered structures or diseases are sometimes named using Latin or Greek word parts, although clinical medicine has been shifting gradually towards using English terms over the past decades.

Memorizing every single medical term is not the best approach to becoming a competent healthcare provider. While students need to learn and know basic prefixes and suffixes as well as the major combining forms, it is even more important for them to understand the structure of medical terms.

**A medical term may have three parts — a prefix, the word root, and a suffix.** Knowing the meaning of each will help students to understand a variety of terms. Prefixes are found at the beginning of the word and modify the word's meaning. Suffixes are found at the end of a word; they also modify the word's meaning.

### 1.4 Word Roots

**The word root of a medical term is the foundation of a word that gives it meaning.** Word roots typically describe the part of the body or organ involved. For example: **cardi** means *heart*, **gastr** means *stomach*, and **neur** means *nerve*.

Word roots are usually combined with a vowel at the end (often an "o") so that a suffix beginning with a consonant can be added. When word roots are written in this way, they are called **combining forms**. The whole term, when put together as one word, can be easily pronounced. For example: **cardi(o)** means *heart*, **gastr(o)** means *stomach*, and **neur(o)** means *nerve*.

#### What are the rules for using combining form vowels?

1. A combining vowel is used when the suffix begins with a consonant. For example, when the word root **hem(o)**, meaning *blood*, is combined with the suffix **-lysis**, meaning *destruction*, the combining vowel "o" is used because -lysis begins with a consonant. **Hemolysis** is a medical term that describes the *destruction of red blood cells*.

- A combining vowel is not used when the suffix already begins with a vowel. For example, when **neur(o)**, meaning *nerve*, is combined with the suffix **-itis**, meaning *inflammation*, no combining vowel is used because **-itis** already begins with a vowel. **Neuritis** is a medical term that means an *inflammation of a nerve or nerves*.
- A combining vowel is used when two or more word roots are joined. **Gastroenteritis** means *inflammation of the stomach and the small intestine*. It combines the word roots **gastr(o)**, meaning *stomach*, and **enter(o)** meaning *small intestine*. A combining vowel is not used after **enter(o)** because it is joined with the suffix **-itis**, meaning *inflammation*, which already begins with a vowel.

Each chapter of this Course Companion will introduce the combining forms as they relate to the various body organs and systems.

**Table 1.1 Combining Forms**

Combining Form	Meaning	Example(s)
alg(o)-, alge-, algesi(o)-	pain	<i>myalgia</i> = pain in a muscle
arthr(o)-	joint	<i>arthritis</i> = inflammation of a joint
bacteri(o)-	bacteria	<i>bacteriuria</i> = bacteria in the urine
cerebr(o)-	cerebrum	<i>cerebrovascular</i> = relating to the blood vessels of the brain
cyan(o)-	blue	<i>cyanosis</i> = blue discoloration of the skin from a lack of oxygen
dermat(o)-, derm(o)-	skin	<i>dermatologist</i> = physician who specializes in diagnosing and treating disorders of the skin
erythr(o)-	red	<i>erythrocyte</i> = red blood cell
gluc(o)-	sugar, glucose	<i>glucosuria</i> = sugar in the urine
leuk(o)-	white	<i>leukemia</i> = a white blood cell cancer
melan(o)-	black	<i>melanocyte</i> = a cell responsible for producing skin pigment
myel(o)-	spinal cord	<i>myelopathy</i> = disease affecting the spinal cord
pancreat(o)-	pancreas	<i>pancreatitis</i> = inflammation of the pancreas
poli(o)-	gray	<i>poliomyelitis</i> = inflammation of the gray matter of the spinal cord

## 1.5 Prefixes

A **prefix** is added to the beginning of the word to influence the meaning of the word root. Prefixes usually indicate the location, time, number, or status. Some examples of prefixes are:

- Peri-** (meaning *around*) as in **pericardium**; the term *pericardium* refers to the membranous sac around the heart.
- Epi-** (meaning *above*) as in **epigastric**; the term *epigastric* describes the area above the stomach.
- Poly-** (meaning *many*) as in **polyneuritis**; the term *polyneuritis* describes an inflammation of many nerves.
- Hemi-** (meaning *half*) as in **hemiplegia**; the term *hemiplegia* describes a paralysis affecting one side of the body only.
- Endo-** (meaning *inside*) as in **endocrine**; the term *endocrine* means secreting into the inside of the body.
- Exo-** (meaning *outside*) as in **exocrine**; the term *exocrine* means secreting onto the outside of the body.
- Intra-** (meaning *inside*) as in **intracellular**; the term *intracellular* means inside a cell.
- Extra-** (meaning *outside*) as in **extracellular**; the term *extracellular* means outside of a cell.

It is important to be aware that some prefixes can have opposing or contrasting meanings. For example, the prefix **intra-** means inside and the prefix **extra-** means outside. It makes all the difference in the world, whether a substance is found inside or outside a cell. **Endo-** and **exo-** form another pair of contrasting prefixes. Endocrine glands secrete their products into the blood, exocrine glands, onto body surfaces, such as the mucous membrane in the mouth and the skin. Table 1.2 lists other **opposing** or **contrasting prefixes** common in medical terminology.

Table 1.2 Contrasting Prefixes

Prefix	Contrasting Prefix
<b>ab-</b> to move away (from) <i>abduct</i> = to move away from the midline of the body	<b>ad-</b> to move toward <i>adduct</i> = to move toward the midline of the body
<b>dys-</b> abnormal, difficult <i>dyspnea</i> = difficult or labored breathing	<b>eu-</b> normal, good <i>euphoria</i> = a state of well being
<b>hyper-</b> excessive, above normal <i>hypertension</i> = high blood pressure	<b>hypo-</b> below normal <i>hypotension</i> = low blood pressure
<b>pre-</b> before <i>prenatal</i> = before birth	<b>post-</b> after <i>postmortem</i> = after death
<b>tachy-</b> fast <i>tachycardia</i> = fast heartbeat	<b>brady-</b> slow <i>bradycardia</i> = slow heartbeat

## 1.6 Suffixes

A suffix is added to the end of the word root and usually indicates a procedure, condition, disorder, or disease. A suffix can totally change the meaning of a word root. For example:

- **-megaly** (meaning enlargement) as in **cardiomegaly**; the term *cardiomegaly* means an enlargement of the heart.
- **-algia** (meaning pain and suffering) as in **gastralgia**; the term *gastralgia* means pain in the stomach.
- **-itis** (meaning inflammation) as in **tonsillitis**; the term *tonsillitis* means an inflammation of the tonsils.
- **-ectomy** (meaning surgical removal of) as in **tonsillectomy**; the term *tonsillectomy* means surgical removal of the tonsils.

A suffix can make a word root a noun or an adjective. For example:

- **-um** acts as a *noun ending* as in **cranium**; the term *cranium* names the part of the skull that encloses the brain.
- **-ac** and **-al** act as *adjective endings* as in **cardiac** and **renal**; the term *cardiac* means relating to the heart, the term *renal* relating to the kidney.

Many suffixes are related to specific disease conditions or pathology. **Path(o)** is the word root for *disease* and **-ology** is the suffix that means “*the study of*”. Therefore, **pathology** is the *study of diseases*. Other suffixes help identify a particular procedure that is performed on the body part relating to the organ system’s word root.

Table 1.3 Common Suffixes related to Disease Conditions and Procedures

Suffix	Meaning	Example(s)
-algia	pain	<i>neuralgia</i> = pain in the nerves
-ectomy	surgical removal	<i>tonsillectomy</i> = surgical removal of the tonsils
-itis	inflammation	<i>laryngitis</i> = inflammation of the larynx (voice box)
-lysis	destruction	<i>hemolysis</i> = destruction of red blood cells
-malacia	softening	<i>osteomalacia</i> = softening of the bone
-megaly	enlargement	<i>cardiomegaly</i> = enlargement of the heart
-necrosis	tissue death	<i>arterionecrosis</i> = tissue death of an artery or arteries
-otomy	cutting or surgical incision	<i>phlebotomy</i> = puncture of a vein for the purpose of drawing blood
-pathy	disease, suffering	<i>myopathy</i> = disease of the muscle
-ptosis	sagging or drooping	<i>blepharoptosis</i> = drooping of the upper eyelid

Some suffixes begin with two letter “Rs.” These suffixes are sometimes referred to the “**double RRs.**” It is important to understand the differences among these suffixes.

**Table 1.4 “Double R” Suffixes**

Suffix	Meaning	Example(s)
-rrhage, -rrhagia	bleeding (sudden, severe flow)	<i>hemorrhage</i> = sudden, severe loss of blood
-rrhaphy	surgical suturing	<i>myorrhaphy</i> = surgical suturing of muscle
-rrhea	flow (of body fluids)	<i>amenorrhea</i> = absence of menstrual flow
-rrhexis	rupture	<i>myorrhexis</i> = rupture of muscle

## 1.7 Abbreviations, Acronyms, and Symbols

There may not be another field that uses more abbreviations and acronyms than healthcare, and it is of paramount importance for students to know as many as possible and to use them correctly. This chapter introduces only a very limited number. There is a list of Acronyms, Abbreviations, and Symbols in the Appendix.

- **An abbreviation is a shortened form of a word or phrase.** For example, *Dr.* stands for Doctor and *epi* for epinephrine. An abbreviation is **also called a contraction or short form.**
- **An acronym is a word formed from the initial letters of other words; it is pronounced as a word.** For example, *AIDS* stands for Acquired Immune Deficiency Syndrome. Acronyms are sometimes incorrectly called abbreviations.
- **Symbols usually consist of one or more letters and/or numbers that represent an object, function, or process.** For example, in chemistry, the letter combination “*Na*” is the symbol for the element “sodium” (from Latin *natrium*).

**Table 1.5 Examples of Abbreviations, Acronyms, and Symbols**

Acronym/Abbreviation/Symbol	Meaning
BP	blood pressure
bpm	beats per minute
Ca	calcium
CNS	central nervous system
COPD	chronic obstructive pulmonary disease
CVA	cerebrovascular accident (stroke)
ECG, EKG	electrocardiogram
EEG	electroencephalogram
GERD	gastroesophageal reflux disease
GYN	gynecology
ICU	intensive care unit
IM	intramuscular
IV	intravenous
KCl	potassium chloride
kg	kilogram
L	liter
mg	milligram

MI	myocardial infarction
mL, ml	milliliter
OTC	over the counter
PE	physical exam
URI	upper respiratory infection

### 1.8 Eponyms, Antonyms, and Synonyms

An **eponym** is a term or word based on or derived from a person's name. For example, **Lou Gehrig's disease** (or **amyotrophic lateral sclerosis, AML**) was named after an American baseball player who battled the disorder. The Eustachian tube connects the nose and the middle ear; it was named after the Italian anatomist Bartolomeo Eustachi.

- **Antonyms** are words opposite in meaning to another. For example, good and bad are antonyms, as are long and short or wide and narrow.
- **Synonyms** are words or phrases that have exactly or nearly the same meaning as another word or phrase. For example, shinbone and tibia are synonyms, as are thigh bone and femur.
- A **thesaurus** is collection of words, terms, or phrases that have the same (synonyms) or opposite meaning (antonyms).

### 1.9 Plural Forms

The **plural form** of most nouns is created simply by adding the letter 's'. However, there are a number of exceptions to this rule. Table 1.7 lists irregular plural forms commonly used in medical terminology.

**Table 1.6 Irregular Plural Forms**

Singular	Example	Plural	Example
-a	vertebra	-ae	vertebrae
-is	diagnosis	-es	diagnoses
-en	lumen	-ina	lumina
-ma	stigma	-mata	stigmata
-on	phenomenon	-a	phenomena
-um	serum	-a	sera
-ex, -ix, -yx	index	-ices	indices
-nx	phalanx	-nges	phalanges
-us*	thrombus	-i	thrombi

\* exceptions virus (viruses), sinus (sinuses), and plexus (plexuses)

### 1.10 Analyzing and Building Medical Terms

As mentioned above, a medical term may have three parts – a prefix, a word root, and a suffix. When analyzing an unfamiliar medical term, try to identify at least one component you may know.

For example, if you are trying to work out the meaning of the word "**osteonecrosis**," you may already know "**osteo**" as a combining form with the meaning of "**bone**." "**Necrosis**" could be a suffix or it could consist of the combining form "**necr(o)**" and the suffix "**-osis**." The list of Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix defines "**-necrosis**" as "**tissue death**." Now, you can put it all together: **osteo** (bone) + **necrosis** (tissue death) = **bone tissue death**, which is correct.

Sometimes, it may be more difficult to separate a term into its parts. For example, "**epididymitis**" could be separated into "**epi-didym-itis**" or "**epidydim-itis**." In such a case, use either the list in the appendix of this book or a dictionary to

look up “*epi*” and “*epididym*” to find the most likely meaning. You will come to: “*epididym(o)-*” (epididymis) + “*-itis*” (inflammation) = **inflammation of the epididymis**).

Words with a very short or unusual prefix, for example “**apnea**” (*a-* no, *-pnea* breathing) can make it difficult to identify the word parts. This can also be a problem with longer terms made of multiple combining forms and a suffix, such as “**otorhinolaryngologist**”: *oto* (ear) + *rhin(o)* (nose) + *laryng(o)* (throat) + *-ologist* (specialist) = **Ear, Nose and Throat (ENT) specialist**).

Creating new terms is fairly easy as long as you remember that medical vocabulary has a different structure than English vocabulary. For example, in English, we use “*inflammation of*” and “*removal of,*” whereas in medical terminology “*of*” is discarded and “*inflammation*” and “*removal*” are moved to the end of the word. Thus, the terms for **inflammation** (“*-itis*”) and **removal** (“*-ectomy*”) of the **stomach** (“*gastr(o)*”) are “**gastritis**” and “**gastrectomy**,” respectively.

You should be very careful about word elements that have a similar spelling but totally different meanings. For example, “*ped(o)*” relates to the foot, but “*pedi(a)-*” to children or childhood.

Let’s now create a term for the cells that create a dark (black) pigment. The prefix with the meaning “black” is “*melan(o)-*” and the suffix for “cell” is “*-cyte*.” Together, they form the term “*melanocyte*.” To indicate the plural form, add an “*s*” at the end. **Melanocytes** produce the pigment melanin that plays an important part in our skin and hair color.

### 1.11 Standard Anatomical Position and Body Planes

The **standard anatomical position** describes the body in a standing upright position with the hands turned out so that the palms are facing forward. Anatomists and clinicians use this standard position to describe the location of organs or body parts to each other.

**Body planes** are flat surfaces along which the body or a structure is cut for anatomical or pathological study. Any diagonal cut, regardless of the plane it lies in, produces an **oblique section**.

Figure 1.1 Standard anatomical position (left) and body planes (right)

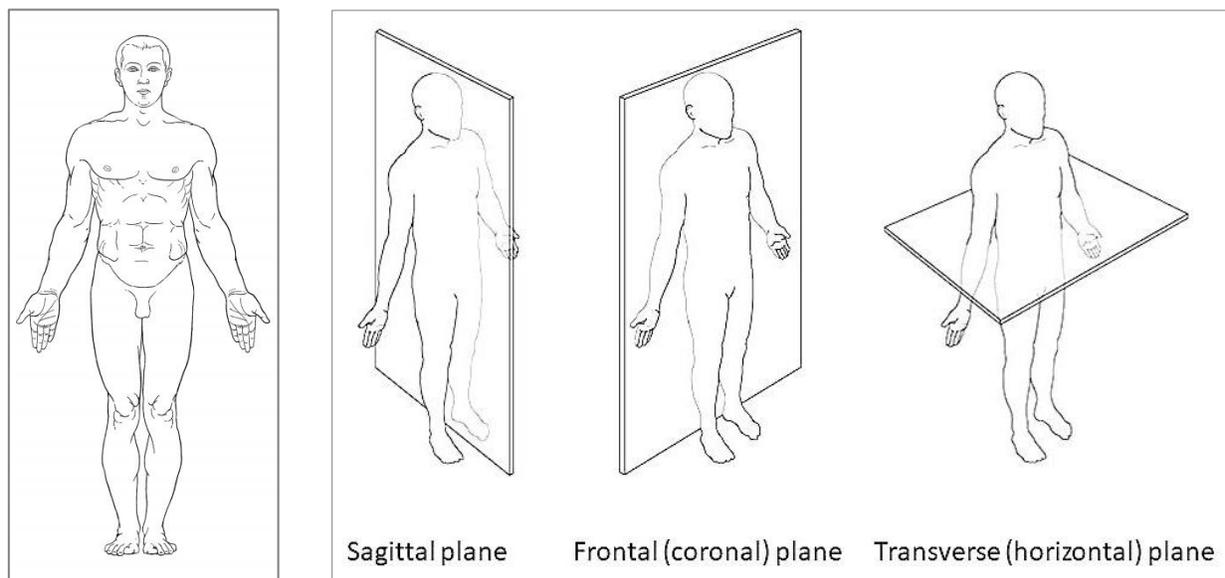
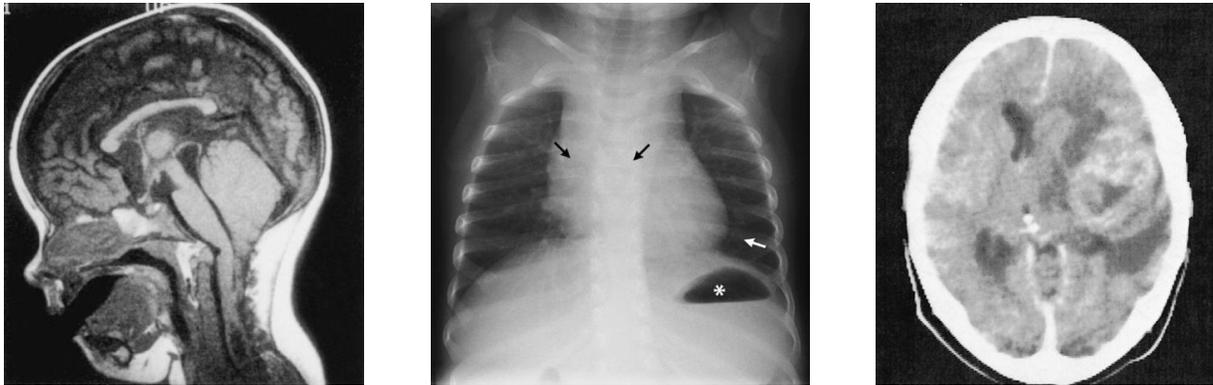


Table 1.7 Body Planes

Plane	Description
Coronal or frontal	Divides the body into anterior and posterior portions.
Transverse or horizontal	Divides the body into superior (upper) and inferior (lower) portions.
Sagittal	Divides the body into left and right portions.
Midsagittal (or median)	Divides the body into <i>equal</i> left and right halves.
Parasagittal	Divides the body into <i>unequal</i> left and right halves.

Figure 1.2 Sagittal plane (MRI, head), frontal plane (X-ray, chest), and transverse plane (CT, brain)



### 1.12 Regional and Directional Terms

**Regional terms** designate specific areas, i.e., they are adjectives relating to a defined structure, while **directional terms** describe the location of a structure in relation to other structures or locations. Some terms, such as cranial, can be used as either regional or directional term.

To remove uncertainty, **directional terms are always based on the standard anatomical position**. For example, the bladder is located lower than the kidney in a standing person, which is why we say “the bladder is inferior to the kidney.” However, in a patient lying flat on their back the kidneys are closer to the ground than the bladder. If we didn’t use the standard anatomical position, we would have to say that the “kidneys are inferior to the bladder.”

Table 1.8 Examples of Regional and Directional Terms

Regional term	Definition	Directional term	Definition
abdominal	relating to the abdomen	anterior	closer to the front of the body
brachial	relating to the arm	contralateral	on opposite sides of the body
cervical	relating to a neck or cervix	cranial	toward the head
cranial	relating to the cranium or skull	deep	farther away from the surface of the body
femoral	relating to the femur	distal	farther away from the body
humeral	relating to the upper arm or humerus	inferior	below, lower
lumbar	relating to the loins	ipsilateral	on the same side of the body
malleolar	relating to ankle/malleolus or ankle region	lateral	away from the midline of the body
nasal	relating to the nose	medial	toward the midline of the body
pelvic	relating to the pelvis	posterior	closer to the back of the body
radial	relating to the radius	proximal	nearer/closer to the body
spinal	relating to the spine or the spinal cord	superficial	close(r) to the surface
thoracic	relating to the thorax or chest region	superior	above; higher

### 1.13 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Meaning	Correct Answer	Answer Options
1.	gray	_____	proct(o)-
2.	before	_____	poli(o)-
3.	rectum	_____	inter-
4.	around	_____	-oma
5.	tumor	_____	pre-
6.	pain	_____	-malacia
7.	excessive	_____	sterc(o)-
8.	between	_____	-algia
9.	feces	_____	peri-
10.	softening	_____	hyper-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

1. The word root of a medical term is the foundation of a word that gives it meaning. \_\_\_\_\_
2. A combining vowel is only used when the suffix begins with a vowel. \_\_\_\_\_
3. Word roots typically describe the part of the body or organ involved. \_\_\_\_\_
4. Prefixes are added to the end of the word root. \_\_\_\_\_
5. A medical term can have three parts — a prefix, the word root, and a suffix. \_\_\_\_\_
6. Suffixes are hardly ever related to specific disease conditions. \_\_\_\_\_
7. A suffix cannot change the meaning of a word root. \_\_\_\_\_
8. Prefixes usually indicate the location, time, number, or status. \_\_\_\_\_
9. Home(o)- is a combining form meaning *same, like or alike*. \_\_\_\_\_
10. Colposcopy is a visual examination of the vagina. \_\_\_\_\_
11. Sideropenia describes a lack of iron in the body. \_\_\_\_\_
12. Arthrodesis is a form of joint inflammation. \_\_\_\_\_
13. A discectomy is a (partial) removal of an intervertebral disc. \_\_\_\_\_
14. The meaning of "ipsilateral" is "away from the midline of the body". \_\_\_\_\_
15. Emet(o)- is a combining form meaning *vomiting*. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                    |                                      |           |
|--------------------|--------------------------------------|-----------|
| 1. Femoral         | a) combining form                    | 1. _____  |
| 2. Graves' disease | b) pain in a muscle                  | 2. _____  |
| 3. Antonyms        | c) gastr(o)-                         | 3. _____  |
| 4. MCHHS           | d) abbreviation                      | 4. _____  |
| 5. Above           | e) opposite meaning                  | 5. _____  |
| 6. Lateral         | f) eponym                            | 6. _____  |
| 7. Myalgia         | g) relating to the femur             | 7. _____  |
| 8. Mrs.            | h) epi-                              | 8. _____  |
| 9. Myel(o)-        | i) acronym                           | 9. _____  |
| 10. Stomach        | j) away from the midline of the body | 10. _____ |

**Multiple Choice**

Choose the one alternative that best completes the statement or answers the question.

- Which terms relate to a defined structure?
  - directional terms
  - regional terms
  - antonyms
  - eponyms
- The suffix “-megaly” means \_\_\_\_\_.
  - shrinking
  - pain
  - enlargement
  - inflammation
- Words that have the same meaning as another word, such as *shinbone* and *tibia*, are called \_\_\_\_\_.
  - eponyms
  - synonyms
  - antonyms
  - hyponyms
- The prefix “tachy-” means \_\_\_\_\_.
  - excessive
  - galloping
  - missing
  - fast
- Which of the following pairs of prefixes is a pair of contrasting prefixes?
  - inter- & endo-
  - pre- & hypo-
  - dys- & eu-
  - mal- & tachy-

6. A \_\_\_\_\_ is a physician specializing in diagnosis and therapy of skin disorders.
- dermatologist
  - proctologist
  - neurologist
  - pulmonologist
7. "AIDS" is a(n)\_\_\_\_\_.
- abbreviation
  - eponym
  - acronym
  - symbol
8. This plane divides the body into right and left halves.
- Frontal
  - Sagittal
  - Transverse
  - Coronal
9. Which plane divides the body horizontally into superior and inferior parts?
- Sagittal plane
  - Median plane
  - Horizontal plane
  - Coronal plane
10. The standard anatomical position describes the body in a \_\_\_\_\_ position.
- sitting
  - standing upright
  - sleeping
  - lying

## Chapter 2 Basic Sciences Review

### 2.1 Chapter Outline

To understand the Anatomy & Physiology of the human body, students need an adequate understanding of basic concepts from Chemistry, Physics, and Biology. This chapter will review some of the major topics; however, students are encouraged to consult textbooks to gain a more thorough understanding if they have not taken college-level classes in Chemistry and/or Biology.

### 2.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the basic structure of carbohydrates, lipids, and proteins.
- Identify and explain the role of major carbohydrates, lipids, and proteins.
- Differentiate between the different lipoproteins relative to their structures and major roles in the body.
- Describe a generalized cell and its main parts and their function.
- Explain the difference between active and passive transport processes across the membrane.
- Define and compare filtration, simple diffusion, facilitated diffusion, and osmosis.
- Describe the different types of ion channels.
- Define resting membrane potential and describe its formation.
- Define and compare graded potentials and action potential.
- Define depolarization and hyperpolarization.
- Describe the events of an action potential and its propagation.
- Define absolute and relative refractory periods.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 2.3 Combining Forms

Table 2.1 lists major combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 2.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
adip(o)-	fat or lipid	<i>adipose</i> = consisting of fat; fat
aqu(i)-, aqu(o)-, aque(o)-	water	<i>aqueous</i> = of or containing water; like water; watery
bi-	two, twice or double	<i>bilayer</i> = a structure consisting of two layers
cyt(o)-	cell	<i>cytosol</i> = the watery component of the cytoplasm
di-	two, twice or double	<i>disaccharide</i> = carbohydrate made of two sugar units
end(o)-	inside	<i>endogenous</i> = growing or originating from inside the body
ex(o)-	outside	<i>exogenous</i> = originating from outside the body
extra-	outside of, beyond, or in addition to	<i>extracellular</i> = located outside a cell
gluc(o)-	sugar or glucose	<i>gluconeogenesis</i> = glucose formation from non-carbohydrate precursors

glyc(o)-, glycos(o)-	sugar or glucose	<i>glycogen</i> = storage form for glucose in animal cells
hydra-, hydr(o)-	water or hydrogen	<i>hydrate</i> = a substance that contains water
inter-	between, among	<i>intercellular</i> = located or happening between cells
intra-	within, into, or during	<i>intracellular</i> = located inside a cell
lipid(o)-, lip(o)-	fat or lipid	<i>lipolysis</i> = the breakdown of fats and other lipids
mono-	one or single	<i>monosaccharide</i> = simple carbohydrate made of one sugar unit
olig(o)-	few	<i>oligosaccharide</i> = carbohydrate made of 3-10 sugar units
poly-	many or much	<i>polypeptide</i> = protein consisting of up to 50 amino acids
prote(o)-	protein	<i>proteolysis</i> = the breakdown of proteins or peptides
sacchar(o)-	sugar	<i>saccharose</i> = table sugar or sucrose
tetra-	four	<i>tetrapeptide</i> = protein consisting of four amino acids
tri-	three	<i>trisaccharide</i> = carbohydrate made of three sugar units

## 2.4 Carbohydrates, Lipids, and Proteins

### Carbohydrates

Carbohydrates contain three chemical elements: carbon (C), hydrogen (H), and oxygen (O). Most carbohydrates contain two atoms of hydrogen and one atom of oxygen for each carbon atom. Therefore, the basic formula is  $C_nH_{2n}O_n$ . **Glucose**, for example, has the formula  $C_6H_{12}O_6$ . Carbohydrates receive their name from the fact that each carbon atom seems to be connected (*hydrated*) with one molecule of water.

Smaller carbohydrate molecules taste sweet, which is why they are called **sugars**. The most basic carbohydrates consist of one unit only and, thus, are called **monosaccharides** (*mono-* one, *saccharide* sugar) or **simple sugars**. **Glucose** (aka **blood sugar** in medicine), **fructose** (**fruit sugar**), and **galactose** are the main monosaccharides of importance for our body. **Ribose** and **deoxyribose** form the backbone of RNA (ribose) and DNA (deoxyribose).

Carbohydrates made of two simple sugar molecules are called **disaccharides**; those consisting of three units are termed **trisaccharides** and so on. The three most common disaccharides are **sucrose** (aka **table sugar**, **cane sugar**, or **saccharose**), **lactose** (aka **milk sugar**), and **maltose** (aka **malt sugar**). Sucrose consists of one molecule each of glucose and fructose; lactose, of one molecule each of glucose and galactose; maltose, of two molecules of glucose.

**Oligosaccharides** are usually formed from 3-10 monosaccharides, and **polysaccharides**, from many sugar units. Polysaccharides can consist of long, linear chains or can be highly branched. These differences in structure determine the properties of specific polysaccharides. Polysaccharides can be used as storage forms for carbohydrates in plants (**starch**) and animals (**glycogen**) as well as structural components, such as **cellulose** in plants and **chitin** in fungi and animals.

### Lipids

Lipids are a diverse group of substances that do not dissolve in polar liquids, such as water, but rather in nonpolar liquids, such as acetone. Lipids are mainly composed of carbon, hydrogen, and oxygen but may contain other elements, such as nitrogen and phosphorus. As far as Anatomy & Physiology is concerned, the major lipids are **neutral fats** or **triglycerides**, **phospholipids**, **cholesterol**, and **eicosanoids**.

Each **triglyceride** consists of one molecule of **glycerol** and three molecules of **fatty acid**. Glycerol is a molecule with three carbon atoms and three **hydroxyl groups** (-OH); fatty acids are long carbon chains with a **carboxyl group** (-COOH) at one end. Triglycerides are mainly used for energy storage and, to a lesser extent, as structural fat. They

make up approximately 95% of all lipids of the human body. Depending on their fatty acids, triglycerides can be subdivided into **saturated fats** that are found in meat, dairy products, and tropical oils (palm oil, coconut oil) and **unsaturated fats** from seeds, nuts, olive oil, and most other vegetable oils. There are **two essential fatty acids (linoleic acid and linolenic acid)** that cannot be synthesized by our body and, therefore, must be ingested with food. They are found in most vegetable oils. All other fatty acids used in our body can be synthesized by the liver.

**Phospholipids** are derived from triglycerides. Replacing one fatty acid by a phosphate group creates a molecule with a **hydrophilic** (“water-loving”) **head** (the phosphate group) and a **hydrophobic** (“water-hating”) **tail** (the two fatty acids). Phospholipids are essential parts of the myelin sheaths of nerves and of the lipid bilayer cell membranes (see below).

**Eicosanoids** are derived from fatty acids. The group contains **prostaglandins**, which have important functions such as smooth muscle contraction and blood pressure control, **thromboxanes**, and **leukotrienes**, which help regulate our immune system.

**Cholesterol** belongs to the **steroids**, which are four-ringed molecules.

It is a substantial part of animal cell membranes and a precursor of steroid hormones, e.g., sex hormones, and of bile salts. Cholesterol is found in egg yolk, meats, shellfish, and milk products. Cholesterol and other lipids cannot be transported in free form in blood because they are not water-soluble. They must be linked to transport proteins; these complexes of lipids and proteins are called **lipoproteins**.

- **HDLs (high-density lipoproteins)** have the highest protein content. They transport excess cholesterol from peripheral tissues to the liver to be broken down and secreted into bile. HDLs also provide cholesterol to steroid-producing organs, such as the adrenal cortex. **High levels of HDL** are thought to protect against heart attack, therefore, HDL is considered to be “*good cholesterol*”.
- **LDLs (low-density lipoproteins)** are cholesterol-rich. They transport cholesterol to peripheral tissues for membranes, storage, or hormone synthesis. **High levels of LDL**, especially lipoprotein (a), increase the risk of heart attack. Consequently, LDL is often called “*bad cholesterol*”.
- **VLDLs (very low density lipoproteins)** contain mostly triglycerides, which they transport to peripheral tissues (mostly adipose connective tissue).
- **Chylomicrons** are formed by cells lining the inside of the small intestine (enterocytes). Their composition depends on the ingested food, but they are mostly made of triglycerides.

The **liver produces cholesterol in response to saturated fatty acids**, which also inhibit cholesterol excretion from the body. Other **factors influencing cholesterol production or excretion** are:

- **Unsaturated fatty acids** enhance excretion of cholesterol. However, **trans fats** increase LDL and reduce HDL. They are found naturally in meat and dairy products. **Cis fats**, on the other hand, are found in most vegetable oils, especially olive oil. They are healthier for us as they enhance the excretion of cholesterol and cannot be used for cholesterol synthesis.
- **Omega-3 fatty acids** from cold-water fish are supposed to lower the proportions of saturated fats and cholesterol, lower blood pressure, help prevent spontaneous blood clotting, and have antiarrhythmic effects on the heart.
- **Stress, cigarette smoking, and coffee** lower HDL levels.
- **Aerobic exercise and estrogen** increase HDL levels and decrease LDL levels.

## Proteins

**Amino acids** are the building blocks of proteins. Each amino acid contains one amino group (-NH<sub>2</sub>), one carboxyl group (-COOH), one hydrogen atom, and one side chain attached to the same carbon atom. There are 20 basic types of amino acids with different side chains. Two amino acids bound together by a so-called peptide bond form a **dipeptide**; three amino acids, a **tripeptide**; four amino acids, a **tetrapeptide** and so forth. **Polypeptides** consist of long

Figure 2.1 Triglyceride

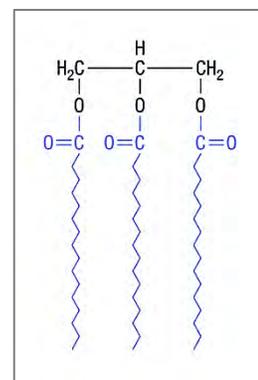
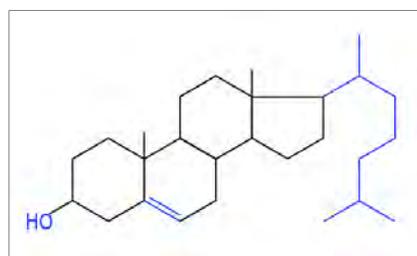


Figure 2.2 Cholesterol



chains of amino acids bound together by peptide bonds. When the chain contains more than 50 amino acids, the substance is called a **protein**.

The sequence of amino acids linked together to form a protein is called the **primary structure** of the protein. The **secondary structure** results from folding of the protein chain, which is caused by hydrogen bonds between the amino acids of the chain. If these hydrogen bonds are broken, the shape of the protein changes and it becomes nonfunctional. This process is called **denaturation**; it happens when eggs get fried or boiled, for example. The three-dimensional structure of a protein caused by the folding of the chain is called **tertiary structure**; it is important for the physical properties of the protein. Complex proteins consist of two or more individual protein chains or subunits, giving them a **quaternary structure** that is based on the spatial arrangement of the subunits. Hemoglobin, the oxygen-carrying protein of the red blood cells, consists of four protein chains, two alpha chains and two beta chains (see **Chapter 18 Blood, Hemostasis, and Blood Groups**). Proteins are used as **structural materials** for our body, for example, as keratin in skin and hair, but also play important roles as **functional proteins**, especially as **enzymes**.

### Check Your Understanding

- Which type of lipid is used to create hormones?
  - Phospholipid
  - Triglyceride
  - Cholesterol
  - Cellulose
- Which lipoprotein is also called “good cholesterol”?
  - Low-density lipoprotein
  - Very low-density lipoprotein
  - Chylomicrons
  - High-density lipoprotein
- The major storage polysaccharide in humans is \_\_\_\_\_.
  - Fats
  - Glycogen
  - Cellulose
  - Lipids
- Amino acids are the building blocks of \_\_\_\_\_.
  - Proteins
  - Carbohydrates
  - Eicosanoids
  - Triglycerides

1.C.2.B.3.D.4.A

## 2.5 Cells

Cells form tissues and organs, and are capable of undergoing changes to carry out specific functions.

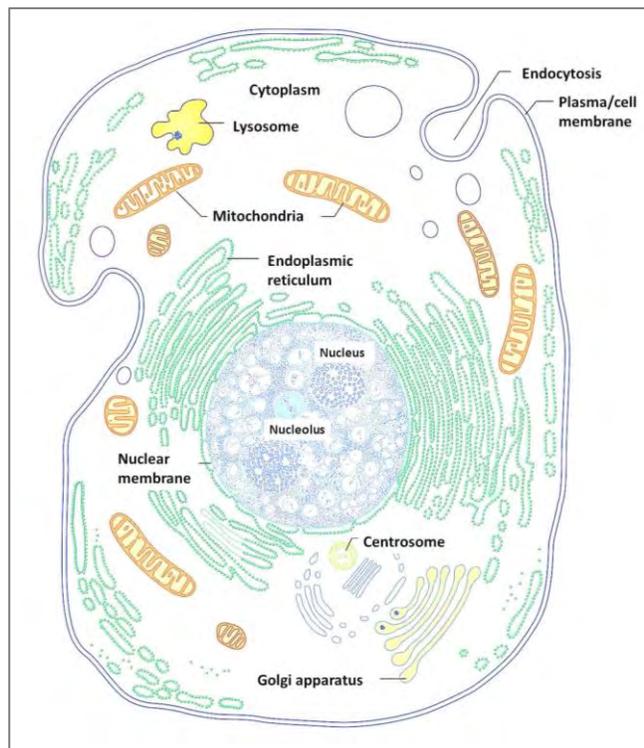
**Cell theory** came about when microscopes were invented, allowing us to see cells for the first time. It has four concepts:

- Cells are the basic structural and functional units of life.
- Tissue, organ, and organismal functions depend on individual and collective cell functions.
- The biochemical activities of cells are dictated by their specific subcellular structures (organelles).
- The continuity of life has a cellular basis; i.e., without living cells, there are no living tissues, organs, or organisms.

### Cell Structure

Animal cells have some common structures and functions. All body cells except mature red blood cells have a **nucleus**. The nucleus is the control center of the cell and contains the cellular **DNA**. Most cells have only one nucleus (**mononucleate cells**), but very large cells, such as skeletal muscle cells, may have many nuclei (**multinucleate cells**).

Figure 2.3 Generalized human cell



The nucleus is surrounded by a nuclear membrane that separates the **nucleoplasm** from the cytoplasm outside of the nucleus. The main component of the nucleoplasm is **chromatin**, which itself is mainly made up of DNA. When a cell prepares to divide, chromatin condenses into dense, rod-like structures called **chromosomes**. A **nucleolus** is a dark-staining, spherical body within the nucleus; typically, one or two per nucleus. The nucleolus is the site where the information contained in our DNA is read and transcribed into instructions for the production of proteins.

The **cytoplasm** is the cellular material inside the cell membrane. Its three major elements are:

1. **Cytosol** – Water with solutes (protein, salts, sugars, etc.).
2. **Cytoplasmic inclusions** – Granules of glycogen (a storage form of glucose), pigments, lipid droplets, vacuoles, or crystals.
  - **Cytoplasmic organelles** – The metabolic machinery of the cell. Each cell contains thousands of organelles with specific functions depending on the overall function of the cell.
  - **Mitochondria** are the powerhouses of the cell. They burn nutrients, such as sugar and fat. They require oxygen and store the energy released from nutrients in the form of ATP (adenosine triphosphate). ATP is used to power biochemical and physical processes inside the cell. Mitochondria have their own DNA and, therefore, can cause certain disorders that are passed on from mothers to their children.
  - The **endoplasmic reticulum (ER)** is the site of protein and fat production (for example, hormones).
  - The **Golgi apparatus** packs proteins and fats and ships them to other parts of the cell.
  - **Lysosomes** are important for destruction of bacteria, viruses, toxins, and injured or non-useful tissue.

### Cellular Extensions

1. **Cilia** are whip-like, motile cellular extensions on the exposed apical surfaces of some cells that move substances across cell surfaces.
2. **Flagella** are long cellular projections that move the cell through the environment, e.g., the tail of the sperm.
3. **Microvilli** are finger-like extensions of the plasma membrane that increase the surface area of a cell, e.g., for absorption.

**Table 2.2 Cytoplasmic Organelles**

#### Membranous Organelles

- **Mitochondria** - Double-membrane structure with shell-like cristae; contain their own DNA and RNA; provide most of the cell's ATP via aerobic cellular respiration (powerhouse of the cell).
- **Endoplasmic Reticulum (ER)** - Interconnected tubes and parallel membranes enclosing cisternae; continuous with nuclear membrane.
  - **Rough ER** - External surface studded with ribosomes; synthesizes all secreted proteins, membrane integral proteins and phospholipids.
  - **Smooth ER** - Tubules arranged in a looping network; enzyme function, e.g., lipid and cholesterol metabolism; synthesis of steroid hormones.
- **Golgi apparatus** - Stacked and flattened membranous sacs; modifies, concentrates, and packages proteins and lipids.
- **Lysosomes** - Spherical membranous bags containing digestive enzymes (acid hydrolases); digest ingested bacteria, viruses, toxins, nonfunctional organelles, and injured or nonuseful tissue.
- **Peroxisomes (aka microbodies)** - Membranous sacs containing powerful oxidases and catalases; detoxify harmful or toxic substances.

#### Nonmembranous Organelles

- **Cytoskeleton**: Elaborate series of rods throughout cytosol.
  - **Microfilaments** - Actin strands involved in cell motility, change in shape, endocytosis and exocytosis.
  - **Intermediate Filaments** - Tough ropelike protein fibers; resist pulling forces on the cell and attach to desmosomes.
  - **Microtubules** - Dynamic hollow tubes mostly radiating from centrosome.
- **Ribosomes** - Granules containing protein and rRNA; site of protein synthesis; free ribosomes synthesize soluble proteins, membrane-bound ribosomes synthesize proteins to be incorporated into membranes or exported from the cell.

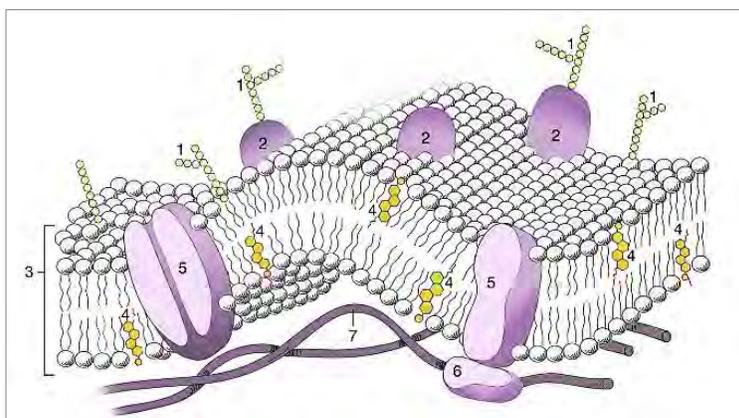
- **Centrosome** - Region near the nucleus that functions as a microtubule organizing center, and forms the mitotic spindle during cell division.
- **Centrioles** - Small, barrel-shaped organelles associated with the centrosome. Also form the bases of cilia and flagella.

The **plasma** or **cell membrane** is not rigid or strong but forms a flexible boundary around the cell. Its main task is to separate the fluid inside the cell (**intracellular fluid**) from the fluid outside the cell (**extracellular fluid**). The fluids have different compositions and need to be separated for normal cell function. However, the membrane will allow certain substances to pass through easily, making it **selectively permeable**.

Cell membranes are made of **two layers of lipids with integrated protein structures**. **Membrane lipids** are 75% **phospholipids** (they have polar and hydrophilic phosphate heads and nonpolar and hydrophobic fatty acid tails), 5% **glycolipids** (lipids with polar sugar groups on the outer membrane surface), and 20% **cholesterol** (increases membrane stability and fluidity).

**Lipid rafts** cover ~ 20% of the outer membrane surface. They contain phospholipids, sphingolipids, and cholesterol. Lipid rafts may function as stable platforms for cell-signaling molecules.

Figure 2.4 Plasma membrane



1. Polysaccharide chain
2. Glycoprotein
3. Phospholipid bilayer
4. Cholesterol molecule
5. Integral protein
6. Peripheral protein
7. Cytoskeleton (filaments)

There are three types of **cell junctions**:

1. **Tight junctions** prevent fluids and most molecules from moving between cells.
2. **Desmosomes** are “rivets” or “spot-welds” that anchor cells together.
3. **Gap junctions** are transmembrane proteins that form pores that allow small molecules to pass from cell to cell, e.g., ions between cardiac or smooth muscle cells.

### Check Your Understanding

1. Plasma membranes consist of which three components?
  - a) Phospholipids, glycoproteins, water
  - b) Proteins, cholesterol, fatty acids
  - c) Cholesterol, fatty acids, glycolipids
  - d) Proteins, phospholipids, cholesterol
2. Which cell junctions are rivets that anchor cells together?
  - a) Tight junctions
  - b) Gap junctions
  - c) Desmosomes
  - d) Full junctions
3. Whip-like, motile cellular extensions that move substances across cell surfaces are called \_\_\_\_\_.
  - a) Flagella
  - b) Microvilli
  - c) Cilia
  - d) Microfilaments
4. In the cell, DNA is found in the \_\_\_\_\_.
  - a) Cytosol
  - b) Nucleus
  - c) Plasma membrane
  - d) Nuclear membrane

## 2.6 Transport Processes across Membranes

### Passive transport

Passive transport processes require no cellular energy (ATP) because a concentration gradient provides the force required to move; i.e., the substance (solute) moves down its concentration gradient from high to low concentration. Whether or not a substance can passively move across (permeate) a membrane is determined by a) the **lipid solubility of the substance** – lipid-soluble molecules permeate freely through the plasma membrane, and b) the **presence or absence of channels of appropriate size or carrier proteins** – water-soluble (hydrophilic) substances cannot cross the plasma membrane and, therefore, require channels or carrier proteins.

In **simple diffusion**, nonpolar lipid-soluble (hydrophobic) substances diffuse directly through the phospholipid bilayer.

In **facilitated diffusion**, transmembrane proteins transport specific molecules. The transport proteins are highly selective, can be saturated (i.e., the transport rate is limited by the number of transport proteins), and can be regulated.

- In **facilitated diffusion using carrier proteins**, the binding of the substrate (e.g., sugars and amino acids) causes a shape change of the transmembrane integral proteins.
- In **facilitated diffusion using channel proteins**, transmembrane proteins form aqueous channels that selectively allow water or ions to pass through. If the channel proteins are always open, then they are called **leakage channels**; if they can be opened or closed by chemical, mechanical, or electrical signals, they are termed **gated channels**.

Movement of solvent (water in the human body) across a selectively permeable membrane along a concentration gradient is called **osmosis**. Some water can diffuse through the plasma membrane, but the bulk uses water channels called **aquaporins**.

The movement of the water is caused by a difference in the solute concentration in the water. Water concentration is determined by solute concentration, because solute particles displace water molecules; i.e., the higher the solute concentration, the lower the water concentration. Therefore, **water moves from the side of lower solute concentration to the side with higher solute concentration**.

### Active transport

Active transport processes require energy (ATP) and, thus, occur only in living cell membranes. They can be subdivided into **active transport**, which uses carrier proteins (solute pumps) to move solutes against a concentration gradient, and **vesicular transport**, which surrounds larger particles or fluids with plasma membrane.

In **primary** (or **direct**) **active transport** energy from hydrolysis of ATP causes shape change in a transport protein so that bound solutes (ions) are “pumped” across the membrane.

- The **sodium-potassium pump** or **Na<sup>+</sup>-K<sup>+</sup> ATPase**, which is found in all plasma membrane, is the most common pump. It is an enzyme complex involved in active transport of ions and nutrients. It helps maintain (electrochemical) gradients essential for functions of muscle and nerve tissues and the kidneys.

**Secondary** (or **indirect**) **active transport** depends on an ion gradient already created by primary active transport. Energy stored in this gradient is used indirectly in the second step to drive transport of other solutes.

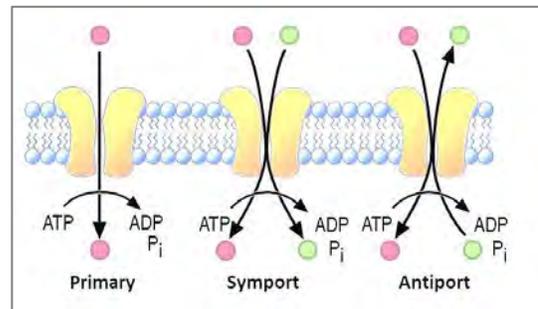
In **cotransport** more than one substance is transported at the same time.

- If the substances are transported in the same direction, it is called a **symport system**.
- If the substances are transported in opposite directions, it is called an **antiport system**.

**Vesicular transport** moves large particles, macromolecules, and fluids across plasma membranes.

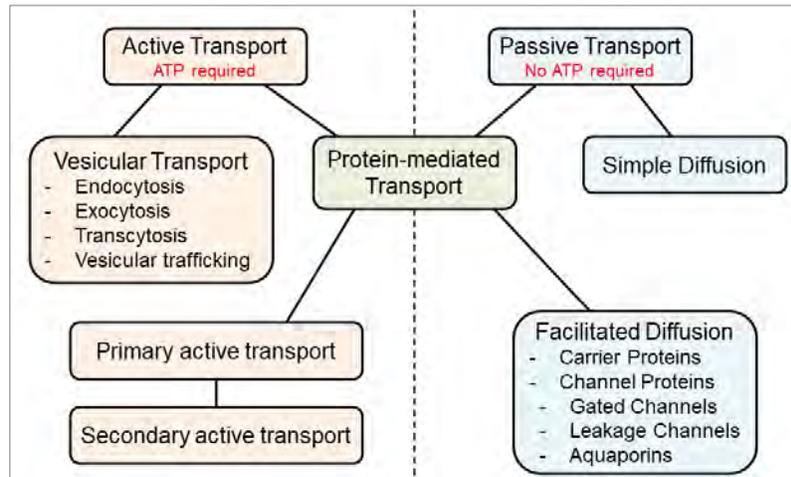
- Transport out of a cell is called **exocytosis**; transport into a cell, **endocytosis**.
- **Phagocytosis** is used by some white blood cells (e.g., macrophages) to engulf solids and bring them into the cell.

**Figure 2.5 Primary and secondary active transport**



- **Pinocytosis** or **fluid-phase endocytosis** is sometimes referred to as “*drinking of the cell*” as it is used to bring fluids into the cell.
- In **receptor-mediated endocytosis**, special proteins (clathrins) are used to import enzymes, low-density lipoproteins, and minerals.
- Transport through a cell (into, across, and then out of the cell) is called **transcytosis**.
- Transport from one area or organelle in cell to another is called **substance** or **vesicular trafficking**.

Figure 2.6 Transport processes across membranes



### Check Your Understanding

1. In which transport process is the energy from hydrolysis of ATP used to drive substances across the membrane against their own concentration gradients?
  - a) Facilitated diffusion
  - b) Primary active transport
  - c) Facilitated diffusion
  - d) Osmosis
2. If the solute concentration is greater in the solution on the inside of the cell, compared to the solute concentration of the solution that is outside the cell, then what direction will water move?
  - a) into the cell
  - b) out of the cell
  - c) into and out of the cell
3. Which is a transport process by which cells take up extracellular substances within vesicles?
  - a) Endocytosis
  - b) Pinocytosis
  - c) Exocytosis
  - d) Osmosis
4. In which transport process is the energy stored in a  $\text{Na}^+$  concentration gradient used to drive other substances across the membrane against their own concentration gradients?
  - a) Primary active transport
  - b) Secondary active transport
  - c) Facilitated diffusion
  - d) Passive diffusion

1.B.2.A.3.A.4.B

## 2.7 Resting Membrane Potential and Action Potential

The **resting membrane potential (RMP)** is the potential difference across the membrane of a resting cell. The RMP ranges from  $-50$  to  $-100$  mV in different cells. It is negative because the inner cytoplasmic side of the membrane is negatively charged relative to the outside. The RMP results from diffusion and active transport of ions and is generated by:

- **Differences in the ionic makeup of ICF and ECF:**  $\text{Na}^+$  has a much higher concentration outside cells (ECF) than inside (ICF), while  $\text{K}^+$  has a much higher concentration inside cells (ICF) than outside (ECF).  **$\text{Na}^+-\text{K}^+$  pumps** continuously eject  $\text{Na}^+$  from cells and carry  $\text{K}^+$  back in.
- **Differential permeability of the plasma membrane**, which is slightly permeable to  $\text{Na}^+$  (through leakage

channels), but is 75-times more permeable to  $K^+$  (more leakage channels).

### Membrane Ion Channels

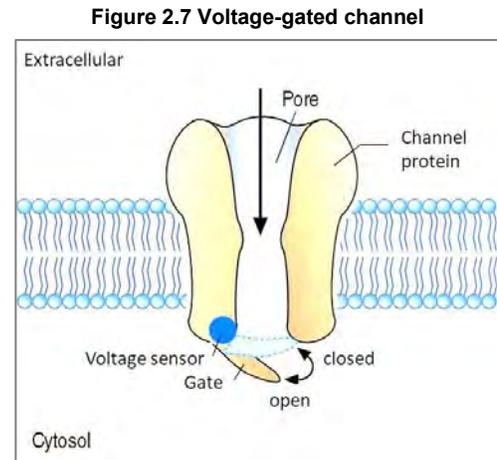
The different types of ion channel play different roles in establishing and maintaining a resting membrane potential. **Leakage (nongated) channels** are always open, **gated channels** can be opened and closed.

There are three types of **gated channels**:

1. **Chemically gated** (ligand-gated) **channels** open with binding of a specific neurotransmitter.
2. **Voltage-gated channels** open and close in response to changes in the membrane potential.
3. **Mechanically gated channels** open and close in response to physical deformation of receptors.

When gated channels are open, ions diffuse quickly across the membrane along their electrochemical gradients:

- Down a **chemical concentration gradient** from higher to lower concentration.
- Along an **electrical gradient** toward an opposite electrical charge.
- The ion flow creates an electrical current and voltage changes across the membrane.



### Generation and Maintenance of the Resting Membrane Potential

Some  $K^+$  **continually diffuses** down its concentration gradient **out of the cell** through  $K^+$  leakage channels, making the interior negative compared to the outside.

Some  $Na^+$  **diffuses** down its concentration gradient **into the cell** through  $Na^+$  leakage channels, offsetting some of the negativity.

**The RMP is established at the point where the electrical gradient balances the  $K^+$  and  $Na^+$  concentration gradients and there is no net flow of ions into or out of the cell.** The negative interior of the cell is due to much greater diffusion of  $K^+$  out of the cell than  $Na^+$  diffusion into the cell.

**Sodium-potassium pumps** stabilize the resting membrane potential by maintaining the concentration gradients for  $Na^+$  and  $K^+$ .

**Changes in the membrane potential** are used to receive, integrate, and send information. The membrane potential changes when:

- Concentrations of ions across the membrane change.
- Permeability of the membrane to ions changes, for example, by opening or closing of gated channels.

**Depolarization** is defined as a reduction in membrane potential toward zero. The inside of the membrane becomes less negative than the resting potential, which increases the probability of producing a nerve impulse.

**Hyperpolarization** is defined as an increase in membrane potential away from zero. The inside of the membrane becomes more negative than the resting potential, which reduces the probability of producing a nerve impulse.

### Graded Potential

A graded potential is a **short-lived, localized change in the membrane potential** that is **used as a short-distance signal**. Graded potentials occur when a stimulus causes gated ion channels to open, leading to depolarization or hyperpolarization. The magnitude varies directly with stimulus strength (i.e., is graded). Graded potentials decrease in magnitude with distance as ions flow and diffuse through leakage channels.

### Generation of an Action Potential

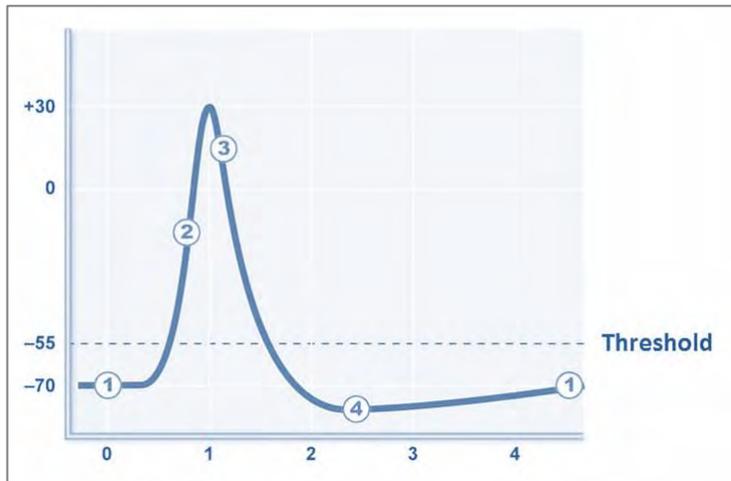
An **action potential (AP)** is a **brief reversal of the membrane potential** with a total amplitude of  $\sim 100$  mV. It occurs only in muscle cells and the axons of neurons. Unlike graded potentials, action potentials do not decrease in magnitude over distance. Therefore, **they are the principal means of long-distance neural communication**.

1. In the **resting state**, only leakage channels for  $Na^+$  and  $K^+$  are open. All gated  $Na^+$  and  $K^+$  channels are closed.
2. **Depolarizing phase**: Depolarizing local currents open voltage-gated  $Na^+$  channels and the increased  $Na^+$  influx

causes more depolarization. At the threshold, a positive feedback leads to opening of all Na<sup>+</sup> channels, leading to a massive influx of Na<sup>+</sup> and a reversal of the membrane polarity to +30mV (spike of the action potential).

3. **Repolarizing phase:** Na<sup>+</sup> channels close and the membrane permeability for Na<sup>+</sup> declines to resting levels. Slow, voltage-sensitive K<sup>+</sup> gates open, K<sup>+</sup> exits the cell, and internal negativity is restored.
4. **Hyperpolarization:** Some K<sup>+</sup> channels remain open, allowing excessive K<sup>+</sup> outflow. This causes after-hyperpolarization of the membrane (**undershoot**).

**Figure 2.8 Action potential**



1. Resting membrane potential
2. Depolarization (spike)
3. Repolarization
4. Hyperpolarization (undershoot)

Repolarization restores the resting electrical conditions of the neuron but not resting ionic conditions. **Sodium-potassium pumps** have to pump Na<sup>+</sup> out and K<sup>+</sup> in to **restore ionic distribution back to resting conditions**.

The **absolute refractory period** is the time from the opening of the Na<sup>+</sup> channels until the resetting of the channels. During this time **no action potential can be generated regardless of the strength of the stimulus!**

The **relative refractory period** follows the absolute refractory period. Most Na<sup>+</sup> channels have returned to their resting state, some K<sup>+</sup> channels are still open, and repolarization is occurring. The threshold for generation a new action potential is elevated, however, exceptionally strong stimuli may generate an AP.

**An action potential is an all-or-nothing phenomenon** - action potentials either happen completely or not at all. All action potentials are alike and independent of the stimulus intensity; i.e., strong or prolonged stimuli cannot generate stronger action potential. But, they can generate action potentials more often than weaker stimuli.

## 2.8 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Meaning	Correct Answer	Answer Options
1.	fat	_____	poly-
2.	cell	_____	sacchar(o)-
3.	twice, double	_____	hydr(o)-
4.	four	_____	olig(o)-
5.	sugar	_____	adip(o)-
6.	many or much	_____	co-

7.	water	_____	end(o)-
8.	together, with	_____	bi-
9.	inside	_____	tetra-
10.	few	_____	cyt(o)-

**True/False**

Write "T" on the line if the statement is true and "F" if the statement is false.

- Desmosomes are junctions that allow cell communication. \_\_\_\_\_
- Diffusion is always from areas of greater concentration to areas of lesser concentration. \_\_\_\_\_
- The process of secondary active transport requires no energy. \_\_\_\_\_
- In osmosis water moves toward the solution with the lower solute concentration. \_\_\_\_\_
- Ribosomes attach to smooth endoplasmic reticulum. \_\_\_\_\_
- Cytosol consists mostly of water. \_\_\_\_\_
- Body cells exhibit a resting membrane potential ranging from -50 to +50 millivolts. \_\_\_\_\_
- A concentration gradient must be present for diffusion to occur. \_\_\_\_\_
- The major energy storage polysaccharide in humans is cellulose. \_\_\_\_\_
- Cholesterol is used by the body to create hormones. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                     |   |           |
|---------------------|---|-----------|
| 1. ATP              | a) transport into the cell                                  | 1. _____  |
| 2. Glucose          | b) finger-like extensions of the plasma membrane            | 2. _____  |
| 3. Endocytosis      | c) actual site of protein synthesis                         | 3. _____  |
| 4. Leakage channel  | d) abundant in tissues subjected to great mechanical stress | 4. _____  |
| 5. Cholesterol      | e) a brief reversal of the membrane potential               | 5. _____  |
| 6. Microvilli       | f) provides the energy needed for synthesis reactions       | 6. _____  |
| 7. Action potential | g) important part of plasma membrane                        | 7. _____  |
| 8. Phospholipid     | h) always open  | 8. _____  |
| 9. Ribosomes        | i) blood sugar  | 9. _____  |
| 10. Desmosomes      | j) steroid  | 10. _____ |

## Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

1. Cell junctions that are important in cell communication are \_\_\_\_\_.
  - a. tight junctions
  - b. gap junctions
  - c. desmosomes
  - d. plaques
2. What must be present for diffusion to occur?
  - a. Energy
  - b. Aquaporins
  - c. Protein carriers
  - d. A concentration gradient
3. In a cell, proteins are synthesized at the \_\_\_\_\_.
  - a. Golgi apparatus
  - b. mitochondrion
  - c. smooth endoplasmic reticulum
  - d. ribosome
4. The characteristic of plasma membranes allowing only some substances to pass through is known as \_\_\_\_\_.
  - a. selective permeability
  - b. concentration gradient
  - c. electrical gradient
  - d. transportation
5. Which part of the cell serves to process, package, and export proteins?
  - a. Rough endoplasmic reticulum
  - b. Mitochondria
  - c. Golgi apparatus
  - d. Centrioles
6. The three parts of a generalized cell are?
  - a. Plasma membrane, cytoplasm, nucleus
  - b. Lysosomes, peroxisomes, mitochondria
  - c. Plasma membrane, cytoskeleton, nucleolus
  - d. Centrioles, ribosomes, endoplasmic reticulum
7. During which period can a second action potential be initiated by a larger than normal stimulus?
  - a. Depolarization period
  - b. Absolute refractory period
  - c. Relative refractory period
  - d. Before the depolarization period
8. At rest, a cell will have more \_\_\_\_\_ ions in the cytoplasm than outside the cell.
  - a. sodium
  - b. chloride
  - c. potassium
  - d. calcium
9. The potential difference across the membrane of a resting cell is referred to as \_\_\_\_\_.
  - a. graded potential
  - b. action potential
  - c. resting membrane potential
  - d. hyperpolarization

10. An increase in cell membrane potential towards a more negative value is known as \_\_\_\_.
- a. depolarization
  - b. repolarization
  - c. overshoot
  - d. hyperpolarization



## Chapter 3 Introduction into Anatomy & Physiology

### 3.1 Chapter Outline

Anatomy & Physiology are the foundation of the Health Sciences. Students not only need to know and understand the structure and function of the whole body, but also have knowledge of its parts down to the cellular level and below. This chapter will help students understand the connection between the different systems and the overall health of the body.

### 3.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Define Anatomy & Physiology and related subdivisions and describe their importance for the medical field.
- Explain the principle of complementarity in terms of structure and function.
- Describe the different levels of structural organization starting with the simplest level.
- Name the eleven organ systems of the body and their major functions.
- Define homeostasis and explain how negative and positive feedback mechanisms work.
- Name and explain necessary life functions and survival needs.
- Name the major body cavities and abdominopelvic regions and quadrants.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 3.3 Combining Forms

Table 3.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 3.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
abdomin(o)-	abdomen	<i>abdominopelvic</i> = relating to the abdomen and pelvis
crani(o)-	skull (cranium)	<i>craniospinal</i> = relating to the cranium and spinal column
dorsi-, dorso-	back (dorsum)	<i>dorsal</i> = relating to the back; towards the back
epi-	upon, above, or beside	<i>epigastric</i> = located above the stomach
end(o)-	inside	<i>endogenous</i> = growing or originating from inside the body
ex(o)-	outside	<i>exogenous</i> = originating from outside the body
extra-	outside of, beyond, or in addition to	<i>extracellular</i> = located outside a cell
gastr(o)-	stomach	<i>gastrophrenic</i> = relating to the stomach and diaphragm
hypo-	below, less than normal, or insufficient	<i>hypogastric</i> = located below the stomach
intra-	within, into, or during	<i>intracellular</i> = located inside a cell
spin(o)-	spine; backbone (spinal column)	<i>spinal</i> = relating to the spine or the spinal cord
ventr(o)-	belly	<i>ventral</i> = toward or at the front of the body; in front of

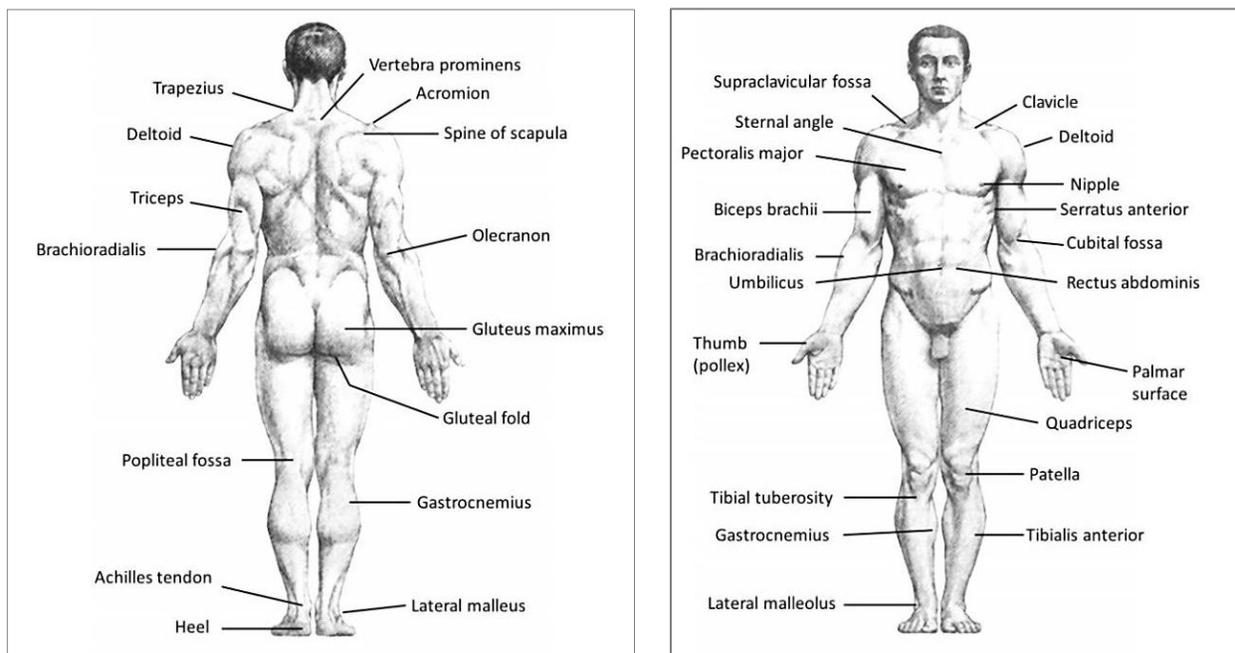
### 3.4 Overview of Anatomy and Physiology

**Anatomy is the study of the structure of the body or its parts.** The term derives from *ana-* (apart) and *-tomy* (cutting), which reflects how early anatomists studied the body: they cut dead bodies into pieces and then described and named those pieces. In the early days, anatomy was restricted to the study of structures that could be seen with the unaided eye (**gross** or **macroscopic anatomy**). Once the microscope was invented at the end of the 16<sup>th</sup> century, scientists were also able to study smaller structures, and **microscopic anatomy** was born.

There are many **subdivisions of anatomy**. The most important for our purpose are:

- **Surface anatomy** studies the surface of the body as well as structures that are visible underneath the surface, such as the kneecaps. It is essential for assessing the human body in a clinical situation. Furthermore, the skin is extremely helpful in revealing general health conditions. For example, in liver disease, the skin turns yellow or becomes jaundiced. In addition, we can identify a number of important muscles by simply looking at the body. Some landmarks of the skeletal system, such as the acromion, sternal angle, and vertebra prominens, will be discussed further in later chapters.
- **Systemic anatomy** subdivides the body into systems, such as the cardiovascular system (**cardiovascular anatomy**).
- **Regional** or **topographical anatomy** focuses on the interaction of different systemic structures in a defined region of the body, such as the shoulder or hip. Many features of the skeletal and muscular systems can be observed by looking at the body or can easily be located via palpation.
- **Developmental anatomy** looks at how our body evolved and developed over time or during our time from conception to birth (**embryology**).
- **Cytology** is the study of cells; **histology** is the study of tissues.

**Figure 3.1 Surface anatomy of the back (left) and front of the body (right)**



**The principal tool for the study of anatomy is mastery of anatomical terminology.** Anatomy is a purely descriptive science and without knowledge and understanding of its language, students will struggle to succeed.

**Physiology is the study of the function of the whole body or its systems and organs on many levels.** Physiology explains the what, where, when, why, and how of things happening in our body. Anatomy describes the structure of the kidney; physiology teaches us how the kidney produces urine and that this process depends on our actual physical needs.

The term physiology is derived from *physi(o)-* (nature, physical) and *-ology* (science or study of). It is subdivided into the physiology of organs (for example **renal physiology**) and systems (for example **cardiovascular physiology**).

**Essential tools** for the study of physiology are an ability to focus on different levels (from systemic to cellular and molecular) and knowledge of basic principles of biology, physics, and chemistry.

The **principle of complementarity** states that a) anatomy and physiology are inseparable, b) structure reflects function, and c) what a structure can do depends on its specific form. For example, if the structure (anatomy) of a bone is changed by a fracture, then the function of the bone (physiology) is also changed - a patient may not be able to walk because their shinbone (tibia) is broken.

There are six **levels of structural organization** starting with the nonliving chemical level leading up to the organismal level (or whole body):

1. **Chemical level:** atoms and molecules
2. **Cellular level:** cells and their organelles
3. **Tissue level:** groups of similar cells
4. **Organ level:** consists two or more types of tissues
5. **Organ system:** organs that work closely together
6. **Organismal level:** all organ systems

The **eleven organ systems** in the human body have to work together to keep the body healthy as all cells depend on them to meet their survival needs. An organ can be defined as a part of a bigger organism, such as the human body, that has a specific function necessary for the overall function. The heart, kidney, and liver are classic organs or body parts. However, when we look closer at the body, we see that other structures, such as blood vessels, should also be considered organs. Consequently, it is better for us to define **organs** as structures that **are made of two or more tissues** (for more on tissues see **Chapter 4 Histology**).

1. The **integumentary system** (see **Chapter 5**) forms the external body covering and protects deeper tissues from injury. It also synthesizes vitamin D and houses receptors (e.g., pain, pressure) as well as sweat and oil glands.
2. The **skeletal system** (see **Chapters 6–8**) protects and supports body organs, and provides a framework for muscles to attach to. All formed blood elements (cells) are formed within bones. Bones also store minerals such as calcium.
3. The **muscular system** (see **Chapters 9–10**) allows for manipulation of the environment, locomotion, facial expression, maintains posture, and produces heat.
4. The **nervous system** (see **Chapters 11–14**) is the fast-acting control system of the body. It responds to internal and external changes by activating appropriate muscles and glands.
5. The **endocrine system** (see **Chapter 15**) consists of hormone-secreting glands that regulate processes such as growth, reproduction, and nutrient use (metabolism) by body cells.
6. The overall function of the **reproductive system** (see **Chapter 16**) is production of offspring. The testes produce sperm and male sex hormone, while male ducts and glands aid in the delivery of sperm to the female reproductive tract. The ovaries produce eggs and female sex hormones. The accessory female structures serve as sites for fertilization and development of the fetus. The mammary (breast) glands produce milk to nourish the newborn.
7. The **cardiovascular system** (see **Chapters 17–19**) consists of a pump (the heart) and blood vessels. The heart pumps blood into vessels that transport it to organs and tissues and back to the heart. The blood carries oxygen, carbon dioxide, nutrients, and wastes.
8. The **lymphatic and immune systems** (see **Chapter 20**) can be considered one system. The lymphatic system picks up fluid leaked from blood vessels and returns it to the blood. It also disposes of debris in the lymphatic stream and houses white blood cells involved in immunity. The immune system protects from invaders from the outside and mounts the attack against foreign substances and changed body structures within the body.
9. The **respiratory system** (see **Chapter 21**) keeps blood constantly supplied with oxygen and removes carbon dioxide from the body. The gas exchanges occur through the walls of the air sacs of the lungs.
10. The **digestive system** (see **Chapter 22**) takes in food and moves it through the GI tract. Along the way it breaks it down into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.

11. The **urinary system** (see **Chapters 23–24**) eliminates nitrogenous wastes from the body and helps regulating the water, electrolyte, and acid-base balance of the body.

### 3.5 Homeostasis

For our body and mind to stay healthy, all cells, tissues, and organs need to be in a normal internal and external environment. For example, if the outside environment gets colder, our body still needs to keep a minimum temperature to function properly and survive. Failure to keep the body temperature up, may lead to hypothermia and death.

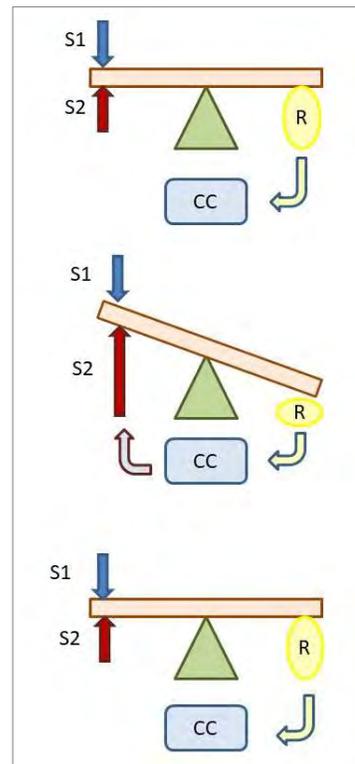
**Maintaining a relatively stable internal environment that allows our body to function at its best is called homeostasis** (*home(o)*- unchanging, constant, -*stasis* control). There are hundreds of parameters that need to be kept at certain levels at all times. Most of them are controlled by mechanisms of which we are not consciously aware. For example, the calcium level in our blood is regulated by two hormones that make sure it's not getting too high (calcitonin) or too low (para-thyroid hormone). We also have two hormones to lower high blood sugar levels (insulin) or raise low blood sugar levels to normal levels (glucagon).

**Homeostatic control mechanisms** involve continuous monitoring and regulation of many factors (variables). In a **control mechanism**, the **receptor/sensor [R]** monitors the environment by responding to stimuli [S1; S2]. It sends input signals to the **control center [CC]**, which compares the signal to a record of the set point at which the variable is to be maintained. If it determines that action is required, it sends instructions to the **effector**, which responds by reducing or enhancing the original stimulus. Because of that, the whole system is called a feedback mechanism.

In **negative feedback**, the response reduces or eliminates the original stimulus, whereas in **positive feedback** the response enhances or exaggerates the original stimulus. Negative feedback systems (e.g., regulation of body temperature or blood glucose level) are much more common than positive feedback systems (e.g., enhancing uterine contractions during labor or stimulating platelet plug formation).

Many signs and symptoms of disorders are based on **homeostatic imbalances** - when the body is unable to maintain a balance for one or more parameters. For example, we may end up with a heat stroke because our blood volume isn't large enough if we don't drink enough water on a hot day.

Figure 3.2 Negative feedback



#### Check Your Understanding

- The integumentary system \_\_\_\_\_.
  - consists of hormone-secreting glands
  - protects and supports body organs
  - allows for manipulation of the environment
  - forms the external body covering
- Which of the following levels is the highest level of structural organization?
  - Cellular level
  - Organismal level
  - Tissue level
  - Organ level
- Which organ system keeps blood constantly supplied with oxygen?
  - Urinary system
  - Digestive system
  - Respiratory system
  - Cardiovascular system
- Structures that are made of two or more tissues are called \_\_\_\_\_.
  - organs
  - organisms
  - cells
  - tissue groups

1.D.2.B.3.C.4.A

### 3.6 Necessary Life Functions and Survival Needs

As we have seen above, our body needs to maintain a stable environment to function properly. There are **necessary life functions** that are essential for keeping our body and mind healthy. **If one or more of them cannot be maintained properly, signs and symptoms of disease will develop.** However, most of the time these disorders will not be life threatening and can often be cured or mitigated. For example, a lack of growth hormone during childhood leads to dwarfism, which is not life-threatening. Diagnosed early, growth hormone can be injected and lead to normal body growth.

The **eight necessary life functions** are:

1. **Maintenance of boundaries** between internal and external environments. This is achieved, for example, by the skin and the plasma membranes around cells.
2. **Movement** of body parts (skeletal muscle) or substances, such as blood or food (cardiac and smooth muscle).
3. **Responsiveness** is the ability to sense and respond to stimuli. Examples are pulling our hand away from a hot plate and control of our breathing rate.
4. **Digestion** involves the breakdown of ingested foodstuffs and the absorption of simple molecules into the blood.
5. **Metabolism** is the sum of all chemical reactions that occur in body cells. We can distinguish between breakdown (catabolism) and synthesis (anabolism) of molecules.
6. **Excretion** is the removal of wastes from metabolism (carbon dioxide) and digestion (feces).
7. **Reproduction** as cellular division for growth and repair, and as a whole in the production of offspring.
8. **Growth** as increase in size of a body part or the whole body.

#### Survival Needs

Unlike the necessary life functions above, the **five survival needs** (i.e., nutrients, oxygen, water, normal body temperature, and appropriate atmospheric pressure) **must be met at all times or the body will suffer and may die.** Yet, some needs are more acute than others. While we may be able to survive for weeks without eating, because we have enough fat and other tissues to burn to create energy for our cells, we need to get oxygen into our body continuously. A lack of oxygen for only four minutes is already enough for some brain cells to die.

**Nutrients** are chemicals extracted from food that promote normal growth, maintenance, and repair. Carbohydrates, lipids (fats), and proteins are **major nutrients**, while vitamins, minerals, and water are **minor nutrients**. Major nutrients are used for energy production and to build body structure.

- **Vitamins** are **organic compounds that cannot be synthesized by our body**. Exceptions are **vitamin D**, which starts life in our skin before being changed in the liver and finally activated in the kidneys, and **vitamin B and K**, which are produced by bacteria living in our large intestine. Vitamins are subdivided into **water-soluble vitamins (B, C)** that are not stored in the body, and **fat-soluble vitamins (A, D, E, K)** that are stored in the body.
- **Minerals are inorganic substances** that are required in moderate amounts (calcium, phosphorus, potassium, sulfur, sodium, chloride, magnesium, and iron in women) or trace amounts (e.g., iodine, fluorine).

Table 3.2 Major Nutrients

Nutrient	Dietary sources	Uses	Dietary Requirements
Carbohydrates	<b>Starch</b> (complex carbohydrates) in grains and vegetables	<b>Glucose:</b> used by cells to make ATP (4 kcal per gram)	<b>Recommended intake:</b> 45–65% of total calorie intake; mostly complex carbohydrates
	<b>Sugars</b> in fruits, sugarcane, sugar beets, honey, and milk	<b>Insoluble fiber:</b> cellulose in vegetables; provides roughage <b>Soluble fiber:</b> pectin in apples and citrus fruits; reduces blood cholesterol levels	<b>Minimum</b> 100 g/day to maintain adequate blood glucose levels
Proteins	Eggs, milk, fish, and most meats contain complete proteins	<b>Structural proteins:</b> keratin, collagen, elastin, muscle proteins	<b>Rule of thumb:</b> daily intake of 0.8 g per kg body weight = 1 egg
	Legumes, nuts, and cereals contain incomplete protein, but	<b>Functional proteins:</b> enzymes, some hormones <b>Adequacy of caloric intake:</b> used as	<b>All-or-none rule:</b> All amino

	together contain all essential amino acids	fuel if insufficient carbohydrate or fat available (4 kcal per gram)	acids needed must be present for protein synthesis to occur
<b>Lipids (fats)</b>	<b>Saturated fats</b> in meat, dairy foods, and tropical oils	<b>Major fuel</b> of liver cells and skeletal muscle (9 kcal per gram)	Fats should represent <b>30% or less of total caloric intake</b>
	<b>Unsaturated fats</b> in seeds, nuts, olive oil, and most vegetable oils	<b>Phospholipids</b> are essential in all cell membranes	<b>Saturated fats</b> should be limited to 10% or less of total fat intake
	<b>Cholesterol</b> in egg yolk, meats, organ meats, shellfish, and milk products	<b>Adipose tissue</b> forms layers around body organs and an insulating layer below the skin; concentrated source of energy	Daily <b>cholesterol</b> intake should be <b>no more than 300 mg</b>
	<b>Essential fatty acids</b> (linoleic and linolenic acid) found in most vegetable oils	<b>Cholesterol</b> stabilizes membranes and is a precursor of steroid hormones	

**Energy intake has to equal the total energy output.** If we take in more energy than we use the excess energy is stored as glycogen or fat and we **gain weight**. Once our **output exceeds the input** we mobilize glycogen and fat and **lose weight**. The average male A&P student (19 years; 5 ft 8 in; 165 lb) utilizes 1,745 kcal per day (excluding extra energy for above average physical activity); the average female A&P student (19 years; 5 ft 4 in; 140 lb) has a lower energy output at 1,400 kcal per day.

**Overweight** and **obesity** are terms used to describe people who weigh more than is recommended. **Overweight** indicates an excess amount of weight compared to a given standard. Once a certain threshold is exceeded, the person is considered extremely overweight and the term **obesity** is used. Nonetheless, there is no scientific method to determine exactly what is 'normal' weight and what is too much or not enough. Still, we know that the heavier people get, the more likely they are to develop heart disease, stroke, diabetes, and cancer, to name just a few common complications.

One indicator that has gained international recognition as a measure of overweight/underweight and body fatness is the **Quetelet index** or **Body Mass Index (BMI)**. This index is based on a person's weight relative to their height [BMI =  $\text{wt (lb)} \times 705/\text{ht (inches)}^2$ ]. It is used to classify people into:

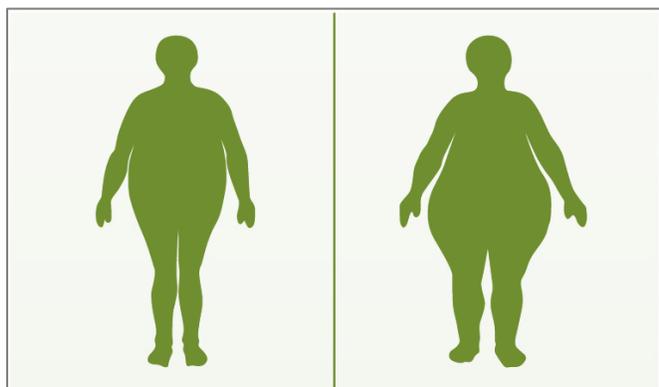
- **Underweight:** < 18.5
- **Normal weight:** 18.5 – 24.9
- **Overweight:** 25 – 29.9
- **Obesity:**  $\geq 30$ ; the **World Health Organization (WHO)** further breaks down obesity into three classes:
  - **Class I: Obesity** (BMI 30.0 – 34.9)
  - **Class II: Severe Obesity** (BMI 35.0 – 39.9)
  - **Class III: Morbid Obesity** (BMI  $\geq 40$ )

However, **BMI does not account for the composition of the body**. Muscle and fat tissue have the same weight, and are considered equal as far as BMI is concerned. People with an increased muscle mass will have a high BMI, although their body fat mass may be rather low.

In order to get a better evaluation of body weight and potential health risks associated with it other parameters have to be considered as well. One of them is the **fat mass** (or **percent body fat**) of the body. Body fat falls into two categories, **essential** (or **structural**) fat and **storage fat**.

- **Essential fat** is needed for normal physiological function. Men have about 3% essential fat (of the total body weight), women 12% (more fat in breasts, hips, and thighs).
- **Storage fat** is stored in adipose tissue around major organs and in the peritoneal cavity and

**Figure 3.3 Apple shape (left) and pear shape (right)**



approx. 50% as subcutaneous fat beneath the skin. Women store fat more around hips and thighs (**pear shape**), men around the waist (**apple shape**).

### Fun Facts About Your Body

The average male undergraduate student is 5'8, weighs 165 lb, and has a BMI of 25.1. His body is made of 37.4 trillion atoms, i.e., there are twelve times as many atoms in his body as there are trees on our planet. Red blood cells make up more than 70% of his body cells (26.5 trillion), brain cells less than 0.5% (0.2 trillion). However, the number of microbes (bacteria, fungi, parasites) his body hosts mainly in the digestive tract is more than three times higher at 100 trillion plus.

His muscles make up one third of his overall body weight (55.4 lb), followed by bones (24.8 lb) and blood (11.3 lb). His heaviest internal organ is the liver at 4.0 lb, closely followed by his brain (3.1 lb) and his lungs (2.5 lb). His heart (0.8 lb) is slightly heavier than his kidneys combined (0.7 lb).

So far, his heart has beaten 710 million times. He took 235 million breaths, blinked 117 million times, yawned 104,205 times (mostly in class), passed gas 93,785 times, and sneezed 8,336 times.

The average female undergraduate student is shorter (5'4), lighter (140 lb), and has a lower BMI (24.0) than her male counterpart. Her body consists mostly of oxygen (86 lb), carbon (32 lb), and hydrogen (14 lb).

During the first 19 years of her life, she has produced 1 billion fl oz of blood (enough to fill 11 Olympic swimming pools), 2,740 lb of feces, 273,501 fl oz (2,136 gallon) of gas, 155,351 fl oz (1,213 gallon) of urine, 87,530 fl oz (688 gallon) of sweat, and 211 fl oz (1.6 gallon) of tears.

A sufficient **oxygen** supply at any given time is essential for all human cells, tissues, and organs. Our cells run on energy released from macro nutrients by burning (oxidizing) them. Inside mitochondria, these nutrients are combined with oxygen and the released energy is stored as adenosine triphosphate (ATP). Water, carbon dioxide, and heat are waste products of this process. Because ATP cannot be shared between cells, all cells have to produce their own ATP; without it, they will not be able to survive.

In **hypoxia** (*hyp(o)*- below or less than normal, *-oxia* oxygen), oxygen supply is not meeting demands and a situation of low oxygen level in the tissues develops. In **anoxia** (*an-* no, without, *-oxia* oxygen), there is no oxygen available at all. The lack of oxygen may be caused by low oxygen level in the blood (**hypoxemia**, *hyp(o)*- below or less than normal, *ox(o)*- oxygen, *-emia* blood) or by poor blood flow (perfusion), which leads to **ischemia**.

Regardless of the underlying cause, severe hypoxia will lead to cell death (necrosis) in the affected area. If the necrosis is caused by poor blood flow (**ischemia**), the area with necrotic tissue is called an **infarct** and the whole mechanism, an **infarction**. For example, a **heart attack** or **myocardial infarction** (MI) is caused by an obstruction of blood flow in the coronary arteries of the heart. Other organs prone to suffer from an infarction are the brain (stroke) and kidneys.

**Water** is the most abundant chemical in the body and site of chemical reactions. Our **body water content depends on our age and gender**. **Infants** have a total body water content of **approx. 75%** and **adults** of **55%**. That percentage goes down even further to **45% in old age**. Two thirds of body water is found inside cells (**intracellular fluid, ICF**) and one third outside the cells (**extracellular fluid, ECF**). The water in our blood (plasma) is part of the extracellular fluid.

- Men have a higher water content (60%) than women (50%) because they have more muscle mass (muscles have a high water content). The total body water for a male weighing 150 lbs. is 90 lbs. or 40 L (10.5 gallons). A woman with a body weight of 120 lbs. has 60 lbs. or 27 L (7 gallons) of total body water.
- When the output (water loss) exceeds water intake, a **negative fluid balance** develops and we become **dehydrated**. Water loss may be due to hemorrhage, severe burns, prolonged vomiting or diarrhea, profuse sweating, water deprivation, and diuretic abuse. Symptoms are thirst, dry, flushed skin, and low urine production (oliguria). It may lead to weight loss, fever, mental confusion, and hypovolemic shock (see also **Chapter 23 Fluid, Electrolyte, and Acid-Base Balance**).

Our **body temperature** reflects the balance between heat production and heat loss. At rest, the liver, heart, brain, kidneys, and endocrine organs generate the most heat while during exercise, heat production from the skeletal muscles increases dramatically.

**Normal body temperature is 98.6°F** on the surface (**shell temperature**). Organs in the **core** have a higher temperature (**100.4°F**) than the body shell. This **core temperature is regulated and remains relatively constant**, while the shell temperature fluctuates substantially (68°F – 104°F). Women have a slightly higher core temperature (97.8°F) than men (97.4°F) but colder hands (87.2°F) compared to men (90°F).

**Heat exchange with the ambient environment** happens via four mechanisms:

1. **Radiation:** Loss of heat in the form of infrared rays.
2. **Conduction:** Transfer of heat by direct contact.
3. **Convection:** Transfer of heat to the surrounding air.
4. **Evaporation:** Heat loss due to the evaporation of water from body surfaces.

**Insensible heat loss accompanies insensible water loss** from lungs, oral mucosa and skin, while **evaporative heat loss becomes sensible** (active) when the body temperature rises and sweating increases water vaporization.

The **hypothalamus** has **two thermoregulatory centers**, one **heat-loss center** and one **heat-promoting center**.

- **Heat-promoting mechanisms** that try to keep the body temperature up are shivering and an increased metabolic rate via hormone release.
- **Heat-loss mechanisms** include dilation of cutaneous blood vessels and increased sweating.

An increased body temperature is called **hyperthermia**. **Above 106°F** a positive feedback mechanism can set in and lead to **heat stroke**. As long as heat-loss mechanisms are still functional this stage is called **heat exhaustion**. The body is dehydrated and the blood pressure low.

A body temperature below normal with decreasing vital signs is called **hypothermia**. If the core temperature falls below 70°F cardiac arrest occurs.

**Appropriate atmospheric pressure** is vital for adequate breathing and gas exchange in the lungs. Humans evolved from animals that lived at sea level; as a result, our respiratory system is based on an average air pressure of 760 mm Hg. When we travel to higher elevations, such as the mountains, the air becomes thinner because air pressure decreases the higher we go. This, in turn, makes it more difficult for our body to absorb enough oxygen into the blood and tissues. Once we reach heights of 30,000 feet or above, we are unable to get any oxygen into the body, which is why cabins in airplanes flying at higher altitudes must be pressurized. If this internal pressure drops to outside pressure, the passengers die unless they wear oxygen masks.

### Check Your Understanding

1. Heat exchange with the ambient environment happens via \_\_\_\_.  
a) breathing  
b) urination  
c) evaporation  
d) defecation
2. Which BMI range indicates severe obesity according to the WHO?  
a) 18.5 – 24.9  
b) 25 – 29.9  
c) 35.0 – 39.9  
d) 30.0 – 34.9
3. Which is a dietary source for cholesterol?  
a) Meat  
b) Vegetables  
c) Cereals  
d) Fruits
4. The process of cell death caused by poor blood flow is called \_\_\_\_.  
a) attack  
b) ischemia  
c) hypoxia  
d) infarction

1.C.2.C.3.A.4.D

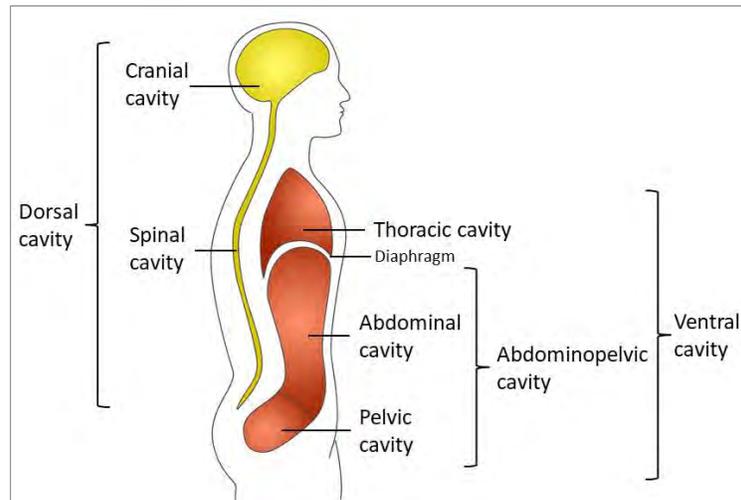
### 3.7 Body Cavities

Our body has a number of cavities that house one or more organ. Some of them are open to the outside, such as the nasal cavity and the oral cavity; others are closed, such as joint cavities and the abdominopelvic cavity.

The **two major body cavities** are the **dorsal cavity** at the back of the body and the **ventral cavity** at the front of the body. The **dorsal cavity** houses and protects the main parts of the nervous system. The brain lies protected by

bones within the **cranial cavity**; the spinal cord is protected by bones and ligaments of the spine that form the **spinal cavity**.

Figure 3.4 Body cavities



The much larger **ventral cavity** is home to our internal organs. Its two subdivisions are separated by the **diaphragm**. The lungs and the heart are the main organ inside the **thoracic cavity**. It is subdivided into two **pleural cavities** that house the **lungs**. The space between the pleural cavities is called the **mediastinum**. The **pericardial cavity**, which houses the heart, is located inside the mediastinum.

The **abdominopelvic cavity** is the part of the ventral cavity below the diaphragm. It has two subdivisions called the **abdominal cavity** (contains stomach, intestines, spleen, and liver) and the **pelvic cavity** (contains urinary bladder, reproductive organs, and rectum). There is no anatomical structure separating the abdominal and pelvic cavities. Organs in the abdominopelvic cavity, especially those located in the upper, abdominal part are less protected from outside forces and injury than organs inside the thoracic cavity.

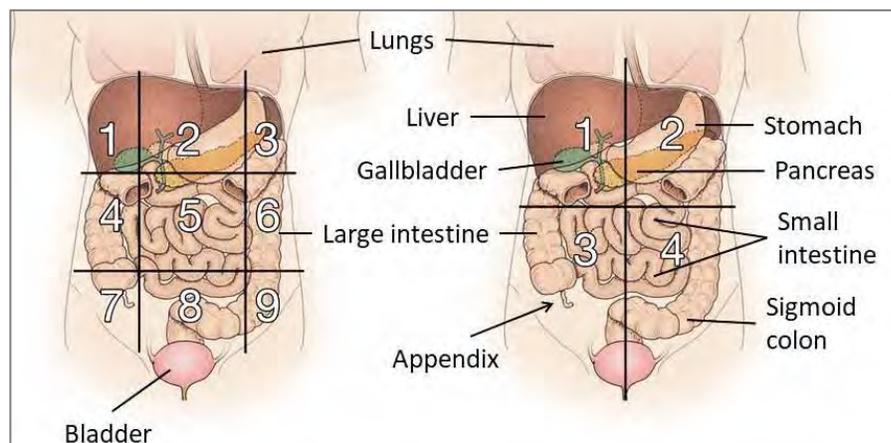
**Other body cavities** are the oral and digestive cavities, nasal cavity, orbital cavities, middle ear cavities, and synovial cavities of joints.

### 3.8 Abdominopelvic Regions and Quadrants

We use nine divisions to refer to **abdominopelvic regions** (numbers refer to Figure 3.5).

- The three middle regions from top to bottom are called epigastric [2], umbilical [5], and hypogastric or pubic region [8]. They are flanked by the right and left hypochondriac [1, 3], lumbar [4, 6], and iliac or inguinal [7, 9] regions.
- Medical personnel often prefer to use **abdominopelvic quadrants**. They are the right [1, RUQ] and left upper [2, LUQ], and right [3, RLQ] and left lower quadrants [4, LLQ].

Figure 3.5 Abdominopelvic regions (left) and quadrants (right)



Knowing the abdominopelvic regions and quadrants is critical in students' progression to becoming a healthcare professional. For example, pain in the epigastric region often points to stomach issues, while pain in the lower right quadrant (LRQ) could be caused by an inflamed appendix.

### 3.9 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Meaning	Correct Answer	Answer Options
1.	thorax, chest	_____	crani(o)-
2.	skull	_____	ventr(o)-
3.	belly	_____	gastr(o)-
4.	abdomen	_____	hyp(o)-
5.	below, less than normal	_____	abdomin(o)-
6.	stomach	_____	thorac(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

1. The cellular level of organization consists of groups of similar cells. \_\_\_\_\_
2. ICF is the abbreviation for intracellular fluid. \_\_\_\_\_
3. The skeletal system is the fast-acting control system of the body. \_\_\_\_\_
4. The digestive system helps regulate the water balance of the body. \_\_\_\_\_
5. There are eight necessary life functions and five survival needs. \_\_\_\_\_
6. Excretion is a survival need. \_\_\_\_\_
7. Vitamins are organic compounds that cannot be synthesized by our body. \_\_\_\_\_
8. The study of the external surface is called surface anatomy. \_\_\_\_\_
9. We use four divisions to refer to abdominopelvic regions. \_\_\_\_\_
10. The abdominopelvic cavity is the part of the ventral cavity below the diaphragm. \_\_\_\_\_
11. A BMI of  $\geq 30$  indicates underweight. \_\_\_\_\_
12. The dorsal cavity protects the nervous system. \_\_\_\_\_

#### Matching

Choose the item in column 2 that best matches each item in column 1.

- |    |   |                  |          |
|----|---|------------------|----------|
| 1. | transfer of heat to the surrounding air | a) hypoxemia     | 1. _____ |
| 2. | negative fluid balance                  | b) immune system | 2. _____ |

- |  |                          |           |
|--|--------------------------|-----------|
| 3. low oxygen level in the blood                   | c) abdominopelvic cavity | 3. _____  |
| 4. the sum of all chemical reactions               | d) dehydration           | 4. _____  |
| 5. severe obesity                                  | e) metabolism            | 5. _____  |
| 6. part of the ventral cavity below the diaphragm  | f) protein               | 6. _____  |
| 7. a substance in food that promotes normal growth | g) oxygen                | 7. _____  |
| 8. survival need                                   | h) BMI 35.0 – 39.9       | 8. _____  |
| 9. major nutrient                                  | i) convection            | 9. _____  |
| 10. protects from invaders from the outside        | j) nutrient              | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- This is the study of the functions of body structures.
  - Anatomy
  - Physiology
  - Histology
  - Immunology
- Which term describes the regulation of body conditions within normal limits?
  - Palpation
  - Percussion
  - Homeostasis
  - Histology
- In negative feedback systems \_\_\_\_.
  - the receptor sends a negative signal
  - the control center receives input from the effector
  - the effector reduces or eliminates the stimulus
  - the stimulus is turned positive
- In which body cavity is the brain located?
  - Cranial cavity
  - Abdominal cavity
  - Pericardial cavity
  - Pleural cavity
- This cavity is situated inferior to the abdominal cavity.
  - Vertebral canal
  - Cranial cavity
  - Pericardial cavity
  - Pelvic cavity
- Which of the following organs is found in the thoracic cavity?
  - Stomach
  - Lung
  - Liver
  - Gallbladder

7. The abdominal region is divided into nine areas. Name the upper right area that contains the liver.
  - a. Right hypochondriac
  - b. Right thoracic
  - c. Right lumbar
  - d. Right iliac
  
8. Which of the following are the two major closed body cavities?
  - a. Ventral and dorsal
  - b. Superior and inferior
  - c. Thoracic and abdominal
  - d. Cranial and spinal
  
9. Which science studies the surface of the body?
  - a. Regional anatomy
  - b. Systemic anatomy
  - c. Surface anatomy
  - d. Microscopic anatomy
  
10. Carbohydrates \_\_\_\_.
  - a. provide more energy per gram than lipids
  - b. can be subdivided into structural and functional carbohydrates
  - c. are essential nutrients
  - d. provide 4 kcal per gram when used to generate ATP
  
11. Which of the following is **not** a necessary life function?
  - a. Breathing
  - b. Responsiveness
  - c. Metabolism
  - d. Growth
  
12. Glucose is a \_\_\_\_.
  - a. protein
  - b. carbohydrate
  - c. lipid
  - d. vitamin
  
13. The male body contains approximately \_\_\_\_ water.
  - a. 10%
  - b. 25%
  - c. 50%
  - d. 60%
  
14. Normal body temperature is \_\_\_\_.
  - a. 98.6°F
  - b. 100.4°F
  - c. 80.4°F
  - d. 104.0°F
  
15. The dorsal cavity \_\_\_\_.
  - a. is much larger than the ventral cavity
  - b. houses and protects the nervous system
  - c. is the part of the ventral cavity below the diaphragm
  - d. is subdivided into two pleural cavities

## Chapter 4 Histology

### 4.1 Chapter Outline

Multicellular organisms, such as the human body, are composed of many different types of cells (see Chapter 2 Basic Science Review) that are grouped together according to structure and function to form tissues. Tissues are the fabric which makes up our organs.

### 4.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Define what tissues are.
- List the four major types of tissues.
- Describe the function and location of tissues.
- Define what glands are and explain the difference between exocrine and endocrine glands.
- Explain the function and location of membranes.
- Describe the process of tissue repair.
- Demonstrate their understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 4.3 Combining Forms

Table 4.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 4.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
epi-	upon, above, or beside	<i>epithelial</i> = relating to epithelium
end(o)-	inside	<i>endogenous</i> = growing or originating from inside the body
ex(o)-	outside	<i>exogenous</i> = originating from outside the body
extra-	outside of, beyond, or in addition to	<i>extracellular</i> = located outside a cell
hist(o)-	tissue	<i>histology</i> = the study of the structure and function of tissues
inter-	between, among	<i>intercellular</i> = located or happening between cells
intra-	within, into, or during	<i>intracellular</i> = located inside a cell
ne(o)-	new	<i>neoplasia</i> = formation of new, abnormal tissue growth
-necrosis	tissue or cell death	<i>osteonecrosis</i> = death of bone tissue
-oma	tumor, neoplasm	<i>melanoma</i> = black skin cancer
-plasia	development, growth, formation	<i>hyperplasia</i> = enlargement of an organ or tissue

### 4.4 Body Tissues

**Histology is the microscopic study of tissues. Tissues** are made of groups of cells similar in structure and function. There are **four basic types of tissue**:

1. **Epithelial tissue** or **epithelium** (*epi-* upon, above; *-thelium* tissue) covers inner and outer surfaces in order to form boundaries between different environments.
2. **Connective tissue** supports, protects, and binds other tissues together.

3. **Nervous tissue** forms the brain, spinal cord, and nerves.
4. **Muscle tissue** has the ability to contract to cause movement.

Epithelial, nervous, and muscle tissue are defined by their cells, whereas connective tissue is defined by a nonliving extracellular matrix that is produced by the tissue cells.

### Epithelial Tissue (Epithelium)

The main **characteristics of epithelial tissue** are:

- **The cells forming epithelial tissues have polarity** - apical (upper, free) and basal (lower, attached) surfaces. Apical surfaces may bear microvilli (e.g., small intestine) or cilia (e.g., respiratory epithelium).
- A **noncellular basal lamina** of glycoprotein and collagen lies adjacent to basal surface.
- Epithelia are composed of closely packed cells. They form continuous sheets held together by tight junctions and desmosomes. They are supported by a connective tissue reticular lamina under the basal lamina and are **avascular**, i.e., have no blood vessels, **but innervated**, i.e., are supplied by nerve fibers. Epithelia have a **high rate of regeneration**.

The two main types of epithelium are defined by their location: **Covering and lining epithelia** are found on external (skin, see **Chapter 5 Integumentary System**) and internal surfaces (for example, the mucous membrane of the mouth). **Glandular epithelia** form the secretory tissue in glands.

### Classification of Epithelia

Epithelia are classified by the number of cell layers into **simple epithelia** (1 layer of cells) and **stratified epithelia** (2 layers or more).

They are named after the shape of the cell that forms the epithelium as **squamous**, **cuboidal**, or **columnar epithelium**. Stratified epithelia are named according to the upper most layer of cells.

**Table 4.2 Epithelia**

Epithelium	Description
<b>Simple squamous</b>	<ul style="list-style-type: none"> <li>• The simplest of the epithelia consisting of a single layer of flattened cells with disc-shaped central nuclei and sparse cytoplasm. It allows the passage of materials by diffusion and filtration.</li> <li>• Is found in sites where protection is not important and where there are minimal mechanical forces. As part of the serosae it secretes lubricating substances in serosae. Typical locations are the glomeruli of the kidneys; air sacs of lungs, and the lining of the ventral body cavity (so-called <b>serosae</b>).</li> <li>• It also forms the lining of lymphatic vessels, blood vessels, and heart (<b>endothelium</b>) and the epithelium of serous membranes in the thoracic cavity (<b>mesothelium</b>).</li> </ul>
<b>Simple cuboidal</b>	<ul style="list-style-type: none"> <li>• Made of a single layer of cube-like cells with large, spherical central nuclei. It functions in secretion and absorption.</li> <li>• Found in areas with low mechanical stress, such as ducts and secretory portions of small glands and the tubules of the kidneys.</li> </ul>
<b>Simple columnar</b>	<ul style="list-style-type: none"> <li>• Consist of a single layer of tall cells with round to oval nuclei. The cells may bear cilia (<b>ciliated type</b>). There also can be a number of mucus-secreting unicellular glands (<b>goblet cells</b>).</li> <li>• The <b>nonciliated type</b> lines most of the digestive tract (stomach to anal canal), gallbladder, and excretory ducts of some glands, while the <b>ciliated type</b> is found in small bronchi, uterine tubes, and some regions of the uterus. The cells function in absorption, secretion of mucus, enzymes, and other substances. The ciliated type propels mucus or reproductive cells by ciliary action.</li> </ul>
<b>Pseudostratified columnar</b>	<ul style="list-style-type: none"> <li>• Made of a single layer of cells of differing heights, with some not reaching the free surface. Therefore, nuclei are seen at different levels, which give it the appearance of a stratified epithelium. It may contain mucus-secreting cells and bear cilia (<b>ciliated type</b>).</li> <li>• Its main function is secretion, particularly of mucus. The <b>nonciliated type</b> is found in the sperm-carrying ducts and the ducts of large glands. The <b>ciliated type</b> lines the trachea and most of the upper respiratory tract, where it propels mucus by ciliary action.</li> </ul>
<b>Stratified squamous</b>	<ul style="list-style-type: none"> <li>• It forms a thin membrane composed of several cell layers. The basal cells are cuboidal or columnar and metabolically active. The surface cells are flattened (hence squamous epithelium). In the <b>keratinized type</b>, the surface cells are dead, but full of keratin for increased mechanical and physical protection. The basal cells are active in mitosis and produce the cells of</li> </ul>

the more superficial layers.

- It is designed to protect underlying tissues in areas subjected to increased mechanical stress, especially abrasion. The **nonkeratinized type** forms the moist lining of esophagus, mouth, and vagina; while the **keratinized type** forms a dry membrane that is the outer most part of the skin (**epidermis**).

#### Stratified cuboidal

- Typically consists of two cell layers.
- Quite rare in the body; found only in some sweat and mammary glands.

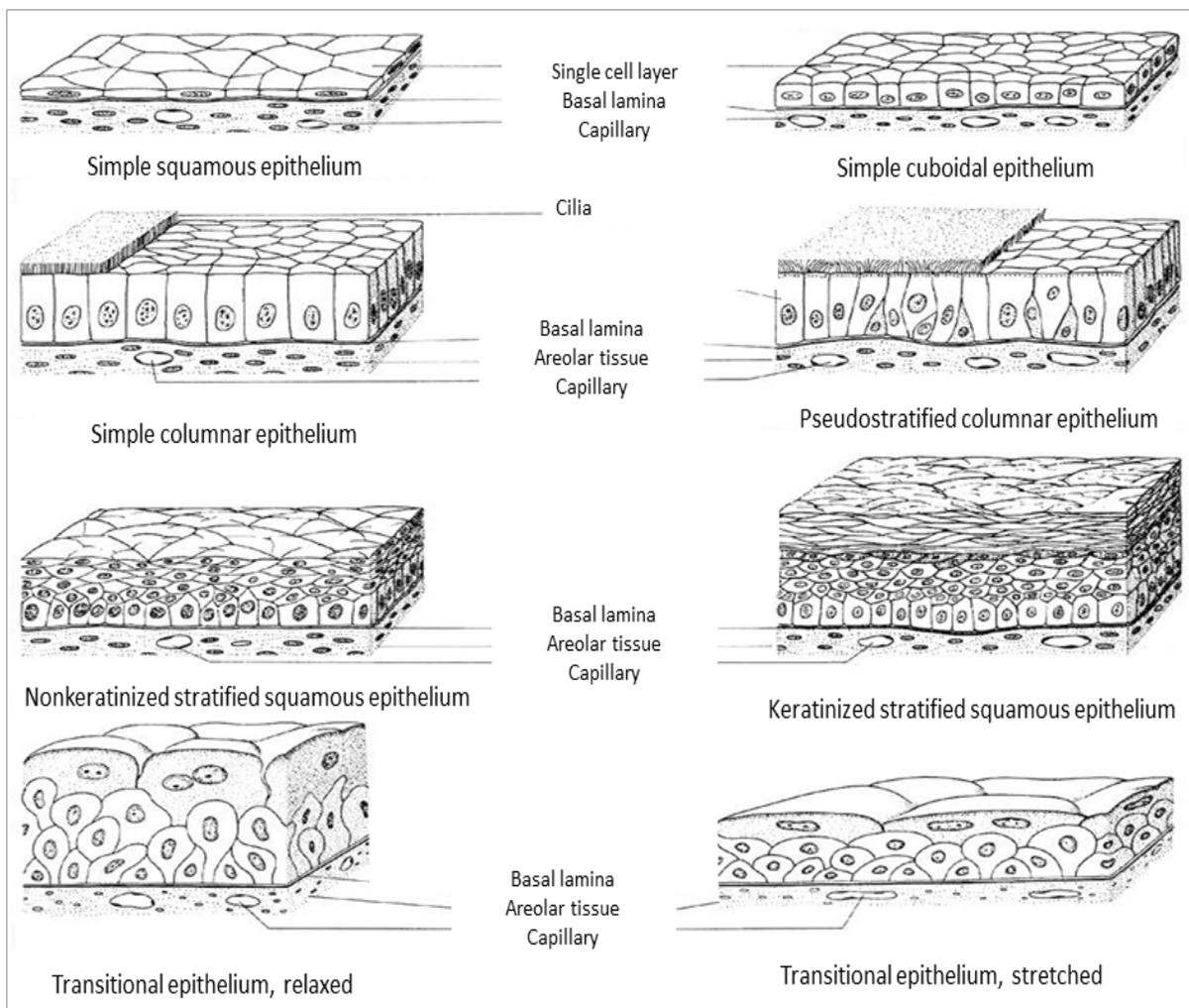
#### Stratified columnar

- Not very common. Found in small amounts in pharynx, male urethra, and lining some glandular ducts.
- Also occurs at transition areas between two other types of epithelia.

#### Transitional

- It resembles both stratified squamous and stratified cuboidal epithelia. The basal cells are cuboidal or columnar and the surface cells dome shaped or squamous-like, depending on the degree of organ stretch.
- It stretches readily and permits distension of the lined structures. Found in urinary organs, such as ureters, urinary bladder, and part of the urethra.

Figure 4.1 Epithelial tissues



#### Glandular Epithelia

**Glands** consist of one or more cells that produce and secrete a mostly watery (aqueous) fluid. Glands that consist of one cell only are called **unicellular glands**. **Multicellular glands** are composed of many cells.

**Endocrine glands** (*endo-* inside, *-crine* secrete) produce hormones that are released inside our body. The hormones travel through body fluids (such as lymph and blood) to their target organs (see also **Chapter 15 Endocrine System**).

**Exocrine glands** are more numerous than endocrine glands. They secrete their products into ducts that release them onto body surfaces (skin) or into body cavities (*exo-* outside, *-crine* secrete). The sweat glands of the skin and the salivary glands of our mouth are typical examples of exocrine glands. The only important **unicellular exocrine gland** is the **goblet cell**.

**Multicellular exocrine glands** are composed of a duct and a secretory unit. They are classified according to their duct type (simple or compound) and the structure of their secretory units (tubular, alveolar, or tubuloalveolar).

Glands can use two ways to secrete their product:

1. **Merocrine glands** secrete their products by exocytosis (e.g., pancreas, sweat and salivary glands).
2. **Holocrine glands** secrete their products by rupture of the gland cells (e.g., sebaceous glands).

## Epithelial Membranes

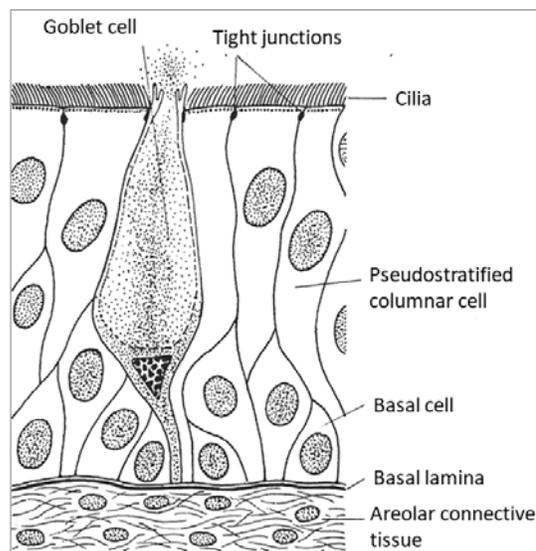
Epithelial membranes cover internal or external body surfaces. The **cutaneous membrane** or **skin** covers the outside of the body (see Chapter 5 Integumentary System).

**Mucous membranes** or **mucosae** line body cavities that are open to the exterior, such as the digestive tract and the airways.

**Serous membranes** or **serosae** are only found in closed body cavities, such as the pericardial cavity around the heart or the abdominopelvic cavity. The membrane is made of **mesothelium** with areolar tissue underneath.

- The layer lining the wall of the cavity is called **parietal serosa** (*paries* = wall) and the layer covering the organs inside the cavity the **visceral serosa** (*viscerum* = internal organ).
- The gap between the two layers forms a **cavity** that is filled with fluid to reduce friction between the layers. The cavity can be almost nonexistent, e.g., pericardial cavity, or fairly big, e.g., peritoneal cavity.

**Figure 4.2 Mucous membrane with ciliated pseudostratified columnar epithelium and goblet cell**



## Check Your Understanding

1. \_\_\_\_\_ tissues cover external and internal surfaces.
  - a) Connective
  - b) Epithelial
  - c) Nervous
  - d) Muscle
2. Which tissue has the ability to contract and cause movement?
  - a) Connective tissue
  - b) Nervous tissue
  - c) Muscle tissue
  - d) Epithelial tissue
3. Glands consisting of many cells are called \_\_\_\_\_.
  - a) exocrine
  - b) endocrine
  - c) multicellular
  - d) merocrine
4. An epithelium with four layers of cells and flat cells in the upper most layer is called \_\_\_\_\_.
  - a) stratified squamous
  - b) simple cuboidal
  - c) stratified simple
  - d) simple squamous

1.B.2.C.3.C.4.A

## Connective Tissue

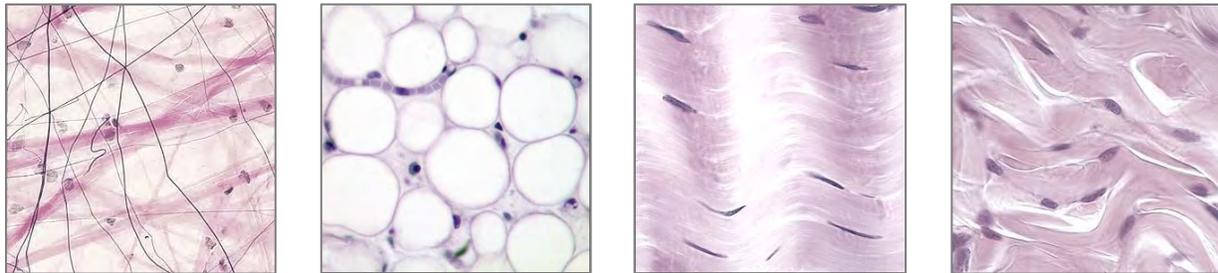
Connective tissues support, protect, and bind other tissues together. The four **classes of connective tissue** are: connective tissue proper, cartilage, bone tissue, and blood. Connective tissues are the most abundant and widely distributed tissue type in the human body. Unlike the other basic tissue types, connective tissues are not defined by their cells. Instead, the structure and function of the different connective tissues is shaped by the **extracellular matrix** that surrounds the cells.

Connective tissues can be liquid (blood), have a rubber-like consistency (cartilage), or be rock-solid (bone). As a result, connective tissues can form elastic structures that are flexible but return to their original form (our ear), structures that are stronger than steel cables (tendon and ligaments), and structures that can withstand high pressure (teeth).

The **major functions** of connective tissues are: Binding and support, protection, insulation, and transportation (blood).

Connective tissues have a **varying degrees of vascularity** (cartilage is avascular). Their cells are separated by a nonliving **extracellular matrix** that **consists of ground substance and fibers**. **Ground substance** is the medium through which solutes diffuse between blood capillaries and cells. Its components are: interstitial fluid, adhesion proteins (“glue”), and proteoglycans that are made of a protein core and large polysaccharides (chondroitin sulfate and hyaluronic acid). They trap water in varying amounts, affecting the viscosity of the ground substance.

**Figure 4.3 Connective tissues.** Areolar tissue (left); adipose tissue (second from left); dense regular tissue (second from right); dense irregular tissue (right).



**Collagen fibers** are the strongest and most abundant of the three fiber types. They are white and have a high tensile strength. **Elastic fibers** are made of networks of long, thin elastin fibers that give it a yellow color and allow for stretch. **Reticular fibers** are short, fine, and highly branched collagenous fibers.

**Juvenile connective tissue cells** that are mitotically active are called **blasts**, whereas **mature cells** are termed **cytes**. Connective tissue proper contains **fibroblasts** and **fibrocytes**, cartilage **chondroblasts** and **chondrocytes**, and bone tissue **osteoblasts** and **osteocytes**. Blood also contains blasts and cytes.

Other cells commonly found in connective tissues are fat cells, white blood cells, mast cells, and macrophages.

**Connective tissue proper** is commonly subdivided into **loose** (mainly protective tissues) and **dense** (mainly connecting tissues) **tissues**.

**Table 4.3 Connective Tissue Proper**

Connective tissue	Description
<b>Areolar loose</b>	<ul style="list-style-type: none"> <li>Has a gel-like matrix with all three fiber types. Contains fibroblasts, macrophages, mast cells, and other white blood cells.</li> <li>Its main function is to wrap and cushion organs. Its macrophages phagocytize bacteria and thus it plays an important role in inflammation. It holds and conveys tissue fluid.</li> <li>Is widely distributed under epithelia, e.g., it forms the lamina propria of mucous membranes, and surrounds organs and capillaries.</li> </ul>
<b>Adipose loose</b>	<ul style="list-style-type: none"> <li>Matrix is as in areolar tissue, but very sparse. Many closely packed adipocytes (fat cells) that have their nucleus pushed to the side by large fat droplet.</li> <li>Provides reserve food fuel. Also insulates against heat loss and supports and protects organs.</li> <li>Found under in the hypodermis of the skin, around kidneys and eyeballs, within the abdominal cavity, and in breast tissue.</li> </ul>
<b>Reticular loose</b>	<ul style="list-style-type: none"> <li>Made of a network of reticular fibers in a typical loose ground substance.</li> <li>The fibers form a soft internal skeleton (stroma) that supports other cell types including white blood cells, mast cells, and macrophages.</li> <li>Found in lymphoid organs (lymph nodes, bone marrow, and spleen) only.</li> </ul>
<b>Dense regular</b>	<ul style="list-style-type: none"> <li>Consists primarily of parallel collagen fibers with a few elastic fibers. Fibroblasts are the major cell type.</li> <li>It withstands great tensile stress when pulling force is applied in one direction. Therefore, it is used to attach muscles to bones or to muscles or bones to bones.</li> </ul>

	<ul style="list-style-type: none"> <li>• Found in tendons and most ligaments and aponeuroses.</li> </ul>
<b>Dense irregular</b>	<ul style="list-style-type: none"> <li>• Primarily made of irregularly arranged collagen fibers with some elastic fibers. Fibroblasts are the major cell type.</li> <li>• Is able to withstand tension exerted in many directions and to provide structural strength.</li> <li>• Found in fibrous capsules of organs and joints, the dermis of the skin and the submucosa of the digestive tract.</li> </ul>
<b>Elastic</b>	<ul style="list-style-type: none"> <li>• A dense regular connective tissue containing a high proportion of elastic fibers.</li> <li>• It allows for recoil of tissue following stretching, e.g., it maintains pulsatile flow of blood through arteries and aids passive recoil of lungs following inspiration.</li> <li>• Found in the walls of large arteries and of bronchial tubes as well as some ligaments associated with the vertebral column.</li> </ul>

The different composition of its ground substance gives **cartilage** a firm consistency. Its three types are defined by their fibers, just like the dense connective tissues. **Chondroblasts** produce the matrix and when mature turn into **chondrocytes** that lie in **lacunae**.

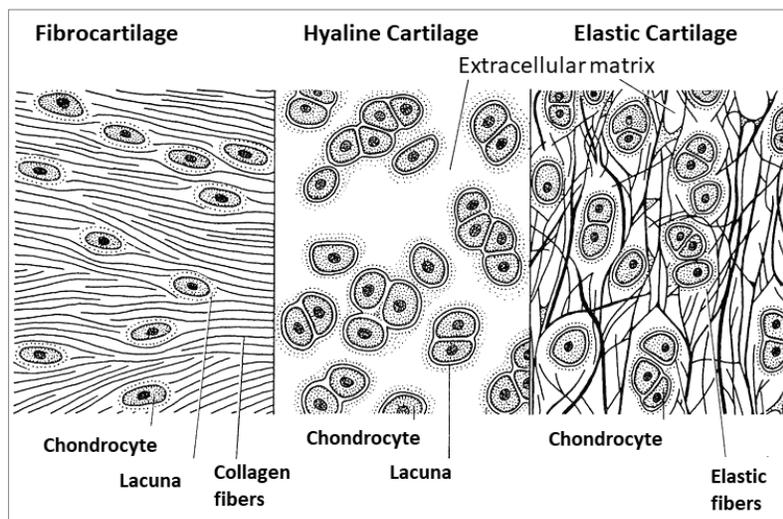
All types of cartilage are avascular, i.e., they have no blood vessels and the cells have to be nourished by diffusion of nutrients through the ground substance. To survive, cartilage has to have a slow metabolism, which explains why cartilage injuries are very slow to heal.

**Hyaline cartilage** has an amorphous but firm matrix. The collagen fibers form an imperceptible network, which makes hyaline cartilage transparent (*hyalos* = glass). It supports and reinforces, has resilient cushioning properties and resists compressive stress. Hyaline cartilage forms most of the embryonic skeleton, covers the ends of long bones, forms rib cartilages; and the cartilages of nose, trachea, and larynx.

The matrix of **elastic cartilage** is similar to hyaline cartilage, but contains many more elastic fibers. Elastic cartilage maintains the shape of a structure while allowing great flexibility. It is found in the external ear (pinna) and epiglottis only.

In **fibrocartilage**, the matrix contains up to 80% thick collagen fibers, giving it great tensile strength with the ability to absorb compressive stress. Fibrocartilage is found in intervertebral discs, the pubic symphysis, and the menisci of the knee joint.

Figure 4.4 Cartilage



**Bone (osseous) tissue** (see **Chapter 6 Bones and Skeletal Tissues**) has a hard, calcified matrix containing many collagen fibers. Mature osteocytes lie in lacunae. Bone tissue is very well vascularized. Bone supports and protects (by enclosing) internal organs and the nervous system, provides levers for the muscles to act on, and stores calcium and other minerals and fat. The marrow inside bones is the site for blood cell formation.

**Blood** (see **Chapter 19 Blood, Hemostasis, and Blood Groups**) consists of cells (red & white blood cells) surrounded by a liquid matrix (plasma). It transports respiratory gases, nutrients, hormones, wastes, and other substances.

### Check Your Understanding

- \_\_\_\_ cartilage has a high percentage of collagen in the matrix.
  - Elastic
  - Hyaline
  - Fibrocartilage
  - Dense
- Which cell produces cartilage matrix?
  - Osteocyte
  - Chondrocyte
  - Chondroblast
  - Fibroblast
- Which connective tissue proper is found in tendons and ligaments?
  - Elastic
  - Reticular loose
  - Dense regular
  - Areolar loose
- Which connective tissue is the hardest tissue of the body?
  - Adipose
  - Cartilage
  - Blood
  - Bone

1. C 2. C 3. C 4. D

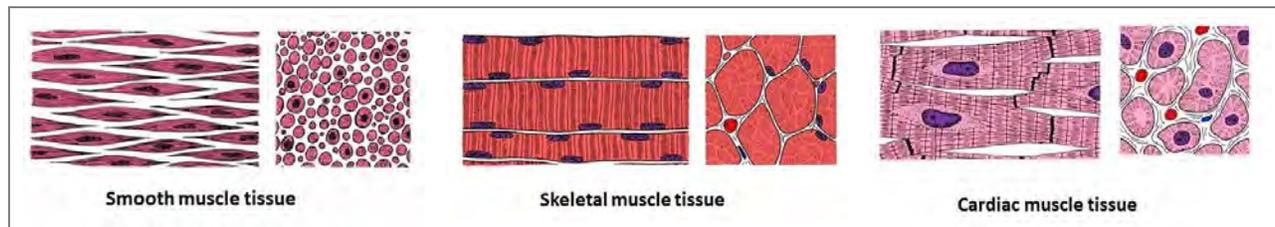
**Nervous tissue** forms the brain, spinal cord, and nerves (see **Chapter 11 Nervous Tissue**). It has two groups of cells:

- Nerve cells** (or **neurons**) have the ability to generate electric signals. These signals are used to collect, transfer, and store information, and to make conscious decisions.
- Neuroglia** are nonirritable supporting cells.

**Muscle tissue** has the ability to contract and cause movement. It achieves this by converting chemical energy from our food into mechanical energy (see **Chapter 9 Muscle Tissue**). There are three types of muscle tissue:

- Smooth muscle** is the oldest muscle tissue. It is found mostly in the walls of hollow organs, such as the bladder and the stomach. It has spindle-shaped cells with central nuclei. The cells are arranged closely to form sheets of muscle tissue. Unlike the other muscle tissue types, smooth muscle has no striations. Smooth muscle is involuntary and can even generate its own contraction rhythm.
- Skeletal muscle** is voluntary and needs signals from the nervous system to contract. It has long, cylindrical cells with many nuclei and shows striations. Skeletal muscles attach to bones or skin and help the body to move and to manipulate its environment.
- Cardiac muscle** is found in the wall of the heart only. It has branching, striated, usually mononucleate cells that interdigitate at specialized junctions (so-called intercalated discs). Just like smooth muscle cardiac muscle is involuntary and can generate its own contraction rhythm.

Figure 4.5 Muscle tissues



## 4.5 Tissue Repair

Tissue damage leads to destruction of cells and can penetrate protective barriers. The necessary repair and replacement of lost cells occurs in two ways:

- Regeneration:** Damaged cells are replaced with the same type of cell and the original function of the tissue is restored.
- Fibrosis:** Damaged cells are replaced with fibrous connective tissue creating scar tissue.

The repair process itself has three steps:

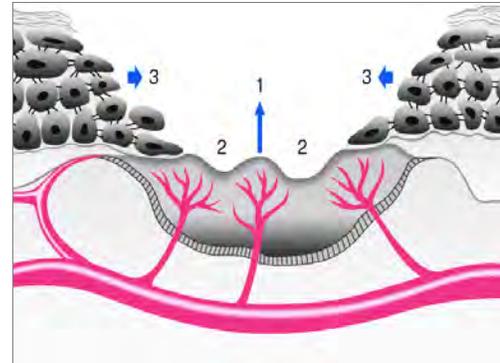
- **Step 1 Inflammatory response:** This step prepares the damaged area for the repair. This step includes release

of inflammatory chemicals, dilation of blood vessels, increase in vessel permeability, and the formation of a blood clot or scab (see also **Chapter 19 Lymphatic System & Immunity**).

- **Step 2 Restoration of blood supply:** The blood clot is replaced with granulation tissue. Epithelium begins to regenerate. Fibroblasts produce collagen fibers to bridge the gap. Debris is phagocytized (taken in and destroyed by special cells).
- **Step 3 Regeneration and fibrosis:** The scab detaches. Fibrous tissue matures; epithelium thickens and begins to resemble adjacent tissue. The result is a fully regenerated epithelium with underlying scar tissue.

**Different tissues have different regenerative capacities.** Epithelial tissues, bone tissue, areolar connective tissue, dense irregular connective tissue, and blood-forming tissue regenerate extremely well. Smooth muscle and dense regular connective tissue have moderate regenerating capacities. Cardiac muscle and the nervous tissue of our brain and spinal cord, however, are amitotic and have more or less no functional regenerative capacity.

**Figure 4.6 Tissue repair.** Blood vessels sprouting into the blood clot [2], transforming it into granulation tissue that grows up toward the surface [1]. Epidermal cells divide and start repairing the epithelial defect (regeneration) [3].



## 4.6 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer Options
1.	tumor, neoplasm	_____	-plasia
2.	tissue	_____	-necrosis
3.	growth, formation	_____	ne(o)-
4.	tissue or cell death	_____	hist(o)-
5.	new	_____	-oma

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Cells are made of groups of tissues similar in structure and function. \_\_\_\_\_
- Muscle tissue has the ability to contract to cause movement. \_\_\_\_\_
- Epithelia are classified by the number of cell layers into simple and stratified epithelia. \_\_\_\_\_
- Stratified squamous epithelium is the simplest of the epithelia. \_\_\_\_\_
- Exocrine glands are also called ductless glands. \_\_\_\_\_
- Collagen fibers are the strongest and most abundant of the three fiber types. \_\_\_\_\_
- Blood is one of the four classes of connective tissue. \_\_\_\_\_
- Skeletal muscle is the oldest muscle tissue. \_\_\_\_\_

9. Dense regular connective tissue has moderate regenerating capacities. \_\_\_\_\_
10. Mucosae line body cavities that are open to the exterior. \_\_\_\_\_
11. Elastic and hyaline cartilage are transparent. \_\_\_\_\_
12. All types of cartilage and epithelia are avascular, i.e., they have no blood vessels. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |  |                       |           |
|--|-----------------------|-----------|
| 1. found in the wall of the heart                            | a) fibrosis           | 1. _____  |
| 2. have the ability to generate electric signals             | b) elastic cartilage  | 2. _____  |
| 3. covers the outside of the body                            | c) merocrine glands   | 3. _____  |
| 4. damaged cells are replaced with fibrous connective tissue | d) collagen fibers    | 4. _____  |
| 5. consists of cells surrounded by a liquid matrix           | e) neurons            | 5. _____  |
| 6. found in the external ear                                 | f) connective tissues | 6. _____  |
| 7. withstand great tensile stress                            | g) osteoblasts        | 7. _____  |
| 8. juvenile bone-forming cells                               | h) cardiac muscle     | 8. _____  |
| 9. secrete their products by exocytosis                      | i) cutaneous membrane | 9. _____  |
| 10. defined by a nonliving extracellular matrix              | j) blood              | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Where would you most likely find transitional epithelial cells?
  - Lining the esophagus
  - Outer layer of skin
  - Urinary bladder
  - Heart
- In connective tissue, the matrix consists of \_\_\_\_\_.
  - protein based enzymes and organelles
  - plasma membranes and ground substance
  - calcified crystals of minerals and enzymes
  - protein fibers and ground substance
- Which fibers can be seen embedded in the matrix of connective tissue?
  - Elastic
  - Reticular
  - Collagen
  - All of the above

4. Which of the following is classified as loose connective tissue?
  - a. Blood
  - b. Bone tissue
  - c. Areolar connective tissue
  - d. Elastic tissue
  
5. This type of membrane lines a body cavity that does **not** open directly to the outside.
  - a. Serous
  - b. Mucous
  - c. Basement
  - d. Connective
  
6. Goblet cells are found in which kind of epithelium?
  - a. Simple squamous
  - b. Simple cuboidal
  - c. Transitional
  - d. Simple columnar
  
7. Of the four major types of tissues, which type forms boundaries between different environments?
  - a. Connective
  - b. Epithelial
  - c. Muscle
  - d. Nervous
  
8. Which of the following is **not** found in cartilage?
  - a. Chondrocytes
  - b. Lacunae
  - c. Blood vessels
  - d. Collagen fibers
  
9. A single layer of epithelial tissue is classified as \_\_\_\_\_.
  - a. squamous
  - b. stratified
  - c. simple
  - d. strong
  
10. Of the four major tissue types which type is always avascular?
  - a. Connective
  - b. Epithelial
  - c. Muscle
  - d. Nervous

## Chapter 5 Integumentary System

### 5.1 Chapter Outline

The integumentary system is made up of the skin and its related structures, which include glands, hair, and the nails. The skin is a vital organ of the body.

### 5.2 Learning Outcomes

Upon completion of this module, students will be able to:

- Describe the structure and functions of the integumentary system.
- Name the cells and layers of the epidermis and their function.
- Describe the layers of the dermis and their function.
- Name and describe the skin appendages.
- Explain burn injuries and define the different degrees of burns.
- Name and describe the major types of skin cancer.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 5.3 Combining Forms

Table 5.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 5.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
alopec(i)-	baldness	<i>alopecia</i> = partial or complete loss of hair
cutane(o)-	skin	<i>subcutaneous</i> = beneath the skin
dermat(o)-, derm(o)-	skin	<i>dermatologist</i> = physician who specializes in diagnosing and treating disorders of the skin
erythr(o)-, erythem(o)-	red	<i>erythroderma</i> = widespread redness accompanied by scaling of the skin
hidr(o)-	sweat	<i>hyperhidrosis</i> = condition of excessive sweating
koil(o)-	hollow, concave	<i>koilonychia</i> = spooning of the nails
melan(o)-	black	<i>melanocyte</i> = pigment-producing cell of the skin
onych(o)-	nail	<i>onychophagia</i> = nail biting
pil(i)-, pil(o)-	hair	<i>pilomatricoma</i> = noncancerous (benign) skin tumor associated with hair follicles
scler(o)-	hard, hardening	<i>scleroderma</i> = condition of hardened skin
seb(o)-	sebum (oil)	<i>seborrhea</i> = condition in which there is an overproduction of the sebum
trich(o)-	hair	<i>trichotillomania</i> = behavior in which one has a compulsion for hair pulling

### 5.4 Skin

The skin, also known as the **integument**, measures approximately 16-20 square feet and is actually the largest body organ. It protects our body by offering **three barriers of protection**:

1. **Chemical barriers** such as the acid mantle that lowers the pH and defensins that suppress bacterial growth.

2. **Physical or mechanical barriers** such as keratin and glycolipids that block most water and water-soluble substances from coming in. Therefore, only lipid-soluble substance can diffuse through the skin.
3. **Biological barriers** such as dendritic cells and macrophages.

Other functions of the skin are:

- **Body temperature regulation** to make sure our core temperature stays within certain limits. Approximately 500 ml of sweat per day is lost to this insensible perspiration. When the body temperature rises, dilation of dermal vessels and increased sweat gland activity (sensible perspirations) cool the body.
- **Cutaneous sensations** for temperature, touch, and pain.
- **Metabolic functions** such as the synthesis of a vitamin D precursor.
- **Blood reservoir** for up to 5% of the total volume of our body's blood.
- **Excretion** of salt and nitrogenous wastes in sweat.

The skin consists of **three major regions**:

1. An uppermost superficial region called **epidermis**.
2. A middle region called **dermis**.
3. The deepest region called **hypodermis**, which technically is not a part of the skin but a subcutaneous layer containing mostly adipose tissue. It is sometimes called the superficial fascia.

The **epidermis** is a typical stratified epithelium with many layers of keratinized cells. Because the superficial layer of cells is flat (squamous), the whole structure is called keratinized stratified squamous epithelium.

There are four types of cells in the epidermis:

1. **Keratinocytes** produce the fibrous protein **keratin**.
2. **Melanocytes** make up 10–25% of the cells in the lower epidermis. They produce the pigment **melanin** (see below).
3. **Epidermal dendritic (Langerhans) cells** are macrophages that help activate the immune system.
4. **Tactile (Merkel) cells** are touch receptors.

The epidermis has **five layers**, although the clear layer (stratum lucidum) is found only in the thick skin of the soles and palms. From the surface downward, the layers are called (see also Table 5.2):

1. **Horny layer** or stratum corneum
2. **Clear layer** or stratum lucidum
3. **Granular layer** or stratum granulosum
4. **Prickly layer** or stratum spinosum
5. **Basal layer** or stratum basale

The **dermis** is the thick layer directly below the epidermis. It contains connective tissue with collagen and elastic fibers, blood and lymph vessels, and nerve endings, along with associated structures such as hair follicles, sebaceous glands, and sweat glands. Collagen fibers endow the skin with the ability to withstand pulling (tearing) forces, while elastic fibers enable the skin to stretch and return to its original size and shape. This combination allows the skin to withstand strong mechanical stress, but also to stretch when needed (e.g., over joints). Sensory nerve endings in the dermis help us to perceive touch, pressure, pain, and temperature.

**Figure 5.1 Layers of the skin and associated structures**

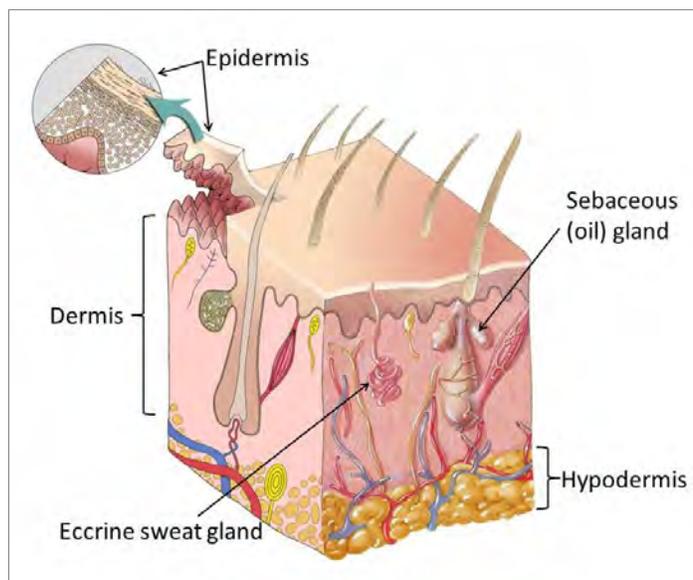
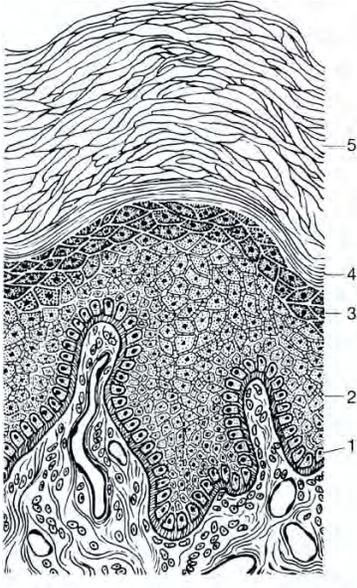


Table 5.2 Layers of the Epidermis

	<p><b>Stratum corneum (horny layer)</b> [5]: Uppermost layer made of 20–30 rows of dead, flat, keratinized membranous sacs. Approx. 75% of the thickness of the epidermis. Protects from abrasion and penetration, as well biological, chemical, and physical assaults. Also waterproofs the skin.</p>
	<p><b>Stratum lucidum (clear layer)</b> [4]: A thin band of a few rows of flat, dead keratinocytes. Doesn't have pigments, thus transparent. <b>Found in thick skin of palms and soles only.</b></p>
	<p><b>Stratum granulosum (granular layer)</b> [3]: Thins layer (3-5 rows) in which cells start to flatten. Keratohyaline and lamellated granules accumulate.</p>
	<p><b>Stratum spinosum (prickly layer)</b> [2]: Cells contain a web-like system of intermediate prekeratin filaments attached to desmosomes as well as lots of melanin granules. Plenty of dendritic cells to stop pathogens from reaching lower areas.</p>
	<p><b>Stratum basale (basal layer)</b> [1]: A single row of stem cells that are firmly attached to the basal lamina. The stem cells undergo rapid division (thus also called stratum germinativum) and gradually move towards the surface, which they reach in 25-45 days.</p>

The **dermis** has two layers:

1. The upper **papillary layer** makes up about 20% of the thickness of the dermis. It is made of areolar connective tissue with collagen and elastic fibers. It contains many blood vessels that supply nutrients for the epidermis above.

**Dermal papillae** contain capillary loops, Meissner's corpuscles and free nerve endings. **Epidermal ridges** that form **fingerprints** lie on the top of the dermal papillae.

2. The lower **reticular layer** is much thicker (~80% of the thickness of the dermis) and tougher due to its collagen fibers providing strength and resiliency, but it also has elastic fibers that provide stretch-recoil properties.

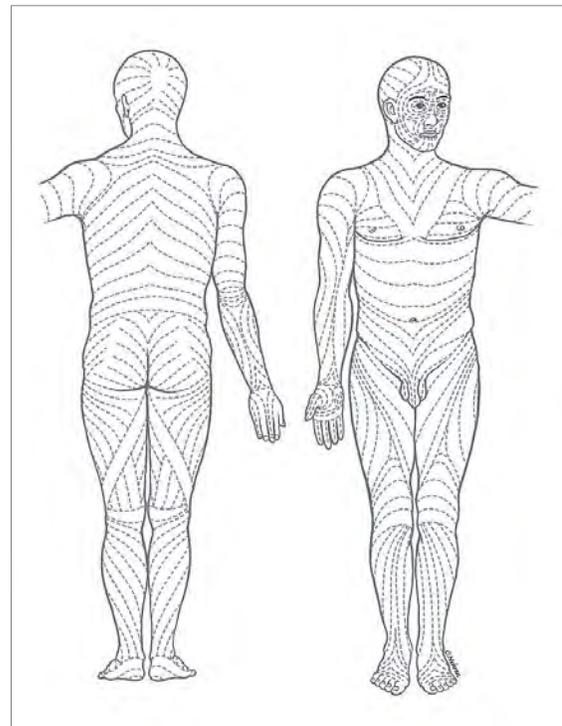
Collagen fibers arranged in bundles form **cleavage (tension) lines**. Incisions made parallel to cleavage lines heal more readily and leave smaller scars.

### Skin Color

Three pigments contribute to skin color:

1. **Melanin** is produced by **melanocytes** (*melano-* black, *-cyte* cell) and then migrates to keratinocytes where it forms pigment shields to protect the DNA in the nuclei. Its color ranges from yellow to reddish-brown to black. Melanin is responsible for dark skin colors. Freckles and pigmented moles are local accumulations of melanin.
2. **Carotenes** are yellow to orange-colored fat-soluble pigments that we take in with food, especially fruit and vegetables. They are stored in the skin and contribute a minor amount to our skin color. These pigments are most visible in areas where we have no melanocytes, such as the palms of the hands and the soles of the feet.
3. **Hemoglobin** is responsible for the pinkish hue of the skin. It is a red protein inside the erythrocytes (red blood cells) of the blood and not found in the skin itself. When we are hot or flushed, the increased blood flow colors our skin pink.

Figure 5.3 Cleavage (tension) lines



### Check Your Understanding

1. The outermost layer of the skin is called \_\_\_\_\_.
  - a) dermis
  - b) hypodermis
  - c) epidermis
  - d) subcutaneous
2. The epidermis contains a fibrous protein called \_\_\_\_\_.
  - a) melanin
  - b) collagen
  - c) elastin
  - d) keratin
3. The subcutaneous layer is mainly made of \_\_\_\_\_.
  - a) fat tissue
  - b) muscles
  - c) glands
  - d) hair follicles
4. Melanocytes are found in the \_\_\_\_\_.
  - a) hypodermis
  - b) epidermis
  - c) dermis
  - d) fat tissue

1.C 2.D 3.A 4.B

### 5.5 Appendages of the Skin

All **skin appendages** are derivatives of the epidermis.

**Sweat glands** are also known as **sudoriferous** (*su-dor(i)-sweat, -ferous* producing) **glands**. They are subdivided into two main types:

1. **Eccrine** (or **merocrine**) **glands** are most numerous on the palms of the hands, the soles of the feet, and the forehead. Their ducts connect to pores, but are not associated with hair. Their main function is thermoregulation by secreting sweat onto the skin.

Sweat (**perspiration**) is mostly water (99%) with a small amount of salt and metabolic waste products. **Hidrosis** is the production and excretion of sweat.

2. **Apocrine sweat glands** are confined to axillary and anogenital areas. Their ducts connect to hair follicles. Apocrine glands become active after puberty. They probably used to be sexual scent glands.

**Ceruminous glands** are specialized apocrine glands that are found in the external ear canal only. They secrete a waxy substance (**cerumen**) that is supposed to deter insects. Together with dead cells, it forms **ear wax**.

**Mammary glands** are specialized apocrine glands as well (see **Chapter 24 Reproductive System and Pregnancy**).

**Sebaceous** or **oil glands** produce **sebum**, a type of skin oil. Sebum lubricates the skin to make it soft. Oil glands are always connected to a hair follicle. The sebum is released into the opening of the hair follicle and from there onto the surface of the skin.

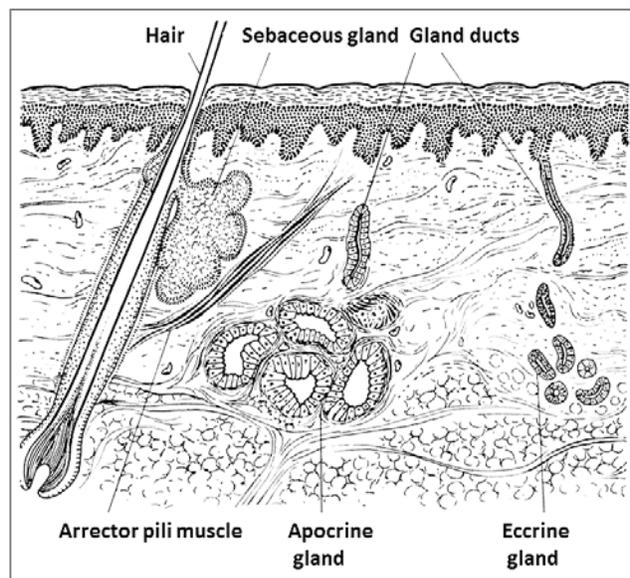
Sebum is slightly acidic and, therefore, prevents growth of bacteria on the skin. Loss of sebum due to dry skin or scrubbing with soap increases the chance of developing bacterial and fungal skin disorders, such as ring worm.

#### Hair

Hair consists of **dead keratinized cells** that contain **hard keratin**, which is more durable than the soft keratin of the skin. Different **melanins give the hair its color** depending on our genetic makeup. In older people, melanin production is decreased and the hair shaft contains air bubbles that give the hair a gray/white color.

The part of a hair above the surface is called the **shaft**, while the **root** is the part below the surface. The **hair follicle** is an invagination that extends from the epidermal surface into the dermis. Its expanded deep end is called the **hair**

Figure 5.4 Skin appendages



**bulb.** The **root hair plexus** or **hair follicle receptor** is made of sensory nerve endings around each hair bulb. They are stimulated by any force that bends the hair.

The smooth **arrector pili muscles** attached to the follicle lift up the hair creating “goose bumps”.

The fine body hair of children and women is called **vellus hair**, while the term **terminal hair** is applied to the coarse long hair of eyebrows, scalp, and axillary and pubic regions. Men also have terminal hair on face and neck.

Figure 5.5 Hair structure

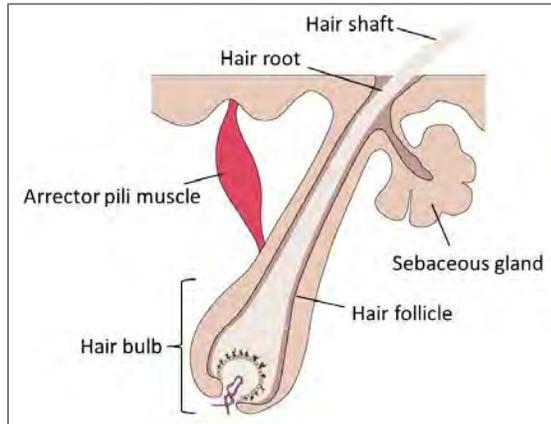
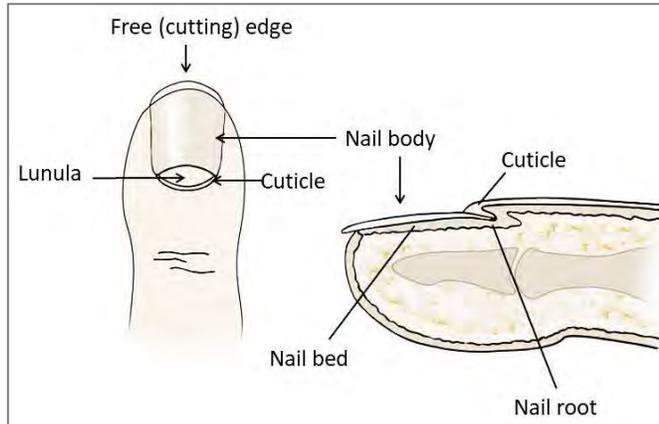


Figure 5.6 Nail structure



### Nails

Nails are scale-like modifications of the epidermis on the distal, dorsal surfaces of fingers and toes. Just like hair, nails are made of hard keratin. The **lunula** (= little moon) is a half-moon shaped area of the nail over the **nail root**, where the nail is formed. The **cuticle** is a clear layer of skin over the nail root area. It acts like a seal, preventing pathogens and other contaminants from getting to the nail root. As they grow, nails slide over the **nail bed** until they form the **free** or **cutting edge of the nail**.

### Fun Facts About Your Skin

- The average male A&P student (19 years; 5 ft 8 in; 165 lb) has 2 trillion skin cells (5% of body cells).
- Because the average lifespan of epidermal cells is 27 days, he has replaced his epidermis 257 times so far.
- The overall weight of his skin is 5.7 lb.
- He has 5 million hair follicles: 120,000 on his scalp, 600 on his eyebrows, 420 on his eyelashes, and 4.8 million spread out over the rest of his body.
- He also has 3.8 million sweat glands: 250,000 on his feet, 100,000 on his palms, and 3.5 million on the rest of his body.
- So far, he has produced 87,530 fluid ounces (688 gallon) of sweat, which would be enough liquid to fill 7,295 empty soda cans.

### 5.6 Burn Injuries

A burn injury is tissue damage inflicted by intense heat, electricity, radiation, or certain chemicals, all of which denature cell proteins and cause cell death to infected areas. Burns are classified according to their severity and how deep from the surface the damage goes.

**Partial thickness burns** affect part of the skin layers only.

- A **degree first burn (superficial burn)** is damage to the upper most layer (epidermis) only. It is characterized by local redness, edema (swelling), and pain. First degree burns are painful but will heal without problems. As a result of the irritation of pigment-forming melanocytes, first degree burns cause a discoloration of the affected area, for example, a tan after a **sunburn**.
- A **second degree burn** is damage only to the epidermis and the upper part of the dermis. Second degree burns **blister** and are red. They are painful but usually heal without complication unless the blisters get popped and the area becomes infected.

**Full thickness (third degree) burns** involve all layers of the skin, i.e., the epidermis, the entire dermis, the hypodermis, and often the tissues below (including muscle or bone) are damaged. The skin will look charred and black-brown. Because the nerve fibers are damaged, third degree burns are not painful. Skin grafting will be required. Dehydration and electrolyte imbalance, leading to renal shutdown and circulatory shock, are of immediate concern and can even cause death. After the first 24-36 hours have passed, the main threat becomes infection to the wound site.

**Table 5.3 Classification of Burns**

Type of Burn	Common Name	Layers of Skin Involved
First degree	Superficial burn	Upper epidermis only
Second degree	Partial thickness burn	Epidermis and part of dermis
Third degree	Full thickness burn	Epidermis, dermis, and hypodermis (may damage muscle and bone below)

**The Rule of Nines** is used to help medical care providers estimate the amount of fluid loss in second and third degree burns of adults. The body surface is subdivided into 11 areas of 9% each.

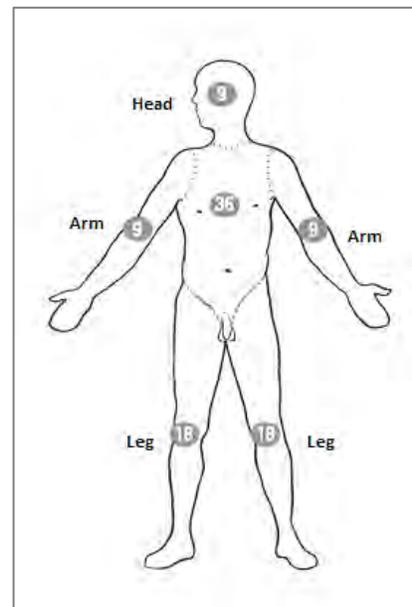
- The head counts as one area of 9%.
- Each upper limb (arm) counts for 9% as well.
- The front and back of the trunk count for 18% each, giving the trunk a total of 36%.
  - The area over the front of the chest counts for 9% as does the area over the abdomen.
  - On the back, the upper and lower back count for 9% each.
- Each lower limb (leg) is counted as two times 9% (9% for the front of the leg and 9% for the back), giving them a total of 18% each.
- The anogenital area makes up the remaining 1%.

**The severely burned areas** (second or third degree burns only) **are added together to estimate the total body area damaged.**

- For example, second degree burn injuries to the front and the back of both legs would add up to an estimated burn damage of 36%.

Burn injuries are considered critical in adults if more than 25% of the skin is damaged by second degree burns or 10% by third degree burns. Young children and older people are more at risk, because they may not be able to cope with the fluid loss and their immune system may not be strong enough to fight off infection of the damaged areas.

**Figure 5.7 Rule of Nines for adults**



### Check Your Understanding

- Sweat consists mainly of \_\_\_\_\_.
  - fat and proteins
  - minerals and vitamins
  - water and fat
  - water and salt
- You just burned your hand. A blister forms and the burn is painful. Your burn is a \_\_\_\_\_.
  - full-thickness burn
  - second-degree burn
  - first-degree burn
  - third-degree burn
- Hair consists of dead cells that contain \_\_\_\_\_.
  - melanin
  - soft keratin
  - hard keratin
  - carotene
- Sudoriferous glands are responsible for \_\_\_\_\_.
  - oily skin
  - fat storage
  - sweating
  - skin color

1.D.2.B.3.C.4.C

## 5.7 Skin Cancer

Skin cancer is extremely common; one in every five Americans will develop skin cancer. The biggest risk factors for developing skin cancer are exposure to UV radiation from the sun and frequent irritation of the skin. However, **most skin tumors, such as moles, are not cancerous!**

A **nevus** (or **mole**) is a small, often raised, dark skin growth that develops from melanocytes in the skin. Moles are benign and very common. They do not change over time, even with sunlight exposure. Other names for a nevus include **birthmark** or **beauty mark**, because they are present at birth. In contrast, a **freckle** is a small, flat patch of pigment that often becomes more pronounced with sun exposure.

**Table 5.4 Classification of Skin Cancers**

Type of Cancer	Prevalence	Degree of Malignancy
Basal cell carcinoma	Most common	Least malignant
Squamous cell carcinoma	Second most common	Second most malignant
Malignant melanoma	Least common	Most malignant

**Basal cell carcinoma** is the least malignant of the skin cancers and also the most common type of skin cancer. It develops from the bottom-most cells of the epidermis or basal layer. It can be cured 99% of the time by surgical excision.

**Squamous cell carcinoma**, the second most common skin cancer, tends to grow rapidly and can potentially spread if not removed. This tumor develops from the flat, squamous cells of the epidermis. Squamous cell carcinoma lesions tend to look like crusty sores that won't heal. This cancer is most commonly found on the scalp, ears, lower lip, and hands. It has a good prognosis if treated early by radiation therapy and surgical excision.

**Malignant melanoma** is the least common type of skin cancer, but the most dangerous due to the risk of spread. It is highly metastatic and resistant to treatment. It can spread even at a small size into internal organs and the brain or spinal cord. This tumor develops from the melanocytes of the epidermis and, because of its dark coloration, is also known as black skin cancer. Melanomas are treated with a wide, deep surgical excision along with immunotherapy.

**ABCDE** is a mnemonic to help us remember the **risk factors for recognizing melanoma**. It stands for:

- **A**symmetry
- **B**order irregular, not smooth
- **C**olor much darker than other moles or unusual color
- **D**iameter greater than the size of a pencil eraser
- **E**volving mole

**Figure 5.8 Basal cell carcinoma (left), squamous cell carcinoma (center), and malignant melanoma (right)**



## 5.8 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	skin	_____	onych(o)-
2.	hair	_____	cutane(o)-
3.	nail	_____	trich(o)-
4.	dry	_____	melan(o)-
5.	baldness	_____	alopec(i)-
6.	black	_____	xer(o)-

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- The stratum basale is the outermost layer of the epidermis. \_\_\_\_\_
- Melanin is found in the lowest layer of the dermis. \_\_\_\_\_
- The epidermis is made up of stratified squamous epithelium. \_\_\_\_\_
- Hair is produced by the hair bulb and is composed primarily of dead keratinized cells. \_\_\_\_\_
- The dermis is rich in blood vessels and nerve fibers. \_\_\_\_\_
- According to the "Rule of Nines" each arm and leg counts for 9% of the body surface. \_\_\_\_\_
- The protein found in large amounts in the outermost layer of epidermal cells is collagen. \_\_\_\_\_
- Moles are benign and very common. \_\_\_\_\_
- Squamous cell carcinoma is the least common type of skin cancer. \_\_\_\_\_
- Second degree burns blister and are red, but not painful. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                              |  |          |
|------------------------------|--|----------|
| 1. Keratinocytes             | a) layer where cells are considered protective but nonviable | 1. _____ |
| 2. Epidermal dendritic cells | b) serve an important function in thermoregulation           | 2. _____ |
| 3. Stratum corneum           | c) upper layer of the dermis                                 | 3. _____ |
| 4. Stratum basale            | d) largely confined to the axillary region                   | 4. _____ |

- |                    |   |           |
|--------------------|---|-----------|
| 5. Eccrine glands  | e) macrophages that help activate the immune system   | 5. _____  |
| 6. Papillary layer | f) wax that deters insects                            | 6. _____  |
| 7. Apocrine gland  | g) makes the palms and soles look orange              | 7. _____  |
| 8. Cerumen         | h) most aggressive and deadliest skin cancer          | 8. _____  |
| 9. Carotene        | i) contains the mitotic viable cells of the epidermis | 9. _____  |
| 10. Melanoma       | j) the most abundant cells of the epidermis           | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Another name for the subcutaneous layer is \_\_\_\_\_.
  - dermis
  - epidermis
  - basale
  - hypodermis
- Which pigment absorbs ultraviolet light?
  - Keratin
  - Melanin
  - Melatonin
  - Carotene
- Which epidermal cell has a role in immunity and disease resistance?
  - Langerhans cell
  - Keratinocytes
  - Melanocytes
  - Merkel cell
- Constant exposure of skin to friction stimulates the formation of a callus, which is the thickening of which layer?
  - Stratum spinosum
  - Stratum granulosum
  - Stratum lucidum
  - Stratum corneum
- Which type of gland is connected to a hair follicle?
  - Sebaceous
  - Sudoriferous
  - Ceruminous
  - Mammary
- All of the following are functions of skin except \_\_\_\_\_.
  - protection
  - blood reservoir
  - excretion
  - vitamin A production
- The protein found in our hair and nails is \_\_\_\_\_.
  - collagen
  - carotene
  - elastin
  - keratin

8. Hair and nails are modifications of the \_\_\_\_.
- dermis
  - epidermis
  - hypodermis
  - hyperdermis
9. The Rule of Nines \_\_\_\_.
- is a good way to estimate the extend of first degree burns
  - applies to infants only
  - is used to estimate the volume of fluid loss in burn injuries
  - assigns a value of 9% to each limb
10. Which of the following statements concerning skin cancer is correct?
- Pain is a common symptom of melanoma.
  - Melanomas are always dark blue-black.
  - Squamous cell carcinoma is the most dangerous form.
  - Basal cell carcinoma can be cured in 99% of all cases.

## Chapter 6 Bones and Skeletal Tissues

### 6.1 Chapter Outline

The skeletal system consists of bones, which, in turn, are made of cartilage and bone tissue. To understand the structure and function of the skeleton and its parts, students need to know the microscopic and macroscopic structure of bones and skeletal tissues.

### 6.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Name and describe the types of cartilage and where they are found in our body.
- Describe the different types of cartilage growth.
- Name the different types of bones based on a macroscopic classification.
- Name the main functions of bones/the skeleton.
- Describe the macroscopic anatomy of long bone and flat bone.
- Describe the microscopic structure of compact and spongy bone.
- List major bone markings.
- Describe the two types of osteogenesis/ossification.
- Explain bone remodeling and discuss the major factors influencing bone growth and remodeling.
- Define Wolff's law.
- Discuss bone density and peak bone mass.
- Define and compare osteopenia, osteoporosis, and osteomalacia.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 6.3 Combining Forms

Table 6.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 6.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
arthr(o)-	joint	<i>arthritis</i> = inflammation of a joint
-blast	bud, germ	<i>osteoblast</i> = juvenile bone tissue-forming cell
chondr(i)-, chondr(o)-	cartilage	<i>chondroepiphyseal</i> = relating to the epiphyseal (disk) cartilage
-cyte	cell	<i>osteocyte</i> = mature bone tissue cell
dia-	passing through; thoroughly, completely; going apart	<i>diaphyseal</i> = relating to a bone shaft (diaphysis)
end(o)-	inside	<i>endosteal</i> = relating to the endosteum
epi-	upon, above, or beside	<i>epiphyseal</i> = relating to an epiphysis
myel(o)-	bone marrow	<i>myelocyte</i> = bone marrow cell
oss(e)-, oss(i)-, oste(o)-, ost(o)-	bone	<i>osteoma</i> = tumor arising from bone tissue
peri-	around	<i>periosteal</i> = relating to the periosteum

## 6.4 Skeletal Cartilages

Skeletal cartilages do not contain blood vessels or nerves but are surrounded by a dense connective tissue layer called **perichondrium** that contains blood vessels for nutrient delivery. There are three types of skeletal cartilages:

1. **Hyaline cartilage**, the most abundant type, is designed to absorb pressure and to provide support and flexibility. It does contain collagen fibers, but they are not visible and, thus, the cartilage is transparent.
2. **Elastic cartilage** contains plenty of elastic fibers that give it great flexibility and allows it to get back to its original shape after being deformed.
3. **Fibrocartilage** has lots of collagen fibers, giving it great tensile strength in addition to the ability to absorb pressure just like hyaline cartilage.

Cartilages can grow by adding additional matrix to the outside of already existing cartilage. This process is called **appositional growth**. In **interstitial growth**, the chondrocytes divide, secrete more matrix, and lead to a growth from within.

## 6.5 Classification and Functions of Bones

Bones can be **classified by their shape** into:

- **Long bones** are longer than they are wide, such as the bones of the upper arm (**humerus**) and the thigh (**femur**).
- **Short bones** are cube-shaped and of equal length and width. These bones are found in the **wrist and ankle**.
  - **Sesamoid bones** look like big sesame seeds. These bones are found embedded in tendons that rub over joints. The **kneecap (patella)** is a sesamoid bone.
- **Flat bones** are thin and usually slightly curved. The **breastbone (sternum)** is a flat bone.
- **Irregular bones** have complicated shapes, such as the bones of the spine (**vertebrae**).

The main **functions of bones** are:

- **Protection** of the brain, spinal cord, and internal organs.
- **Support** for the body and soft organs.
- **Levers** for muscle action and thus, movement.
- **Storage** of minerals, such as calcium and phosphorus.
- **Blood cell formation** (hemopoiesis) in **red bone marrow**.
- **Fat storage** (triglycerides) in the **yellow bone marrow** of bone cavities.

## 6.6 Bone Markings

Bulges, depressions, and holes in the bone surface serve as sites of attachment for muscles, ligaments, and tendons, joint surfaces, and points of entry and exit for blood vessels and nerves.

**Table 6.2 Bone Markings**

Projections	
<b>Projections that help to form joints</b>	
Condyle	Large, rounded articular projection, e.g., femoral condyles
Facet	Smooth, nearly flat articular surface, e.g., facet of vertebra
Head	Bony expansion carried on a narrow neck, e.g., neck of femur
Ramus	Arm-like bar, e.g., pubic ramus
<b>Sites of muscle and ligament attachment</b>	
Crest	Narrow, prominent ridge, e.g., iliac crest
Epicondyle	Raised area above a condyle, e.g., medial femoral epicondyle

Line (Linea)	Narrow ridge of bone, e.g., linea aspera
Process	Any bony prominence, e.g., styloid process of ulna
Spine	Sharp, slender projection, e.g., anterior superior iliac spine
Trochanter	Large, blunt, irregular surface, e.g., greater trochanter
Tubercle	Small rounded projection, e.g., tubercle of humerus
Tuberosity	Rounded projection, e.g., tibial tuberosity
<b>Depressions and Openings</b>	
Fissure	Narrow, slit-like opening, e.g., sphenoid fissure
Foramen	Round or oval opening through a bone, e.g., infraorbital foramen
Fossa	Shallow, basin-like depression, e.g., mandibular fossa
Meatus	Canal-like passageway, e.g., external acoustic meatus
Sinus	Cavity within a bone, e.g., frontal sinus

## 6.7 Bone Structure and Histology

There are two **types of bone tissues**:

1. **Compact bone** forms the strong, dense outer layer of bones.
2. **Spongy or cancellous bone** forms a less strong honeycomb structure known as **trabeculae**.

### Long Bone Structure

Any bone that is longer than wide is called a long bone. The middle part is called the **shaft** or **diaphysis**, and the two expanded ends are called **epiphyses**. These ends have joint surfaces that are covered by **articular cartilage**. From the three types of cartilage, only hyaline cartilage is used for this purpose.

The hollow space inside the shaft is the **marrow** or **medullary cavity**. In babies, it is filled with blood-forming **red bone marrow**. Later in life, it is replaced by fat and is then called **yellow bone marrow**.

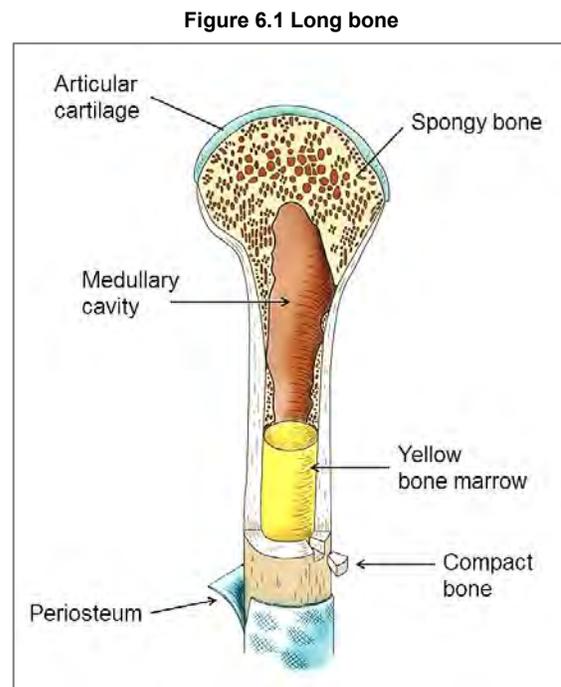
The **compact bone** surrounding the cavity is very strong and dense. The ends also have an outer layer of compact bone, but inside it is a lighter, less dense bone tissue that is called **spongy** or **cancellous bone**, because of its structure.

The growing bones of children and teenagers have an **epiphyseal (growth) plate** located between the diaphysis and the epiphysis. Once we stop growing, the cartilage forming the growth plate is replaced by bone, and the epiphyseal plate turns into the **epiphyseal line**.

The membrane covering the outside of a bone is called **periosteum** (*peri-* = around), while the membrane lining the inside surfaces of a bone is called **endosteum** (*endo-* = inner, within). The endosteum is rather delicate, because there are no mechanical forces to withstand.

The **periosteum** is subject to much more mechanical stress and therefore has an additional **outer fibrous layer** made of collagen fibers. These so-called **Sharpey's** or **perforating fibers** spread through the inner layer and insert into the upper bone layers.

The periosteum has openings for nerve fibers and blood vessels (**nutrient foramina**). The inner layer of the periosteum is the bone-forming or **osteogenic layer**. It has osteogenic **stem cells** that can differentiate into **osteoblasts** or



### osteoclasts.

**Short, flat, and irregular bones** have a sandwich structure with an **outer and inner layer of compact bone** and a **middle layer of spongy bone**. In **flat bones**, the middle layer is called **diploë**.

In **newborn infants**, blood-forming or hematopoietic **red blood marrow** is found in all medullary cavities and in spongy bone of all bodies. In the **adult skeleton**, it is found mainly in the head of femur and humerus and the diploë of flat bones like the sternum, skull bones, and hip bones.

**Bone tissue is the only connective tissue with four cell types:** osteogenic stem cells in periosteum and endosteum, bone-forming **osteoblasts**, mature **osteocytes**, and **osteoclasts** that break down and resorb bone matrix.

Bone tissue is the only tissue with an organic and an inorganic component. The **organic part** is made up of the **four cell types** (osteogenic cells, osteoblasts, osteocytes, osteoclasts) plus **organic bone matrix** secreted by osteoblasts. This so-called **osteoid** consists of **ground substance** and **collagen fibers** that provide strength and flexibility.

The **inorganic part** forms approximately 65% of the total bone mass, making bone tissue the only tissue where water is not the main ingredient by weight. The **minerals salts** give bone tissue its hardness and the ability to withstand compression/pressure. They are mainly **calcium phosphate crystals** and are collectively called **hydroxyapatites**. Trace minerals that add additional strength are fluorine and manganese.

### Compact Bone

Compact bone has a very regular microscopic structure. The basic structural unit of compact bone is called **osteon** or **Haversian system** [#2, Figure 6.2]. It consists of column-like, weight-bearing tubes of extracellular matrix called **lamellae** [#3] and, thus, is also called **lamellar bone**. At the center runs the **Haversian or central canal** [#7], which contains nerves and blood vessels.

**Perforating or Volkmann's canals** [#6] run at a right angle to the central canals. They carry blood vessels and nerves from the periosteum [#5] to the central canals and the medullary cavity.

At the junctions of the lamellae are hollow spaces or cavities called **lacunae** [#8] in which mature bone cells (**osteocytes**) [#9] reside. **Canaliculi** [#10] are hair-like canals connecting the lacunae with each other and the medullary cavity.

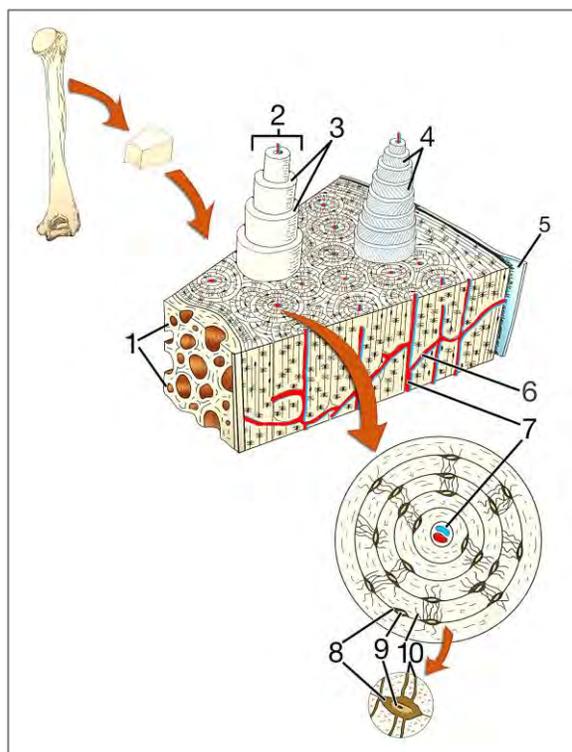
Although lamellae resemble growth rings in trees, they are not related to bone growth at all. They are weight-bearing, column-like matrix tubes. The ring pattern is created by **collagen fibers** running up and down the columns at different angles [#4].

This arrangement guarantees that no matter from what angle a bending or rotating force acts upon a bone, there are collagen fibers aligned to withstand the tensile stress, increasing the overall strength of the bone tissue. Without the collagen fibers, compact bone would be able to withstand pressure but not bending or rotational forces.

### Spongy Bone

Spongy bone [#1 Figure 6.2] is found in areas with less mechanical stress, such as the diploë of flat bones, and therefore can be less strong. Instead of osteons it is made of so-called **trabeculae** that are aligned along the lines of stress. Trabeculae don't have osteons, but contain irregularly arranged lamellae, osteocytes, and canaliculi.

Figure 6.2 Microscopic structure of compact bone



### Check Your Understanding

- |   |   |
|---|---|
| <p>1. Which of the following is <i>not</i> a function of bones?</p> <ol style="list-style-type: none"> <li>Protection of the brain</li> <li>Moving the body</li> <li>Blood cell formation</li> <li>Vitamin storage</li> </ol> | <p>2. The middle layer of a flat bone is called ____.</p> <ol style="list-style-type: none"> <li>diaphysis</li> <li>diploë</li> <li>medullary cavity</li> <li>trabeculae</li> </ol>                             |
| <p>3. The membrane covering the outside of a bone is called ____.</p> <ol style="list-style-type: none"> <li>endosteum</li> <li>Sharpey's fibers</li> <li>osteon</li> <li>periosteum</li> </ol>                               | <p>4. Osteoclasts are cells that ____.</p> <ol style="list-style-type: none"> <li>deposit osteoid</li> <li>are found in lacunae</li> <li>break down and resorb bone matrix</li> <li>form spongy bone</li> </ol> |

1.D.2.B.3.D.4.C

## 6.8 Bone Development and Remodeling

Bone tissue formation, also known as **osteogenesis** or **ossification**, can be subdivided into three stages: **Bone formation**, which begins in the second month of life, **bone growth** until early adulthood, and the lifelong process of **bone remodeling and repair**.

Depending on which original tissue is replaced, there are **two types of ossification: intramembranous and endochondral ossification**. In **intramembranous ossification**, the bone tissue develops from fibrous membranes that preform the flat bone. The bone formation starts with an **ossification center** inside the membrane. **Osteoblasts** secrete bone matrix, which calcifies, and the osteoblasts inside the matrix turn into **osteocytes**. The bone formation goes through a stage of **woven bone**, before the final sandwich structure of an inner and outer layer of compact bone with a middle layer of spongy bone develops.

Most of the skeleton, however, is preformed as hyaline cartilage. The bone that replaces the cartilage is called **endochondral** or **periosteal bone**. The growth from the outside is called **appositional growth** and leads to increased thickness of bones, whereas the **interstitial growth** within the bone lengthens it (**longitudinal growth**).

This **endochondral ossification** starts with a **primary ossification center** in the middle of the **diaphysis**. The cartilage in this area calcifies and is replaced by newly formed bone. In the center, a cavity forms, which later becomes the medullary cavity. A **secondary ossification center** develops in the upper and lower **epiphysis**. In the center of it, cartilage is replaced by spongy bone, but on the outside a strong layer of compact bone develops.

The only areas where hyaline cartilage remains is the articular cartilage on the joint-forming epiphyseal surface and the area between diaphysis and epiphysis called the **epiphyseal growth plate**. But, only the cartilage right under the epiphysis is resting, giving this zone the name resting or quiet zone. The area below grows by pushing the epiphysis away from the diaphysis leading to longitudinal growth.

The growing part of the epiphyseal plate can be subdivided into four functional layers:

- Proliferation** or **growth zone** - cartilages cells divide and form stacks or columns of cartilage cells.
- Hypertrophic zone** - older, stressed cartilage cells enlarge.
- Calcification zone** - the matrix calcifies and chondrocytes die.
- Ossification** or **osteogenic zone** - cartilage is replaced by bone tissue.

**Bone formation is hormonally controlled.** **Growth hormone** is the most important hormone for bone growth and remodeling. Lack of growth hormone during childhood leads to dwarfism; too much hormone leads to gigantism. **Thyroid hormone** modulates the activity of growth hormone. The sex hormones **testosterone** (men) and **estrogens** (women) promote growth spurts during adolescence but also induce the end of longitudinal growth as they lead to closure of the epiphyseal growth plate, which is then converted into the epiphyseal line.

**Bone remodeling** is the ongoing change of bone tissue to accommodate our changing needs. Unlike bone growth, bone remodeling doesn't lead to a lengthening of bones but strengthening, if there's more stress placed on the bones, or weakening, if less work is demanded from the bones. Because the epiphyseal growth plates have closed, the bones cannot become longer, just bigger overall.

Bone tissue responds to mechanical or gravitational stress or the lack thereof. If bones are immobilized by inactivity or after injury, the bone mass will be reduced and the bones become weaker. On the other hand, bone grows or remodels in response to forces or demands placed upon it (**Wolff's law**). Bones in the dominant limbs (e.g., right arm in right-handedness) are stronger than in the other limbs.

If bone tissue is damaged or no longer needed, **osteoclasts** release enzymes to digest the organic matrix as well as acid to dissolve the minerals of the inorganic matrix. The dissolved matrix is taken up and released into the interstitial fluid before making its way into the blood.

The deposition of new bone to repair damaged bone or add extra strength happens in two steps. At first, unmineralized matrix is secreted by **osteoblasts** leading to the formation of an **osteoid seam**. This matrix will mineralize over the course of the next few weeks. The abrupt transition zone between the osteoid seam and the mineralized bone is called the **calcification front**.

Bone remodeling is controlled by hormones as well as mechanical and gravitational forces (see Wolff's law above). However, the two hormones that are controlling bone remodeling, **calcitonin** and **parathyroid hormone (PTH)**, are not interested in maintaining sufficient bone mass; their primary task is to control the blood level of **calcium** within its normal range (see also **Chapter 15 Endocrine System**).

- Calcium is of importance for transmission of nerve impulses, muscle contraction, blood coagulation, secretion by glands and nerve cells, and cell division. A low blood calcium level (**hypocalcemia**) is more dangerous than an elevated level (**hypercalcemia**). Therefore, **PTH**, which is released by the **parathyroid glands** in response to low  $\text{Ca}^{2+}$  levels, is the more important of the two hormones. Once released, PTH stimulates **osteoclasts** to digest bone matrix so that  $\text{Ca}^{2+}$  can be released into the blood stream. It also **enhances reabsorption of  $\text{Ca}^{2+}$**  and secretion of phosphate by the **kidneys**, **promotes activation of vitamin D** by the kidneys, and **increases absorption of  $\text{Ca}^{2+}$  by the intestinal mucosa**.
- **Calcitonin** will be released by the **thyroid gland** when  $\text{Ca}^{2+}$  blood level increases above normal levels. It activates **osteoblasts**, which take  $\text{Ca}^{2+}$  out of the blood and deposit it as new matrix in the bone.

## 6.9 Bone Density

Bone density or **bone mineral density (BMD)** is the amount of mineral material in the bone matrix. The higher the mineral content, the stronger the bone tissue gets and the more it can resist weight and pressure stress. However, if the mineral content becomes too much, the bone tissue loses its elasticity and becomes brittle and fractures easily.

There are a number of factors that influence bone density over our lifetime, with sex hormones (testosterone in men and estrogens in women) having by far the biggest influence. Other factors are age (BMD goes down when we get older), genetics, nutrition (vitamins and minerals are important for normal bone growth and strength), and physical activity (Wolff's law).

The amount of bone matrix in our bones keeps growing from childhood through adolescence and into young adulthood. We reach our **peak bone mass (PBM)** at around age 30. After age 40, our bone mass gradually declines with an acceleration after age 70 for men. In women, menopause (i.e., the cessation of the monthly hormone cycle) is the watershed for bone density loss. The earlier women reach menopause (the average age for menopause among women in the U.S. is 52 years) and the longer they live, the more pronounced the bone density loss will be.

Because of the natural decline of bone density, low bone density or **osteopenia** (*oste(o)-* bone, *-penia* deficiency) **is a normal process for both older men and women**. However, this process is more pronounced in women because they stop producing estrogens after menopause. Men keep producing testosterone throughout their lives, albeit in smaller quantities as they age.

Once the bone substance becomes depleted and is susceptible to fracture under almost normal stress, we talk about **osteoporosis** (*oste(o)-* bone, *-porosis* porous condition). The **major risk factors** for developing osteoporosis are lack of estrogen (women after menopause), vitamin D deficiency, lack of calcium, petite body shape, and lack of physical activity. In the past, osteoporosis was a diagnosis made after people broke their bones during normal activities. Nowadays, we can measure bone density to diagnose and treat osteopenia before it develops into osteoporosis. The best way to prevent and treat osteoporosis is with weight-bearing exercises along with an increase in calcium, vitamin D, and fluoride in the diet.

A lack of calcium salts leads to **softening of the bones**, which may bend under the weight of the body. The medical term for bone softening is **osteomalacia** (*oste(o)-* bone, *-malacia* softening). If the cause is a lack of vitamin D and/or calcium during childhood, the disease is called **rickets**.

### 6.10 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	joint	_____	calci-
2.	bone marrow	_____	oste(o)-
3.	calcium	_____	-blast
4.	bud, germ	_____	myelo(o)-
5.	bone	_____	dia-
6.	passing through	_____	arthr(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- The diaphysis of a long bone is composed of spongy bone. \_\_\_\_\_
- All flat bones are formed from hyaline cartilage. \_\_\_\_\_
- The trabeculae of spongy bone are oriented toward lines of stress. \_\_\_\_\_
- Closure of the epiphyseal plate stops all bone growth. \_\_\_\_\_
- Sixty-five percent of the mass of bone is a mineral compound called *hydroxyapatite*. \_\_\_\_\_
- Osteons are found in compact bone only. \_\_\_\_\_
- Osteomalacia can be caused by a lack of vitamin D. \_\_\_\_\_
- Long bones are cube-shaped and of equal length and width. \_\_\_\_\_
- The major risk factor for developing osteoporosis is lack of estrogen in older women. \_\_\_\_\_
- Parathyroid hormone is the most important hormone for bone growth. \_\_\_\_\_

#### Matching

Choose the item in column 2 that best matches each item in column 1.

- |    |                 |   |          |
|----|-----------------|---|----------|
| 1. | Osteoporosis    | a) lining of the marrow cavity                                | 1. _____ |
| 2. | Osteomalacia    | b) cells that can build bony matrix                           | 2. _____ |
| 3. | Spiral fracture | c) growth pattern in which matrix is laid down on the surface | 3. _____ |
| 4. | Endosteum       | d) area where bone longitudinal growth takes place            | 4. _____ |

- |                        |   |           |
|------------------------|---|-----------|
| 5. Osteoclasts         | e) appearance signals the end of bone growth                | 5. _____  |
| 6. Osteoblasts         | f) fracture resulting from a twisting force                 | 6. _____  |
| 7. Appositional growth | g) bones are porous and thin but bone composition is normal | 7. _____  |
| 8. Epiphyseal plate    | h) sesamoid bone  | 8. _____  |
| 9. Epiphyseal line     | i) cells that can dissolve the bony matrix                  | 9. _____  |
| 10. Patella            | j) bones deform on weight bearing                           | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- The shaft of a long bone is also called \_\_\_\_\_.
  - diaphysis
  - epiphysis
  - metaphysis
  - periosteum
- Which of the following is a lining found inside a bone that promotes bone growth in width?
  - Periosteum
  - Endosteum
  - Marrow
  - Metaphysis
- Which cells are considered bone-building cells?
  - Osteotrophs
  - Osteoclasts
  - Osteocytes
  - Osteoblasts
- Which of the following structures contains osteocytes?
  - Haversian system
  - Volkman's canal
  - Lacunae
  - Canaliculi
- Bones that grow within tendons are classified as \_\_\_\_\_ bones.
  - flat
  - axial
  - sesamoid
  - irregular
- Central canals are connected to each other by \_\_\_\_\_.
  - Volkman's canals
  - lamellae
  - canaliculi
  - lacunae
- In bone, collagen is found in the \_\_\_\_\_.
  - lacunae
  - central canals
  - lamellae
  - canaliculi

8. Spongy bone is made up of smaller parts of bone called \_\_\_\_.
- a. Volkmann's canals
  - b. canaliculi
  - c. osteons
  - d. trabeculae
9. The primary ossification center of a long bone is found in the \_\_\_\_.
- a. epiphysis
  - b. diaphysis
  - c. periosteum
  - d. endosteum
10. A vitamin that is important for optimal bone density is \_\_\_\_.
- a. fluorine
  - b. vitamin C
  - c. vitamin D
  - d. manganese



## Chapter 7 Skeleton

### 7.1 Chapter Outline

The skeletal system is made up of 204 bones, cartilage, joints, and ligaments. The skeleton is subdivided into an axial skeleton, which forms the long axis of the body, and an appendicular skeleton, which consists of the bones of the upper and lower limbs.

### 7.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Name the two major parts of the human skeleton.
- Name and identify the facial and cranial bones on a skull.
- Name the major skull openings and sutures.
- Name the four paranasal sinuses.
- Name the parts and curves of the vertebral column.
- Describe the structure and function of intervertebral discs.
- Describe the parts of a typical vertebra.
- Compare cervical, thoracic, and lumbar vertebrae.
- Name and identify the bones of the thoracic cage on a skeleton.
- Name the different types of ribs.
- Name the major parts of the appendicular skeleton.
- Name and identify the parts of the shoulder girdle and their function on a skeleton.
- Name and identify the bones of the upper limb and their major markings on a skeleton.
- Name and identify the parts of the pelvic girdle and their function on a skeleton.
- Compare the male pelvis with the female.
- Name and identify the bones of the lower limb and their major markings on a skeleton.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 7.3 Combining Forms

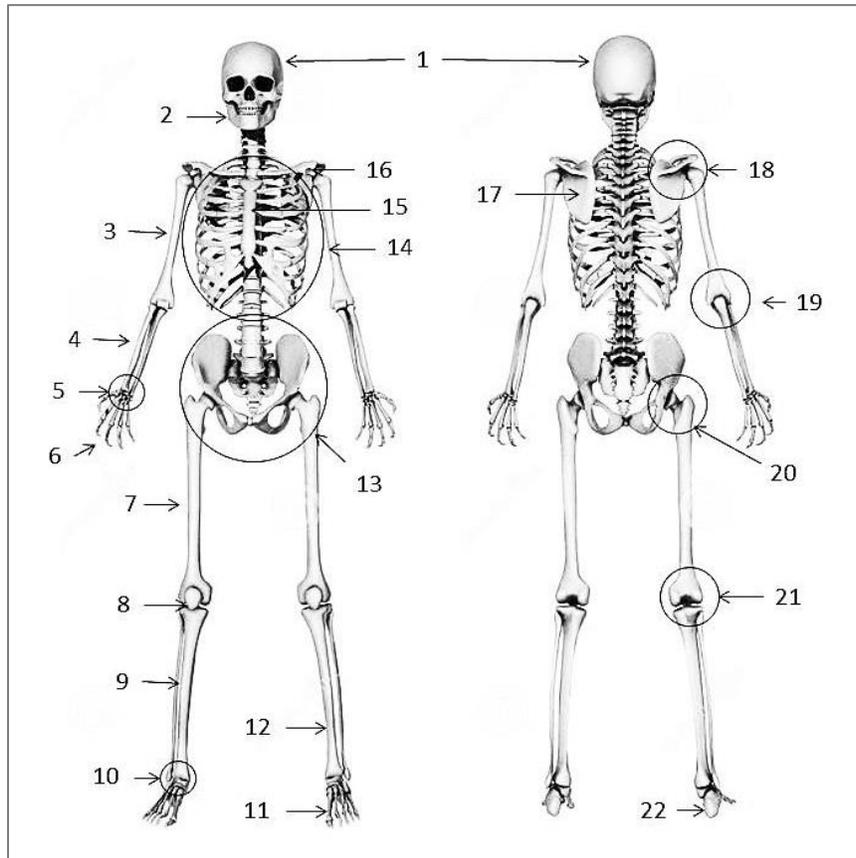
Table 7.3 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 7.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
brachi(o)-	(upper) arm	<i>brachialgia</i> = pain in the (upper) arm
calcane(o)-	heel or heel bone (calcaneus)	<i>calcaneodynia</i> = pain in the heel
carp(o)-	wrist (carpus)	<i>carpal</i> = relating to the wrist or wrist bones
cervic(o)-	neck	<i>cervicodynia</i> = pain in the neck
clavicul(o)-	collar bone (clavicle)	<i>clavicular</i> = relating to the collar bone
cost(o)-	rib(s)	<i>costectomy</i> = removal of a rib
crani(o)-	skull	<i>craniotomy</i> = incision (opening) of the skull
dactyl(o)-	finger(s), toe(s)	<i>dactylitis</i> = inflammation of the fingers or toes

ethm(o)-	sieve	<i>ethmoid bone</i> = skull bone with a sieve-like area with tiny holes
femor(o)-	thigh or thigh bone (femur)	<i>femoral</i> = relating to the thigh or thigh bone
fibul(o)-	calf bone (fibula)	<i>fibular</i> = relating to the fibula
humer(o)-	humerus (upper arm bone)	<i>humeral</i> = relating to the humerus
lumb(o)-	loins (lower back)	<i>lumbodinia</i> = lower back pain; also called lumbago
oss(e)-, oss(i)-, oste(o)-, ost(o)-	bone	<i>osteoma</i> = tumor arising from bone tissue
ped(o)-, pod(o)-	foot	<i>podiatry</i> = diagnosis and treatment of disorders of the foot, ankle, and lower leg
pelv(i)-, pelv(o)-	pelvis	<i>pelvimetry</i> = measuring of the pelvis, for example in obstetrics
radi(o)-	1. radius (outer bone of the forearm) 2. radiation, X-ray	<i>radial</i> = relating to the radius <i>radiotherapy</i> = use of X-rays and other high-energy rays for treatment of tumors
scoli(o)-	bent, crooked	<i>scoliosis</i> = abnormal sideward bending of the spine
sphen(o)-	wedge	<i>sphenoid bone</i> = bone at the base of the skull wedged between other skull bones
spondyl(o)-	vertebra	<i>spondylitis</i> = inflammation of the vertebrae
thorac(o)-	chest (thorax)	<i>thoracodynia</i> = pain in the chest
vertebr(o)-	vertebra	<i>vertebral</i> = relating to a vertebra

Figure 7.1 Human skeleton from the front (left) and back (right)



1. Skull
2. Mandible (jaw bone)
3. Humerus
4. Radius and ulna
5. Wrist with carpal bones
6. Digits with phalanges
7. Femur (thigh bone)
8. Patella (kneecap)
9. Fibula (calf bone)
10. Ankle with tarsal bones
11. Metatarsal bone
12. Tibia (shinbone)
13. Pelvis
14. Thoracic or rib cage
15. Sternum (breastbone)
16. Clavicle (collar bone)
17. Scapula (shoulder blade)
18. Shoulder joint
19. Elbow joint
20. Hip joint
21. Knee joint
22. Calcaneus (heel bone)

## 7.4 Axial Skeleton

The axial skeleton is made up of the **skull**, the **vertebral column** (also called the **backbone** or **spine**), and the **thoracic** or **rib cage**. It consists of **80 bones overall**.

The **upper** and **lower limbs** are attached to the axial skeleton by so-called girdles. The **shoulder** or **pectoral girdle** connects the upper limb to the thorax; the **hip** or **pelvic girdle** connects the lower limb to the pelvis.

**Table 7.2 Bones of the Axial Skeleton**

Skull	
<b>Facial bones</b>	Maxilla (2), Palatine bone (2), Zygomatic bone (2), Lacrimal bone (2), Nasal bone (2), Vomer, Inferior nasal concha (2), Mandible
<b>Cranial bones</b>	Frontal bone, Parietal bone (2), Occipital bone, Temporal bone (2), Sphenoid bone, Ethmoid bone
<b>Rib (thoracic) cage</b>	Ribs (24), Sternum
<b>Vertebral column</b>	Cervical vertebrae (7), Thoracic vertebrae (12), Lumbar vertebrae (5), Sacrum, Coccyx
<b>Auditory ossicles</b>	Malleus (2), Incus (2), Stapes (2)
<b>Hyoid</b>	Hyoid

### Skull

The skull has two sets of bones: **14 facial bones** and **8 cranial bones**. The **cranial bones** encase the brain in the **cranial cavity**, which consists of the cranial vault (**calvaria**) and the **cranial base**. The bones provide the sites of attachment for our head and neck muscles.

**Table 7.3 Cranial Bones**

<b>Frontal bone</b>	<ul style="list-style-type: none"> <li>Forms the anterior portion of the cranium and most of the anterior cranial fossa. It also forms the superior wall of the orbits and contains the air-filled <b>frontal sinus</b>.</li> </ul>
<b>Parietal bones and associated sutures</b>	<ul style="list-style-type: none"> <li>Form the superior and lateral aspects of cranial vault.</li> <li>Four sutures mark the articulations of the parietal bones with the frontal, occipital, and temporal bones:               <ul style="list-style-type: none"> <li><b>Coronal suture</b> - connects parietal bones and frontal bone.</li> <li><b>Sagittal suture</b> - connects right and left parietal bones.</li> <li><b>Lambdoid suture</b> - connects parietal bones and occipital bone.</li> <li><b>Squamous (squamosal) sutures</b> – connect parietal and temporal bones on each side of skull.</li> </ul> </li> </ul>
<b>Occipital bone</b>	<ul style="list-style-type: none"> <li>Forms most of skull's posterior wall and posterior cranial fossa and surrounds the <b>foramen magnum</b></li> <li>Articulates with 1<sup>st</sup> vertebra (atlas).</li> <li>Site of attachment for ligamentum nuchae and neck and back muscles.</li> </ul>
<b>Temporal bones</b>	<ul style="list-style-type: none"> <li>Form the inferolateral aspects of skull and parts of cranial floor.</li> <li>Have four major regions: Squamous, tympanic, mastoid with <b>mastoid process</b>, petrous region.</li> </ul>
<b>Sphenoid bone</b>	<ul style="list-style-type: none"> <li>Complex, bat-shaped bone; called a keystone bone because it articulates with all other cranial bones.</li> <li>Three pairs of processes:               <ul style="list-style-type: none"> <li>Greater wings</li> <li>Lesser wings</li> <li>Pterygoid processes</li> </ul> </li> </ul>
<b>Ethmoid bone</b>	<ul style="list-style-type: none"> <li>Deepest skull bone.</li> <li>Forms the superior part of nasal septum, roof of nasal cavities with cribriform plate for olfactory fibers, and contributes to the medial wall of the orbits.</li> </ul>

The **frontal bone** forms the anterior portion of the cranial cavity, including most of the floor. It also forms the superior wall of the orbits and contains the air-filled **frontal sinus**.

The **parietal bones** form the middle part of the roof and sides of the cranial cavity.

The **occipital bone** forms the posterior wall and floor of the cranial cavity. The bone surrounds the **foramen magnum** (the spinal cord enters the skull through the foramen and becomes the brain stem) and forms a joint with the first cervical vertebra (atlas).

The **temporal bones** on the lateral aspect of the skull contain the inner ear structures (see **Chapter 14 General & Special Senses**). The **mastoid process** behind the ear is important for the attachment of muscles, in particular the sternocleidomastoid muscle. It contains air cells that can get infected.

The **facial bones** form the framework of the face, including cavities for the special sense organs for sight (orbit), smell (nose), and taste (mouth). The facial bones are sites of attachment for the teeth and the muscles for chewing (mastication) and facial expression.

**Sutures** (see Table 7.3 above and Chapter 8 Joints) are jagged lines that connect the bones of the skull. The only cranial bone that is not connected by sutures with the other bones and, thus, can form a movable joint is the **mandible** (lower jaw bone). Important sutures are the coronal, sagittal, lambdoid, and squamous sutures. Tiny, irregular bones within sutures are called **sutural bones**.

The **orbits** house the eyes and lacrimal glands and are the sites of attachment for eye muscles. They are formed by parts of seven bones: **three cranial bones** (frontal, ethmoid, sphenoid) and **four facial bones** (maxilla, lacrimal bone, zygomatic bone, palatine bone).

The **bridge of the nose** is formed by the **nasal bones**, whereas the **lacrimal bones** form part of the medial wall of the **orbit**.

The **nasal cavity** is even more complex. The roof, lateral walls, and floor are formed by parts of one cranial bone (ethmoid bone) and three facial bones (palatine, maxillary, inferior nasal concha).

The **nasal septum** consists of a bony part (ethmoid and **vomer**) and the anterior **septal cartilage**.

The **paranasal sinuses** are hidden cavities that cannot be seen from the outside. They are mucosa-lined, air-filled spaces that lighten the skull and enhance resonance of the voice. Based on the bone in which they are situated, we refer to them as the **frontal, sphenoid, ethmoid, and maxillary sinus**.

The medially fused **maxillary bones** form the upper jaw (**maxilla**) and the central portion of the facial skeleton.

The **zygomatic bones** or **cheekbones** form the basis for the cheeks and part of the eye socket (orbit).

Figure 7.2 Skull, frontal view

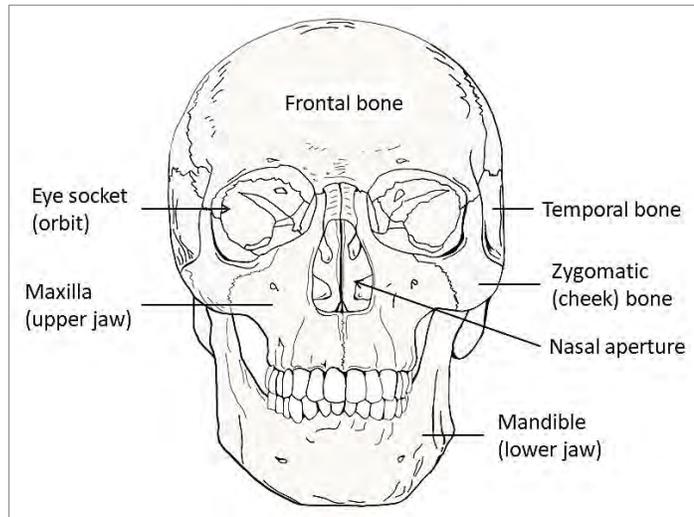
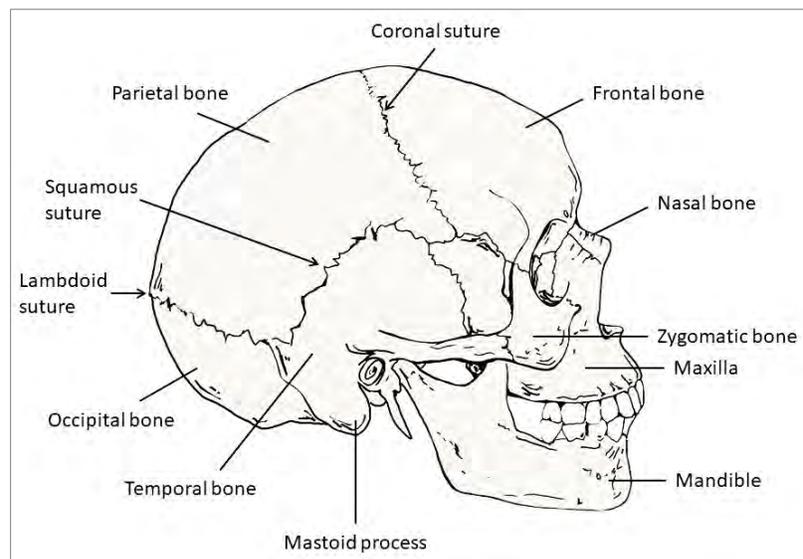


Figure 7.3 Skull, lateral view



The **mandible** (or **lower jaw**) is the largest and strongest bone of the face because it must withstand the pressure created when biting and chewing. The **temporomandibular joint** is the only freely movable joint in skull.

The U-shaped **hyoid bone** is the only bone in the body not connected directly to another bone. It is an important site of attachment for muscles used in swallowing and speech.

**Table 7.4 Facial Bones**

<b>Mandible</b>	<ul style="list-style-type: none"> <li>The lower jaw is the largest, strongest bone of the face.</li> <li>The <b>temporomandibular joint</b> is the only freely movable joint in skull.</li> </ul>
<b>Maxillary bones</b>	<ul style="list-style-type: none"> <li>They are medially fused to form the <b>upper jaw</b> (maxilla) and the central portion of the facial skeleton.</li> <li>They articulate with all other facial bones except the mandible.</li> </ul>
<b>Zygomatic bones</b>	<ul style="list-style-type: none"> <li>Also called <b>cheekbones</b>.</li> <li>They form the inferolateral margins of the orbits.</li> </ul>
<b>Nasal bones</b>	<ul style="list-style-type: none"> <li>They form the bridge of the nose.</li> </ul>
<b>Lacrimal bones</b>	<ul style="list-style-type: none"> <li>They are found in the medial walls of the orbits.</li> <li>The <b>lacrimal fossa</b> houses <b>lacrimal sac</b>.</li> </ul>
<b>Palatine bones</b>	<ul style="list-style-type: none"> <li>They form the posterior one-third of the hard palate and the posterolateral walls of the nasal cavity.</li> <li>They form a small part of the orbits.</li> </ul>
<b>Vomer</b>	<ul style="list-style-type: none"> <li>The plow-shaped lower part of the nasal septum.</li> </ul>
<b>Inferior nasal conchae</b>	<ul style="list-style-type: none"> <li>They form part of the lateral walls of the nasal cavity.</li> </ul>

### Vertebral Column (Spine)

The vertebral column forms the backbone of the body. It distributes the weight of the trunk to the lower limbs and surrounds and protects the spinal cord. It consists of 26 bones overall.

There are **24 vertebrae** – **7** in the neck region (**cervical vertebrae**), **12** in the thoracic region (**thoracic vertebrae**), and **5** in the lower back (**lumbar vertebrae**). The numbers are easy to remember when you think of breakfast (7 am), lunch (12 pm), and dinner (5 pm).

Each vertebra but one (the atlas) has an anterior weight-bearing region called the **body** or **centrum**. The posterior part that surrounds the **vertebral foramen** is the **vertebral arch**, which is composed of **pedicles** and **laminae**. All the foramina together make up the **vertebral canal**, which houses the **spinal cord**.

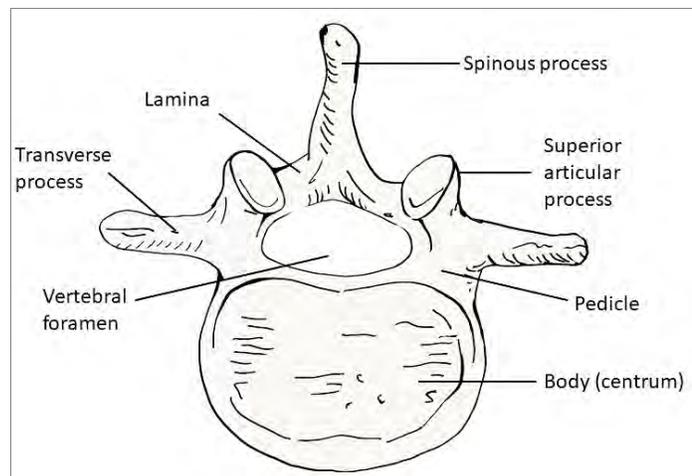
The pedicles from two adjacent vertebrae form openings called **intervertebral foramina**, through which spinal nerves leave the spinal cord.

Each vertebra has seven processes overall. The **spinous process** projects straight to the back and the two **transverse processes** project to the sides. There are also two processes protruding from the upper (**superior articular process**) and lower pedicle-lamina junction (**inferior articular process**). They form part of the joints connecting adjacent vertebrae.

The vertebrae of the different regions differ in size and shape depending on the mechanical forces they have to withstand.

**Cervical vertebrae (C<sub>1</sub>–C<sub>7</sub>)** are the smallest vertebrae because they only carry the weight of the head and don't have strong muscles pulling on them.

**Figure 7.4 Vertebra (general structure)**



- **C<sub>3</sub>-C<sub>7</sub>** have special features other vertebrae don't have. For example, their **spinous processes** are usually **bi-fid** (except C<sub>7</sub>); they have an oval body, and a large, triangular vertebral foramen. Plus, they have an additional **transverse foramen** in each transverse process.
- The **first cervical vertebra** (C<sub>1</sub>) is the only vertebra without a body. Because C<sub>1</sub> carries the skull, it was named **atlas** after a Greek mythological figure.
- The **second cervical vertebra** (C<sub>2</sub>) is called **axis** because it has a tooth-like projection (**dens axis**), around which the atlas rotates when we shake our head to say "no".
- The **last cervical vertebra** (C<sub>7</sub>) has a rather long spinous process. This makes it easy to palpate the process and use it as an important landmark; thus, this vertebra is called **vertebra prominens**.

The twelve **thoracic vertebrae (T<sub>1</sub>-T<sub>12</sub>)** are bigger than the cervical vertebrae as they have to carry more weight. Because they all form joints with ribs, they have additional **facets** or **demifacets** on their bodies and transverse processes. Their **spinous processes are long and point downwards** because of the back muscles pulling on them. The **alignment of the inferior and superior articular facets** inhibits flexion and extension but **allows for rotation** of the thoracic spine.

The **lumbar vertebrae (L<sub>1</sub>-L<sub>5</sub>)** are the biggest because they have to carry all the weight of the upper body and any additional weight carried.

Their pedicles and laminae are short and thick, and their **spinous processes are flat and hatchet-shaped**. The **articular facets** lock lumbar vertebrae together to **prevent rotation, but allow for flexion and extension**.

The spine used to have more vertebrae, but during evolution the last vertebrae started to fuse together forming two bones, the **sacrum**, which is the keystone bone of the pelvis, and the **tailbone** or **coccyx**. The sacrum consists of five fused vertebrae (S<sub>1</sub>-S<sub>5</sub>) and the coccyx of three - five fused vertebrae.

The sacrum articulates with L<sub>5</sub> superiorly and with **auricular surfaces** of the hip bones laterally; the coccyx articulates with the sacrum above.

### Ligaments of the vertebral column

The vertebrae of the spine are held together by **strong ligaments** that either connect neighboring vertebrae or run all the way from the skull down to the sacrum. The **anterior** and **posterior longitudinal ligaments** run on the anterior and posterior side of the bodies of the vertebrae from the neck down to the sacrum. **Short ligaments** connect each vertebra to those above and below. One of the unique short ligaments is the **ligamentum flavum**. It is yellow in color because it contains elastic fibers. It connects adjacent vertebrae and stores energy when the spine flexes, which it uses to help straighten the spine again.

### Intervertebral discs

The intervertebral discs are cushion-like pads composed of two parts:

1. An inner gelatinous nucleus that gives the disc its elasticity and compressibility called **nucleus pulposus**.
2. An outer ring of collagen and fibrocartilage called **anulus fibrosus**.

Together, they form a disc strong enough to withstand the pressure created by our body weight and any additional weight we carry.

Figure 7.5 Cervical vertebrae

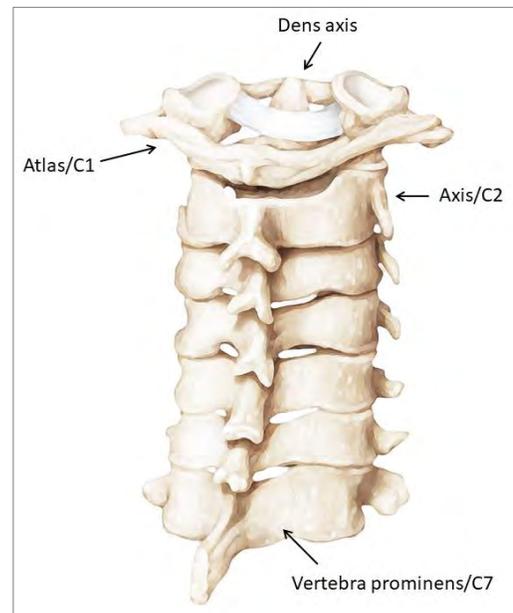
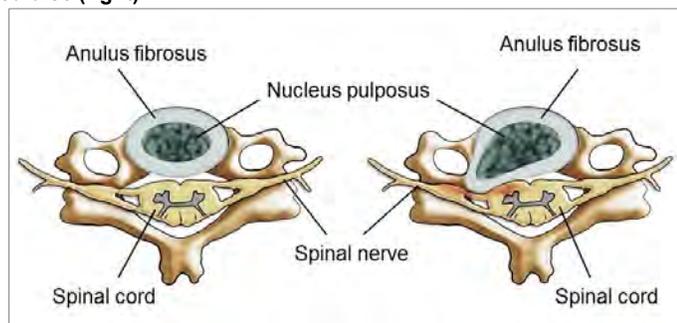


Figure 7.6 Cervical vertebra and intervertebral disc (left) and herniated disc (right)



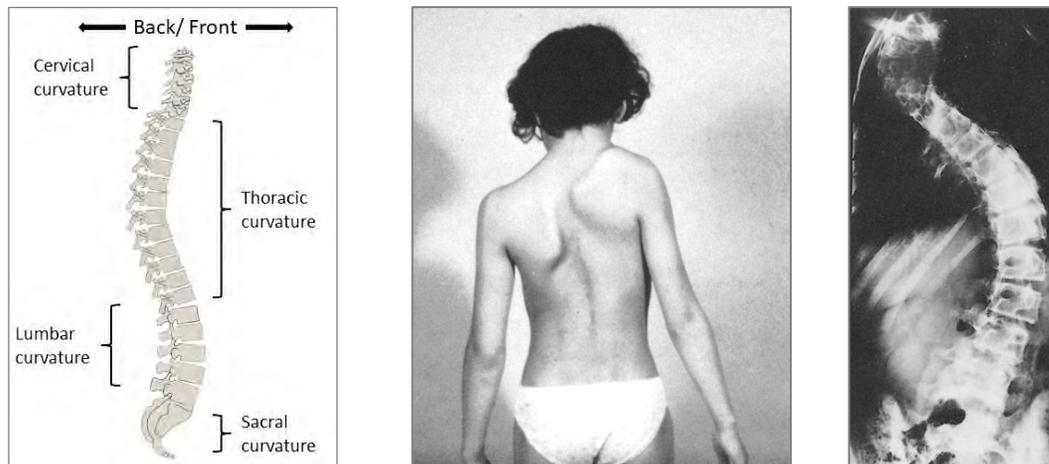
A **herniation** of a part of the nucleus pulposus protrudes through cracks in the anulus fibrosus, which may lead to pressure on spinal nerves or the spinal cord and potentially cause permanent damage if not treated adequately.

### Curvatures of the spine

Curvatures increase the resilience and flexibility of the spine. Newborn babies have a C-shaped spine because they only have convex curvatures. During the first year of their life, the concave curvatures gradually develop, allowing them to balance their head when they sit up or stand up. There are four curvatures overall:

- Two **cervical and lumbar curvatures** open to the back (concave curvatures).
- Two **thoracic and sacral curvatures** open to the front (convex curvatures).

**Figure 7.7** Spinal curvatures (left), young girl with scoliosis (center), and X-ray of a scoliotic spine (right)



### Abnormal spinal curvatures

Excessive lumbar lordosis (**lumbar hyperlordosis**) is often called **hollow back**, **saddle back**, or **swayback**. It is a common cause of lower back pain. Most of time, it is caused by poor posture and can be improved with physical therapy.

Excessive thoracic curvature is called **kyphosis** (from Greek *kyphos* = hump), **roundback**, or **hunchback**. It can be caused by vertebral fractures or infection and osteoporosis (**dowager's hump** of the upper back). The most common type, however, is **postural kyphosis**, which in younger people is frequently caused by slouching. It can usually be improved with physical therapy. **Structural kyphosis**, caused by changes to the shape of vertebrae, requires surgical intervention.

While the spine has natural curvatures in the sagittal plane, it must be completely straight in the frontal plane. Any curve to the side (**scoliosis**) is pathologic and will lead to health problems. Treatment is not always easy or successful. The earlier a scoliosis condition is diagnosed, the more successful conservative treatment (physical therapy, braces) will be.

### Thoracic Cage

The **thoracic** or **rib cage** is composed of the **thoracic vertebrae**, **sternum** (**breast bone**), and **ribs** with **costal cartilages**. Its function is to protect the vital organs of the thoracic cavity (heart, lungs), to support the shoulder girdle and upper limbs, and to provide attachment sites for many muscles, e.g., intercostal muscles used during breathing.

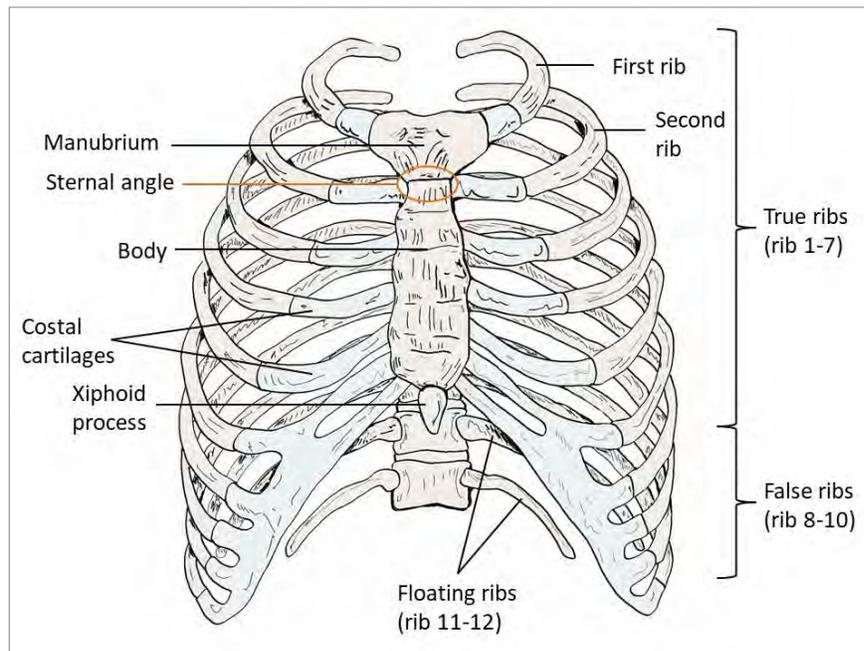
The **sternum** or **breastbone** looks a bit like a Roman sword. It has three parts: a handle or **manubrium**, a **body**, and a tip called **xiphoid process**. The connection between the manubrium and body forms a visible and palpable prominence in the midline of our chest called **sternal angle**. It is an important anatomical landmark for finding the second rib and the second intercostal space below.

Each **rib** has four main parts: a **head** that articulates with facets or demifacets on bodies of two adjacent vertebrae, a short **neck**, a **tubercle** with an articular facet that articulates with the transverse costal facet of a thoracic vertebra, and a **shaft** that can be short or long depending on the rib.

The **twelve pairs of ribs** can be subdivided into **true ribs** (pairs 1-7) that attach directly to the sternum via individual costal cartilages. Because they connect the vertebrae with the sternum they are also called **vertebrosternal ribs**.

**Pairs 8-12** are called **false ribs** because they don't directly connect with the sternum. **Pairs 8–10** are also called **vertebrochondral ribs** because they attach indirectly to the sternum by joining the costal cartilage of the rib above. **Pairs 11-12** have no connection whatsoever with the sternum and, thus, are called **vertebral** or **floating ribs**.

Figure 7.8 Thoracic cage



### Check Your Understanding

- The axial skeleton is made up of the \_\_\_\_\_.
  - skull, vertebral column and thoracic cage
  - skull, vertebral column and upper limbs
  - skull, upper and lower limbs
  - vertebral column, upper and lower limbs
- Which of the following is not a facial bone?
  - Maxilla
  - Frontal bone
  - Palatine bone
  - Mandible
- The zygomatic bones are also known as the \_\_\_\_\_.
  - lower jaw
  - upper jaw
  - cheekbones
  - nasal bones
- The rib cage has \_\_\_\_ pairs of ribs.
  - 6
  - 10
  - 8
  - 12
- The coccyx is also called the \_\_\_\_\_.
  - sacrum
  - hip bone
  - cheekbone
  - tailbone
- The axial skeleton consists of \_\_\_\_ bones.
  - 30
  - 204
  - 80
  - 15

1 A 2 B 3 C 4 D 5 D 6 C

### 7.5 Appendicular Skeleton

The appendicular skeleton is formed by the bones of the limbs and the pectoral and pelvic girdles.

Table 7.5 Bones of the Appendicular Skeleton

<b>Pectoral girdle</b>	<ul style="list-style-type: none"> <li>Scapula (2), Clavicle (2)</li> </ul>
<b>Upper limbs</b>	<ul style="list-style-type: none"> <li>Humerus, Radius, Ulna, Carpal bones (8): scaphoid, lunate, triquetrum, pisiform, trapezoid, trapezium, capitate and hamate, Metacarpal bones (5), Phalanges (14)</li> </ul>

<b>Pelvic girdle</b>	<ul style="list-style-type: none"> <li>• Hip bone (2); each consisting of ilium, ischium and pubis</li> </ul>
<b>Lower limbs</b>	<ul style="list-style-type: none"> <li>• Femur, Patella, Tibia, Fibula, Tarsal bones (7): talus, calcaneus, navicular, cuboid, lateral, intermediate and medial cuneiform, Metatarsal bones (5), Phalanges (14)</li> </ul>

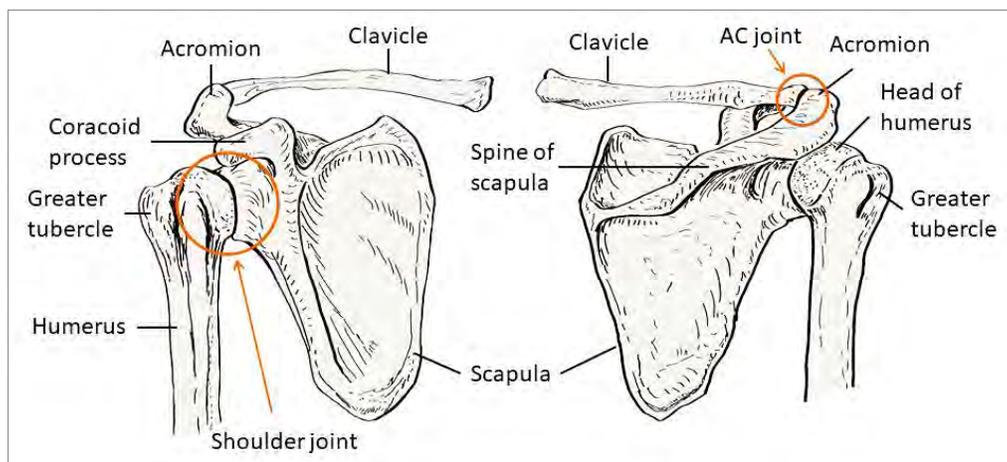
### Pectoral Girdle

The **pectoral** or **shoulder girdle** consists of the **collarbones** (clavicles) and **shoulder blades** (scapulae). They attach the upper limbs to the axial skeleton and provide attachment sites for muscles that move the upper limbs.

The S-shaped **clavicles** connect the scapula with the sternum. They act as a brace to hold the scapula and the arm out laterally. The flattened outer or lateral end is called the **acromial end** because it articulates with the acromion in the acromioclavicular joint. The cone-shaped inner or medial end articulates with the manubrium of the sternum and is called the **sternal end**.

The **scapula** is a flat, triangular bone with three borders and three corners (angles). It is located on the back of the rib cage between ribs 2 and 7 and is held in place by strong muscles. The **glenoid fossa** at the upper end of the lateral border articulates with the **humerus** to form the **shoulder joint**. Above it is the beak-like **coracoid process**. The **spine of the scapula** is on the posterior surface. It ends in an enlarged process called **acromion**, which articulates with the lateral end of the clavicle to form the **acromioclavicular [AC] joint**.

Figure 7.9 Right shoulder girdle, anterior (left) and posterior view (right)



### Upper Limbs

The upper limbs consist of **30 bones and three parts** (arm, forearm, hand). The (upper) **arm** has one bone (the **humerus**), the **forearm** has two bones (the **radius and ulna**), and the **hand** has 27 bones.

The **humerus** is the largest and longest bone of the upper limb. Its proximal end forms the rounded, smooth **head**, which articulates with the glenoid cavity of the scapula to form the **shoulder joint**. Just inferior to it are the **greater** and **lesser tubercle**, which are attachment sites for various muscles. Midway down its shaft is the V-shaped **deltoid tuberosity**, the attachment site for the deltoid muscle.

The distal end of the humerus has **two condyles**. The medial hour-glass shaped condyle is called **trochlea**; the lateral condyle is ball-shaped and called **capitulum**. Both condyles articulate with the forearm bones (radius and ulna) to form the elbow joint. Each condyle carries a little raised attachment area for various muscles, the so-called **medial** and **lateral epicondyles**.

On the anterior aspect of the proximal part are two fossae, a shallow **radial fossa** that accommodates the head of the radius when the elbow is flexed and a deeper **coronoid fossa**. On the posterior aspect is the **olecranon fossa** for the olecranon process of the ulna.

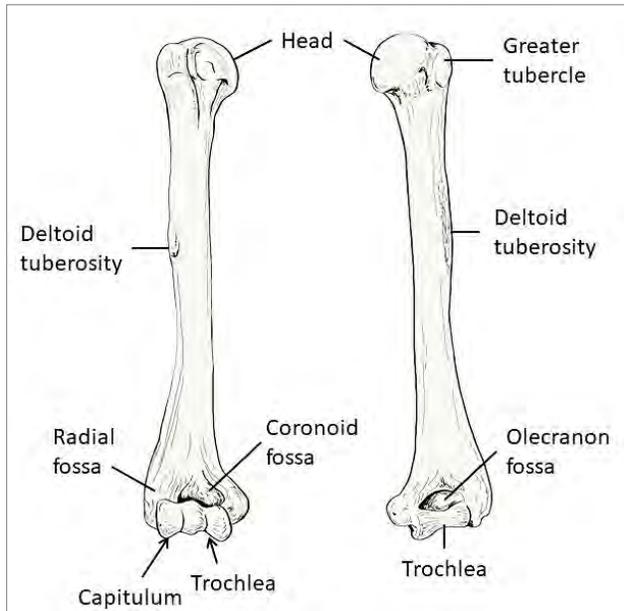
The **forearm** has two bones: the **radius** on the lateral side and the **ulna** on the medial side.

The thin **proximal end of the radius** is called the **radial head**; it articulates with the capitulum of the humerus and the radial notch of the ulna. Just below the head is a rough patch called **radial tuberosity** for attachment of the biceps brachii muscle. The distal, expanded end of the radius is part of the wrist joint. The **ulnar notch** on its medial

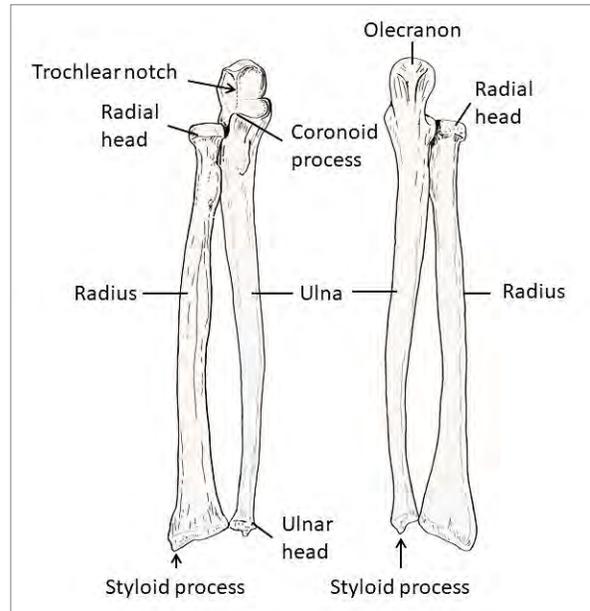
side articulates with the ulna in the distal radioulnar joint. The **styloid process** on the lateral side acts as an anchoring site for wrist ligaments.

The **ulna** is longer than the radius and forms the major part of the elbow joint, together with the humerus. Its thick proximal end carries the **olecranon** and **coronoid process**. They are separated by a deep concavity called the **trochlear notch**, which is perfectly shaped to articulate with the trochlea of the humerus. On the lateral side of the coronoid process is the **radial notch** for articulation with the head of the radius. The distal end of the ulna is smaller and ends in a lateral **head** and a medial **styloid process**.

**Figure 7.10 Right humerus, anterior (left) and posterior view (right)**



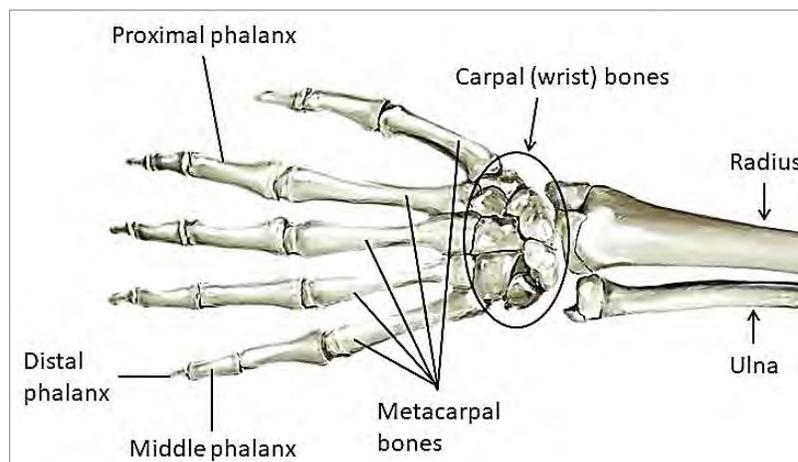
**Figure 7.11 Right forearm bones, anterior (left) and posterior view (right)**



The **skeleton of the hand** consists of **27 bones**: eight **carpal bones** in the wrist, five **metacarpal bones** in the palm, and fourteen **phalanges** (*phalanx* is the singular of phalanges) in the fingers. The **carpal bones** or **carpals** are arranged in two rows of four bones each.

- Starting from the lateral side, the **proximal row** is made up of **scaphoid**, **lunate**, **triquetrum**, and **pisiform bone**. However, only the scaphoid and the lunate articulate with the radius to form the wrist joint.
- The **distal row** also has four bones, which are called **trapezium**, **trapezoid**, **capitate**, and **hamate**.

**Figure 7.12 Hand, posterior view**



All carpal bones received their names from their shape: the pisiform is pea-shaped, the lunate like a slightly deformed moon, the triquetrum is triangular, and the trapezoid has four sides. The scaphoid is boat-shaped and the capitate is shaped like a head. The hamate looks like it has a hook and the trapezium looks a bit like a little table.

The **metacarpus** consists of **five metacarpal bones** (I-V), while the **fingers (digits)** have 14 bones (**phalanges**) overall. Each **finger** has three bones called **proximal, middle, and distal phalanx**, with the exception of the **thumb**; it only has two phalanges as the middle phalanx is missing.

The first finger is also called **thumb** or **pollex**; the second finger is called **index** (finger); the third finger is also called **middle finger**; the fourth finger is also called **ring finger**; and the fifth finger is also called **little finger** or **pinky**.

The **middle finger is the longest finger** of the hand in both sexes. But, the ring finger usually is longer than the index finger in men. In women, the index finger usually is longer than the ring finger.

### Check Your Understanding

- Finger bones are also known as \_\_\_\_\_.
  - carpals
  - digits
  - phalanges
  - metacarpals
- Which of the following bones is part of the shoulder girdle?
  - Sternum
  - Humerus
  - Radius
  - Clavicle
- The spine of the scapula ends in a process called \_\_\_\_\_.
  - acromion
  - coracoid
  - carpus
  - trochlea
- The hour-glass shaped condyle of the humerus is called \_\_\_\_\_.
  - acromion
  - capitulum
  - trochlea
  - styloid

1.C.2.D.3.A.4.C

### Pelvic Girdle

The **pelvic** or **hip girdle** attaches the lower limbs to the axial skeleton via strong ligaments, transmits the weight of the upper body to the lower limbs, and protects pelvic organs, such as urinary bladder and uterus. It consists of the two **hip bones** (also called **coxal bone** or os coxae) that together with the **sacrum** and the **coccyx** form the **bony pelvis**.

Each **hip bone** consists of three fused bones: **ilium**, **ischium**, and **pubis**. At the center of the hip, where the three bones fuse, is a deep fossa called **acetabulum**, which accommodates the head of the femur to form the hip joint.

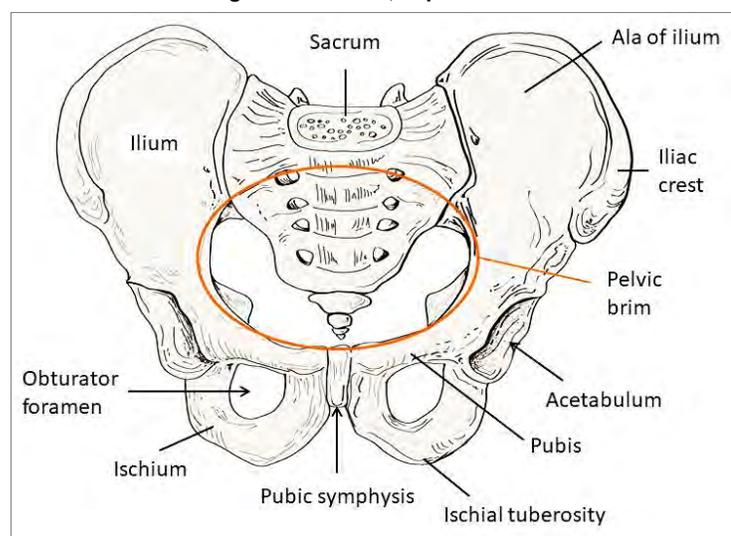
The **ilium** is the upper part of the hip bone. It has a **body** that connects with the other two parts of the hip bone and an upper wing-like portion called **ala** with a thickened superior margin known as the **iliac crest**. The medial surface of the ala has a concave fossa called **iliac fossa**. The posterior ear-shaped **auricular surface** articulates with the **sacrum** at the sacroiliac joint.

The posteroinferior part of the hip bone is formed by the **ischium**. It has two parts: a thicker, superior part called the **body** and a thinner inferior **ramus** that connects with the pubis. The lower, thickened surface of the body, the **ischial tuberosity**, is the part that we sit on. Because of that, the tuberosity is also known as **sit** or **sitting bone**.

The **pubis** or **pubic bone** forms the anterior portion of the hip bone. It is V-shaped with an **inferior** and a **superior ramus** and a medial **body**. The two medial bodies form the **pubic symphysis** in the midline of the pelvis.

The **true** or **lesser pelvis** is located below the **pelvic brim**, the **false** or **greater pelvis** above it. There are marked differences be-

Figure 7.13 Pelvis, superior view



tween a **female pelvis**, which is adapted for childbearing, and a **male pelvis**, which must withstand greater mechanical stress. In women, the true pelvis is broad, shallow, and has a greater outlet for delivery of a baby.

### Lower Limbs

The lower limb carries the weight of the body and, thus, is subject to exceptionally strong forces. It has **three regions** with a total of **30 bones**. The regions are the **thigh, leg, and foot**.

The **thigh bone** or **femur** is the largest, longest, and strongest bone in the body. The proximal end has an elongated **neck** with a ball-like **head** that articulates with the acetabulum of the hip bone to form the hip joint. There are two projections at the junction of the **shaft** and **neck**, the **greater trochanter** on the lateral side and the **lesser trochanter** on the posteromedial aspect. They serve as attachment sites for the large thigh and gluteal muscles.

Figure 7.14 Right femur, anterior (left) and posterior view (right)

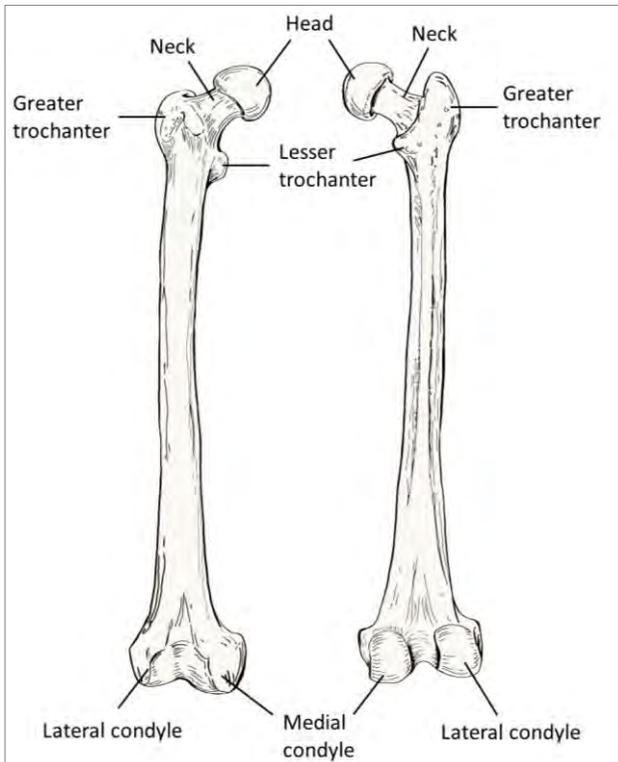
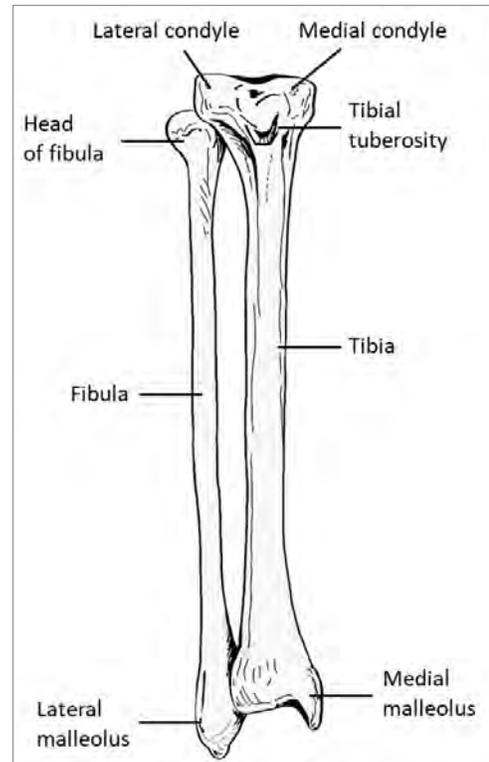


Figure 7.15 Right tibia and fibula, anterior view



The distal femur broadens and forms two wheel-like processes, the **medial** and **lateral condyle**. Each condyle carries small elevations called the **medial** and **lateral epicondyle** as well as an articular surface that connects with the tibia as part of the knee joint.

In between the condyles on the anterior femur is another cartilage-covered surface, the **patellar surface**. The **intercondylar fossa** is a U-shaped fossa on the posterior aspect of the distal femur.

The **patella** or **kneecap** is the largest sesamoid bone of the human body. It is triangular with the **apex** pointing down towards the leg. It is embedded into the tendon of the quadriceps muscle and its cartilage-covered posterior surface allows for smooth gliding of the tendon over the lower end of the femur.

The **leg**, just like the forearm, has two bones: the lateral **fibula** and the medial **tibia**. They are connected by the **proximal tibiofibular joint** proximally, the **distal tibiofibular joint** distally, and the **interosseous membrane** along the shaft.

The **tibia** (aka **shinbone**) carries all the weight of the body, while the **fibula** (aka **calf bone**) is a non-weight-bearing bone because it does not articulate with the femur. The triangular tibia is the second only to the femur as far as strength and size are concerned. Its broad upper end forms an almost flat surface, which is subdivided into the **medial** and **lateral condyle** by the **intercondylar eminence**. The tibial condyles articulate with the corresponding condyles of the femur as part of the knee joint.

Just below the condyles on the anterior aspect of the tibia is the **tibial tuberosity**, the attachment site for the tendon

of the quadriceps muscle. The distal tibia carries an articular surface for articulation with the talus. Next to it on the medial side is a projection called **medial malleolus**.

The **fibula** is much thinner, more like a stick with expanded ends, as it is a non-weight-bearing bone. It is, however, a site of muscle attachment. It has a proximal **head** and a distal **lateral malleolus** that forms the bulge of the lateral ankle.

The **foot** has a similar number of bones (26) as the hand (27). The difference is the first part, the **tarsus**, which has only 7 bones, compared to 8 for the wrist. Because the foot has to carry all the weight when we walk, the tarsal bones are stronger than the carpal bones of the hands and have a different alignment. The **calcaneus** or **heel bone** is the biggest and strongest of the tarsals. It is also the attachment site for the strongest and thickest tendon of our body, the **Achilles** or **calcaneal tendon**.

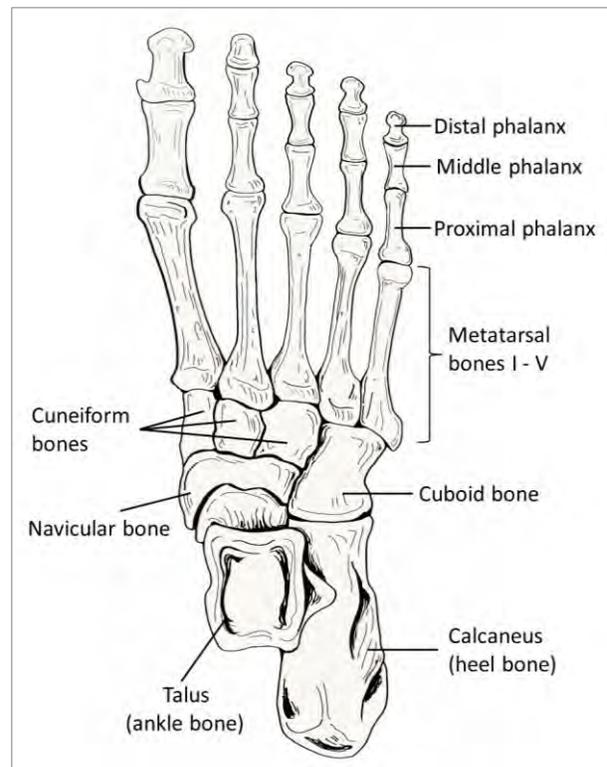
On top of the calcaneus sits the **talus** or **ankle bone**, which articulates with the tibia and fibula above. The two bones lying distally to the calcaneus and talus are the **cuboid** and **navicular bones**. Three wedge-shaped bones, the **lateral, intermediate, and medial cuneiform bone**, complete the tarsus.

The **metatarsus** consists of 5 **metatarsal bones [I - V]**. The distal head of the metatarsal bone 1 is enlarged and forms the so-called **ball of the foot**.

There are 14 **phalanges**. Each **toe** (digit) has three phalanges (**distal, middle, proximal**) except for the **big toe** (aka **hallux**) which has only two.

In order to be able to withstand the forces pushing down on the foot it has to have a structure similar to an arched doorway. Because it is fairly wide, one arch wouldn't be sufficient and therefore we have three arches: a **lateral and medial longitudinal arch** as well as a **transverse arch**.

Figure 7.16 Right foot, superior view



## 7.6 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	(upper) arm	_____	spondyl(o)-
2.	straight	_____	carp(o)-
3.	vertebra	_____	lumb(o)-
4.	foot	_____	chir(o)-
5.	loins	_____	orth(o)-
6.	rib(s)	_____	cervic(o)-
7.	hand	_____	scoli(o)-

- |     |               |       |            |
|-----|---------------|-------|------------|
| 8.  | neck          | _____ | brachi(o)- |
| 9.  | wrist         | _____ | pod(o)-    |
| 10. | bent, crooked | _____ | cost(o)-   |

**True/False**

Write "T" on the line if the statement is true and "F" if the statement is false.

- |     |  |       |
|-----|--|-------|
| 1.  | Ribs 11 and 12 are called vertebral or floating ribs.                                    | _____ |
| 2.  | In the anatomical position, the lateral lower leg bone is the fibula.                    | _____ |
| 3.  | The strongest bone in the body is the femur.   | _____ |
| 4.  | The layman's name for the scapula is the collarbone.                                     | _____ |
| 5.  | The vomer forms part of the nasal septum.  | _____ |
| 6.  | Costal cartilages join all ribs to the sternum.  | _____ |
| 7.  | Most of the stress on the vertebral column occurs on the vertebrae in the sacral region. | _____ |
| 8.  | The last cervical vertebra is called vertebra prominens.                                 | _____ |
| 9.  | We have 8 carpal bones but only 7 tarsal bones.  | _____ |
| 10. | Scoliosis is pathologic and will lead to health problems.                                | _____ |

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                     |   |           |
|---------------------|---|-----------|
| 1. Maxillae         | a) lateral forearm bone                   | 1. _____  |
| 2. Phalanges        | b) fused rudimentary tailbone             | 2. _____  |
| 3. Humerus          | c) surrounds the foramen magnum           | 3. _____  |
| 4. Radius           | d) only movable skull bone                | 4. _____  |
| 5. Atlas            | e) the thumb has only two                 | 5. _____  |
| 6. Coccyx           | f) connects right and left parietal bones | 6. _____  |
| 7. Fibula           | g) bones that contain teeth               | 7. _____  |
| 8. Occipital bone   | h) articulates with the glenoid fossa     | 8. _____  |
| 9. Mandible         | i) non-weight-bearing bone                | 9. _____  |
| 10. Sagittal suture | j) allows the head to nod "yes"           | 10. _____ |

**Multiple Choice**

Choose the one alternative that best completes the statement or answers the question.

1. Bones in the following area protect the brain.
  - a. Cranium
  - b. Vertebral column
  - c. Sacrum
  - d. Face
  
2. Which of the following is true?
  - a. There are 5 carpals, 8 metacarpals and 14 phalanges.
  - b. There are 8 carpals, 6 metacarpals and 14 phalanges
  - c. There are 8 carpals, 5 metacarpals and 12 phalanges
  - d. There are 8 carpals, 5 metacarpals and 14 phalanges
  
3. What is the purpose of the nucleus pulposus?
  - a. To compress the vertebral bones
  - b. To absorb vertical shock
  - c. Spinal fluid reservoir
  - d. Muscle attachment
  
4. The function of vertebral processes is \_\_\_\_\_.
  - a. to serve as attachment site for muscles
  - b. to support the body of the vertebrae
  - c. to hold the spine in place
  - d. to allow passage of the spinal cord
  
5. What is the junction between the manubrium and the body of the sternum called?
  - a. Xiphoid process
  - b. Sternoclavicular joint
  - c. Sternal angle
  - d. Manubrium joint
  
6. Which bone is **not** part of the pelvic girdle?
  - a. Ilium
  - b. Ischium
  - c. Pubis
  - d. Sacrum
  
7. The lateral malleolus is found on the distal end of which bone?
  - a. Tibia
  - b. Fibula
  - c. Tarsal
  - d. Metatarsals
  
8. Which of the following is a sesamoid bone?
  - a. Femur
  - b. Tibia
  - c. Patella
  - d. Sternum
  
9. The \_\_\_\_\_ bones form the upper jaw.
  - a. zygomatic
  - b. maxillary
  - c. parietal
  - d. facial

10. The \_\_\_\_ is a non-weight bearing bone of the leg.
- a. femur
  - b. tibia
  - c. talus
  - d. fibula

## Chapter 8 Joints

### 8.1 Chapter Outline

Joints connect bones to give our skeleton its overall structure. Some joints are designed for stability of the connection; others are designed to allow for movement (mobility) of the articulating bones. It is those movable joints that are often affected by injury or inflammation, leading people to seek the assistance of health professionals.

### 8.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Define the term “joint”.
- Describe the functional classification of joints.
- Name the different types of joints using the structural classification.
- Describe the different types of fibrous and cartilaginous joints.
- Explain the structural characteristics of synovial joints.
- Describe friction reducing structures.
- Discuss the factors that stabilize a synovial joint.
- Name the different types of ligaments relating to a joint.
- Demonstrate the different movements of synovial joints and name the different joint types based on movement around axes.
- Name and describe the parts of major joints (knee joint, shoulder joint, elbow joint, hip joint, temporomandibular joint).
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 8.3 Combining Forms

Table 8.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 8.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
acromi(o)-	acromion	<i>acromioclavicular</i> = relating to acromion and clavicle
cyt(o)-	cell	<i>cytosol</i> = the watery component of the cytoplasm
-algia	pain	<i>arthralgia</i> = pain in a joint
anky(o)-	stiffness; bent, crooked	<i>ankylosis</i> = abnormal stiffness of a joint
arthr(o)-	joint	<i>arthritic</i> = affected by or associated with arthritis
calcane(o)-	heel or heel bone (calcaneus)	<i>calcaneal</i> = relating to the calcaneus or the heel
carp(o)-	wrist (carpus)	<i>carpometaacarpal</i> = relating to carpus and metacarpus
cartilag(o)-	cartilage	<i>cartilaginous</i> = relating to cartilage, consisting of cartilage
cox(o)-	hip or hip joint	<i>coxal</i> = relating to the hip or hip joint
cubit(o)-	elbow; ulna	<i>cubital</i> = relating to the ulna or the elbow (joint)

femor(o)-	thigh/femur	<i>femoropatellar</i> = relating to femur and patella
fibul(o)-	calf bone (fibula)	<i>fibular</i> = relating to the fibula
glen(o)-	socket or pit	<i>glenohumeral</i> = relating to glenoid cavity and humerus
humer(o)-	humerus	<i>humeroulnar</i> = relating to humerus and ulna
ost(e)-, oste(o)-	bone or the bones	<i>osteoarticular</i> = relating to bones and joints
radi(o)-	radius	<i>radioulnar</i> = relating to radius and ulna
rheum(o)-, rheumat(o)-	watery flow	<i>rheumatoid</i> = relating to, or affected by, or resembling rheumatism
tibi(o)-	shinbone/tibia	<i>tibiofibular</i> = relating to tibia and fibula
uln(o)-	ulna	<i>ulnoradial</i> = relating to ulna and radius

## 8.4 Overview

**A joint or articulation is the site where two or more bones meet.** Joints can be classified based on the amount of movement allowed by the joint or on the material binding bones together and whether or not a joint cavity is present. Joints that don't have a joint cavity and are either immovable or only slightly movable are essential to holding our skeleton together. From a health professional's point of view, these joints are less important because they rarely cause medical issues.

In the **functional classification**, joints are classified based on the amount of movement allowed by the joint.

- **Synarthroses** are immovable joints
- **Amphiarthroses** are slightly movable joints
- **Diarthroses** are freely movable joints

Joints can also be classified based on the material binding the bones together and whether or not a joint cavity is present; this is called a **structural classification** and has three types of joints: **fibrous**, **cartilaginous**, and **synovial joints**.

In **fibrous joints**, the bones are joined by **dense fibrous connective tissue**. There is no joint cavity, and most joints are **synarthrotic**, i.e., immovable. The types of fibrous joints are:

- **Sutures** are **rigid, interlocking joints containing short connective tissue fibers**. They are found mainly between bones of the skull. Later in life, sutures ossify and are then called **synostoses**.
- In **syndesmoses**, the bones are connected by bands of fibrous tissue called **ligaments**. Movement in these joints varies from **immovable to slightly movable**.
- **Gomphoses** are **peg-in-socket joints** that keep our **teeth** in the alveolar sockets. The teeth are held in place by the **periodontal ligament**.

If the bones forming a joint are united by **cartilage**, the joint is called a **cartilaginous joint**. There are two types:

- In **synchondroses**, a bar or plate of **hyaline cartilage** unites the bones creating a **synarthrotic joint**.
- In **symphyses**, hyaline cartilage covers the articulating surfaces and is fused to an intervening pad of **fibrocartilage**. This creates strong, flexible **amphiarthroses**.

**Table 8.2 Classification of Joints**

Functional Classification - Based on the amount of movement allowed by the joint	
Synarthrosis	Immovable
Amphiarthrosis	Slightly movable
Diarthrosis	Freely movable
Structural Classification - Based on the material binding bones together and the presence or absence of a joint cavity	

<p><b>Fibrous joints</b> - bones are joined by dense fibrous connective tissue; no joint cavity; most are synarthrotic</p>	<ul style="list-style-type: none"> <li>• <b>Sutures</b> - rigid, interlocking joints containing short connective tissue fibers; Allow for growth during youth; In middle age, sutures ossify and are called <b>synostoses</b>, e.g., joints between cranial bones</li> <li>• <b>Syndesmoses</b> - bones connected by ligaments; movement varies from immovable to slightly movable, e.g., joint between radius and ulna</li> <li>• <b>Gomphoses</b> - peg-in-socket joints of the teeth in alveolar sockets; fibrous connection is the periodontal ligament</li> </ul>
<p><b>Cartilaginous joints</b> - bones are united by cartilage; no joint cavity</p>	<ul style="list-style-type: none"> <li>• <b>Synchondroses</b> - a bar or plate of hyaline cartilage unites the bones; synarthroses, e.g., joints between ribs and sternum</li> <li>• <b>Symphyses</b> - hyaline cartilage covers the articulating surfaces and is fused to an intervening pad of fibrocartilage; strong, flexible amphiarthroses, e.g., intervertebral joints</li> </ul>
<p><b>Synovial joints</b> - joint (synovial) cavity surrounded by an articular (joint) capsule filled with synovial fluid; all are diarthrotic (freely movable); most joints of the body, including all limb joints</p>	<ul style="list-style-type: none"> <li>• <b>Plane Joints</b> – nonaxial; flat articular surfaces; short gliding movements, e.g., intercarpal joints</li> <li>• <b>Hinge Joints</b> – uniaxial; motion along a single plane; flexion and extension only, e.g., elbow (humeroulnar) joint</li> <li>• <b>Pivot Joints</b> – uniaxial; rounded end of one bone conforms to a “sleeve,” or ring of another bone, e.g., atlantoaxial joint</li> <li>• <b>Condyloid (Ellipsoidal) Joints</b> – biaxial; both articular surfaces are oval; permit all angular movements, e.g., radiocarpal (wrist) joint</li> <li>• <b>Saddle Joints</b> – biaxial; each articular surface has both concave and convex areas; allow greater freedom of movement than condyloid joints, e.g., joint at the base of the thumb</li> <li>• <b>Ball-and-Socket Joints</b> – multiaxial; rounded convex surface of one bone articulates with cup-shaped surface of other bone; most freely movable joints, e.g., shoulder (glenohumeral) joint</li> </ul>

**Most joints of the body**, including all joints of our limbs, are **freely movable joints** (diarthrotic joints). They are called **synovial joints**.

They have a **joint** or **articular capsule** that consists of two layers, a tough **outer fibrous layer** and an **inner synovial membrane**. The space inside the capsule, the **joint cavity**, is filled with **synovial fluid**, a viscous filtrate that lubricates and nourishes the articular cartilage. The synovial fluid is produced by the synovial membrane of the capsule.

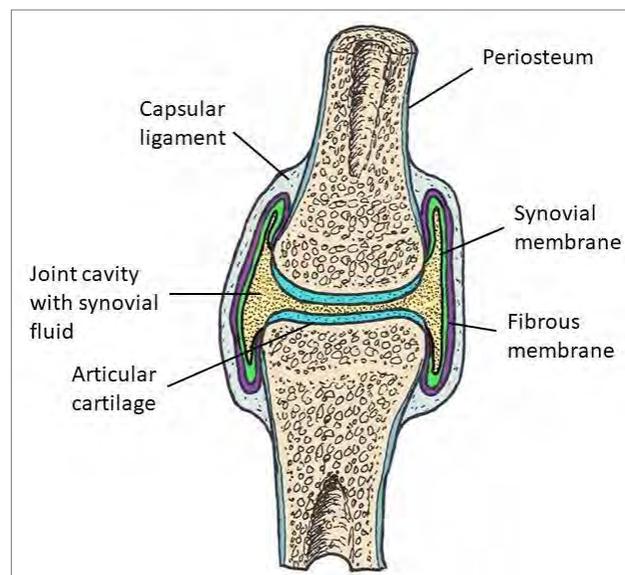
The ends of the joint-forming bones are covered by hyaline cartilage; this cartilage layer is called **articular cartilage**.

**Ligaments** are rope-like structures made mainly of the protein collagen, which is as strong as a steel rope. They are used to connect and tie bones together. There are three types of ligaments used to stabilize joints:

1. **Capsular** or **intrinsic ligaments** are part of the joint capsule.
2. **Extracapsular ligaments** run outside the capsule and insert into the joint-forming bones. Ligaments that run parallel on its lateral and medial side are specifically called **collateral ligaments**.
3. **Intracapsular ligaments** run deep to the capsule. They are covered by the synovial membrane.

Synovial joints have a **rich nerve and blood supply**. The nerve fibers detect pain and continuously monitor joint position and stretch. The blood vessels produce the synovial fluid via filtration in capillaries.

**Figure 8.1 Synovial joint**



**Bursae** are friction-reducing structures that are found in and around joints. They are flattened, fibrous sacs lined with synovial membranes that contain synovial fluid. They commonly act as “ball bearing” at sites where ligaments, muscles, skin and bones rub together.

**Tendon sheaths** are similar to bursae but usually form elongated structures that wrap around muscles tendons to reduce friction in that area (see **Chapter 9 Muscle Tissue**).

It takes **stabilizing factors** to keep synovial joints strong and fully functional. The **shape** of the **articular surfaces** usually only plays a minor role. **Ligaments** usually also play a minor role, depending on their number and location. Overall, **the most important stabilizing factor for a joint is the tone of the surrounding muscles** as well as their tendons that cross a joint.

## 8.5 Movements at Synovial Joints

**Bones that form a joint are moved out of their position by the force generated during contraction of muscles.** Muscles always have a point of origin (the immovable bone) and an insertion, which is the attachment to the movable bone.

Movement can occur along the **frontal, sagittal, and transverse plane**. Depending on the range of motion there are four kinds of joints:

1. **Nonaxial joints** allow for slipping movements only.
2. **Uniaxial joints** permit movement in one plane only.
3. **Biaxial joints** can move in two planes.
4. **Multiaxial joints** enable movement in or around all three planes.

In a **gliding movement**, one flat bone surface glides or slips over another similar surface, while **angular movements** change the angle between connected bones. Angular movements can be subdivided into **movements** that occur **along the sagittal plane** and **movements** that occur **along the frontal plane**. The turning of a bone around its own long axis is called **rotation**.

**Table 8.3 Movements at Synovial Joints**

**Gliding Movements** - One flat bone surface glides or slips over another similar surface

**Angular Movements** - Increase or decrease the angle between the articulating bones (joint angle)

**Flexion** - decreases the angle of the joint

**Extension** - increases the angle of the joint

**Hyperextension** - excessive extension beyond normal range of motion

**Abduction** - movement away from the midline

**Adduction** - movement toward the midline

**Dorsiflexion** - upward movement of the foot

**Plantar flexion** - downward movement of the foot

**Inversion** – turning the sole of the foot medially (sometimes called **supination of the foot**)

**Eversion** - turning the sole of the foot laterally (sometimes called **pronation of the foot**)

**Protraction** - anterior movement of a body part in the horizontal plane

**Retraction** - posterior movement of a body part in the horizontal plane

**Elevation** - lifting a body part superiorly

**Depression** - moving a body part inferiorly

**Opposition** - movement in the saddle joint so that the thumb touches the tips of the other fingers

**Circular Movements**

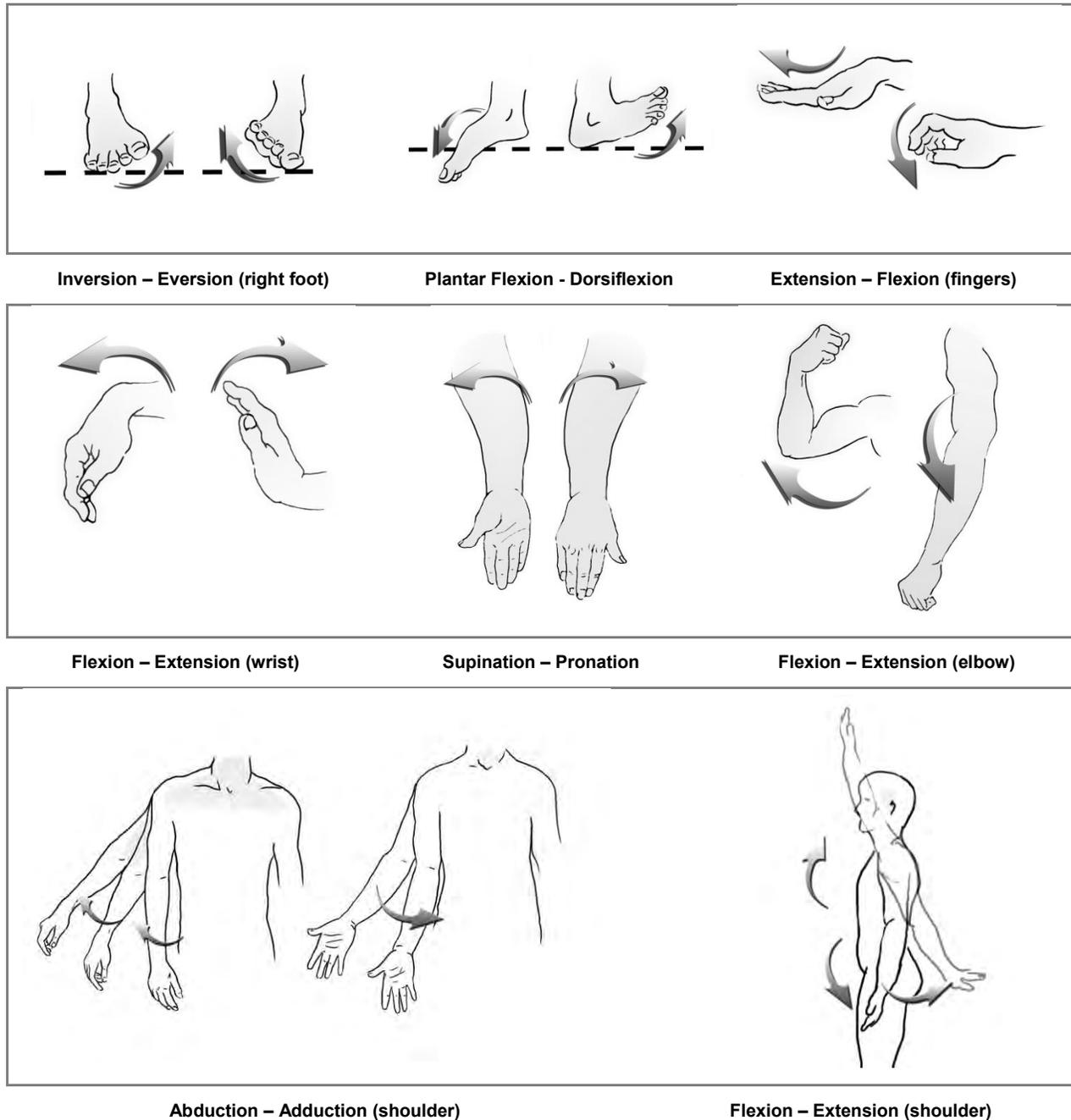
**Rotation** - turning of a bone around its own long axis

**Pronation** - turning the hand forward

**Supination** – turning the hand backward

**Circumduction** - flexion + abduction + extension + adduction of a limb to describe a cone in space

Figure 8.2 Movements at synovial joints



## 8.6 Classification of Synovial Joints

There are **six types of synovial joints** based on the **shape of the articular** surfaces of the joint-forming bones:

1. **Plane joints** have flat articular surfaces. They are **nonaxial** joints that allow for short gliding movements only.
2. **Hinge joints** are **uniaxial** joints that allow for flexion and extension only.

3. **Pivot joints** are created by the rounded end of one bone being surrounded by a sleeve or ring of another bone. They are also **uniaxial** joints.
4. In **condyloid** or **ellipsoidal joints**, the articular surfaces of all joint-forming bones are oval. This makes them **biaxial** joints that permit all angular movements.
5. In **saddle joints**, both articular surfaces have concave and convex areas. This creates a **biaxial** joint that is more stable and has more freedom of movement than a condyloid joint.
6. **Ball-and-Socket joints** are the most freely movable joints of the body. They permit motion in three planes making them **multiaxial** joints. The only examples in the human body are the shoulder and hip joints.

### Check Your Understanding

- |  |   |
|--|---|
| <ol style="list-style-type: none"> <li>1. The meaning of fibular is _____.                     <ol style="list-style-type: none"> <li>a) relating to the thigh</li> <li>b) relating to the fibula</li> <li>c) relating to the hip</li> <li>d) relating to the foot</li> </ol> </li> <li>3. Which type of cartilage is used in synchondroses?                     <ol style="list-style-type: none"> <li>a) Elastic cartilage</li> <li>b) Articular cartilage</li> <li>c) Hyaline cartilage</li> <li>d) Fibrocartilage</li> </ol> </li> </ol> | <ol style="list-style-type: none"> <li>2. ____ connect bones and tie them together.                     <ol style="list-style-type: none"> <li>a) Joints</li> <li>b) Cartilages</li> <li>c) Tendons</li> <li>d) Ligaments</li> </ol> </li> <li>4. ____ joints are uniaxial joints that allow for flexion and extension only.                     <ol style="list-style-type: none"> <li>a) Ball and socket</li> <li>b) Pivot</li> <li>c) Plane</li> <li>d) Hinge</li> </ol> </li> </ol> |
|--|---|

1.B.2.D.3.C.4.D

## 8.7 Major Joints

### Shoulder Joint

The **shoulder** or **glenohumeral joint** is a typical ball-and-socket joint. It is formed by the articulation of the **head of the humerus** with the **glenoid fossa of the scapula**. The shoulder joint is a **multiaxial joint** with an enormous range of motion because the head of the humerus is much bigger than the articular fossa. But, this great mobility comes with less stability and, in fact, the shoulder joint is the second most easily dislocated joint of the body after the temporomandibular joint.

Figure 8.3 Right shoulder joint, anterior view

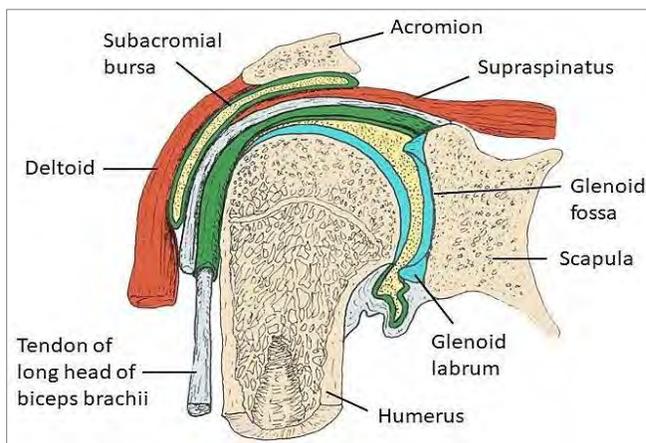
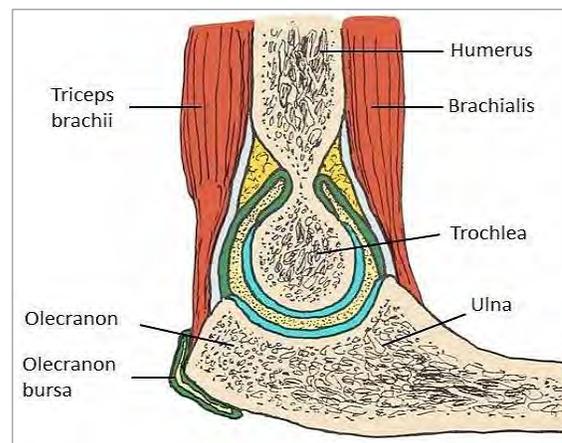


Figure 8.4 Right elbow joint, lateral view



The shoulder joint has some **reinforcing ligaments**, like the **coracohumeral ligament** between the coracoid process of the scapula and the proximal humerus, and the three **glenohumeral ligaments**, that are somewhat weak reinforcements at the front of the capsule.

However, the **major stabilizers are five muscle tendons**. The **tendon of the long head of the biceps muscle** runs through the intertubercular groove over the head of the humerus to the superior margin of the glenoid cavity.

The other four tendons form the so-called **rotator cuff** that encircles the joint. They are the tendons of the **subscapularis, infraspinatus, supraspinatus, and teres minor muscles**.

### Elbow Joint

The **elbow joint** is formed by three bones: **humerus, radius, and ulna**. It is a strong **hinge joint** that is formed mainly by the **trochlear notch of the ulna** and the **trochlea of the humerus (humeroulnar joint)**. The joint between the radius and the humerus (**humeroradial joint**) does not contribute much to the overall joint.

However, the radius is responsible for pronation and supination of the forearm. Thus, the head of the radius rotates within the **anular ligament** (proximal radioulnar joint) during pronation and supination of the forearm.

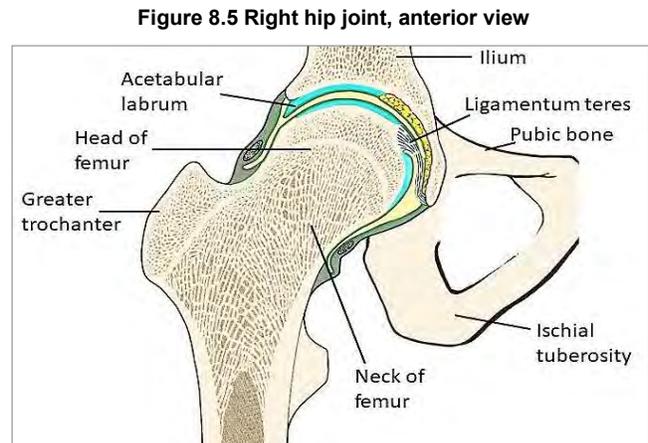
The **ulnar [UCL]** and **radial collateral ligaments [RCL]** reinforce the capsule and restrict side-to-side movement. The joint is also **stabilized by** tendons, such as the **biceps, brachialis, and triceps tendons**, that cross the joint.

### Hip Joint

The **hip** or **coxal joint** is the other multiaxial ball-and-socket joint of the body. It is formed by the **head of the femur** articulating with the articular socket of the hip bone (**acetabulum**).

Unlike the shoulder joint, the hip joint rarely dislocates because the deep acetabulum is enhanced by a fibrocartilage ring (**acetabular labrum**) and the strength of three ligaments (**iliofemoral, pubofemoral, and ischiofemoral ligament**).

The **ligamentum teres** runs from the lower lip of the acetabulum to the center of the head of the femur. It is not a strong ligament but carries an artery which is important for the blood supply to the femoral head.



### Knee Joint

The **knee joint** is the largest and most complex joint of the body. It is a **modified hinge joint** that allows for flexion and extension, and a small degree of rotation when the knee is flexed.

The knee joint is unique because it consists of three joints that are surrounded by a single joint cavity. The **femoropatellar joint** is a plane joint between the **articular surface** on the posterior aspect of the patella and the distal end of the femur.

The **lateral and medial tibiofemoral joints** allow the **lateral and medial condyles** to articulate with the **lateral and medial condyle** of the tibia.

Because the tibial articular surfaces are shallow and small, there are two fibrocartilage pads (**lateral and medial meniscus**) on either side of the joint that increase the articular surface of the tibia and help absorb mechanical stress.

The **knee joint capsule** is thin and even absent anteriorly, but is reinforced by muscle tendons. The **quadriceps tendon** gives rise to the **patellar ligament**, which runs from the apex of the patella to the **tibial tuberosity**. The **lateral and medial patellar retinacula** stabilize the position of the patella and prevent dislocation.

There are at least twelve **associated bursae** around the knee joint, although that number can be as high as twenty or more.

The knee joint is the only joint with all three types of ligaments: extracapsular, intracapsular, and capsular. The capsular ligaments are integrated into the joint capsule.

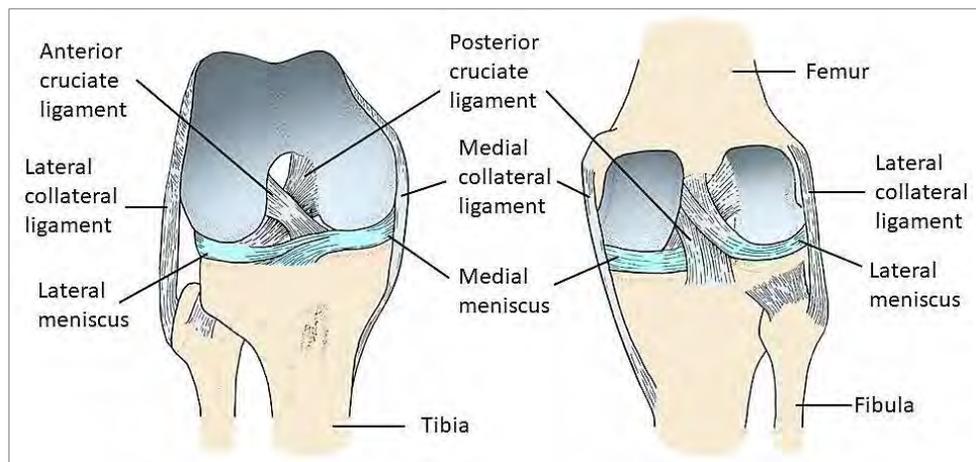
The **fibular** or **lateral collateral ligament [LCL]** is the outer extracapsular ligament; the **tibial** or **medial collateral ligament [MCL]** is the inner extracapsular ligament. Because the MCL has fibers that insert into the medial meniscus, MCL injuries often involve damage to the medial meniscus as well.

Because they cross each other's path when looked at from the front, the **intracapsular ligaments** are called **cruciate ligaments**. Although they are inside the capsule, they are outside the synovial cavity.

- The **anterior cruciate ligament [ACL]** stretches from the anterior intercondylar area of the tibia to the medial side of the lateral condyle of the femur. The main job of the ACL is to prevent forward sliding of the tibia against the femur and hyperextension of the knee joint.

- The **posterior cruciate ligament [PCL]** is stronger, which is one reason why there are fewer PCL injuries. It stretches from the posterior intercondylar area of the tibia to the lateral side of the medial condyle of the femur. The PCL helps prevent a backward sliding of the tibia (or a forward sliding of the femur).

**Figure 8.6 Right knee joint, anterior (left) and posterior view (right)**



### Temporomandibular Joint

The **temporomandibular** or **jaw joint [TMJ]** is the only freely movable joint in the skull. It connects the **mandibular condyle** with the inferior surface of the **temporal bone**. The joint cavity is subdivided by an **articular disc**, which turns the TMJ into two joints with two types of movement:

1. A **hinge joint** for depression and elevation of the mandible.
2. A **gliding joint** for lateral excursion, i.e., side-to-side grinding movements.

Because of its unique structure and loose joint capsule, **the TMJ is the most easily dislocated joint of the human body.**

### 8.8 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	socket or pit	_____	femor(o)-
2.	thigh	_____	calcane(o)-
3.	elbow	_____	glen(o)-
4.	joint	_____	cox(o)-
5.	hip	_____	cubit(o)-
6.	heel or heel bone	_____	arthr(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

1. Hinge joints permit movement in only two planes. \_\_\_\_\_
2. The wrist joint can exhibit adduction and eversion movements. \_\_\_\_\_

3. Cruciate ligaments are important ligaments that stabilize all ball-and-socket joints. \_\_\_\_\_
4. Glenohumeral joint is another name for the hip joint. \_\_\_\_\_
5. Bending of the tip of the finger exhibits flexion. \_\_\_\_\_
6. All joints permit some degree of movement, even if very slight. \_\_\_\_\_
7. The hip joint is the largest and most complex joint of the body. \_\_\_\_\_
8. Synovial joints have a joint capsule and a joint cavity. \_\_\_\_\_
9. A movement of a limb away from the body is called adduction. \_\_\_\_\_
10. Nonaxial joints allow for slipping movements only. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                   |   |           |
|-------------------|---|-----------|
| 1. Knee joint     | a) hinge joint                            | 1. _____  |
| 2. Wrist joint    | b) immovable                              | 2. _____  |
| 3. Elbow joint    | c) synovial joint                         | 3. _____  |
| 4. Knuckle joints | d) hip joint                              | 4. _____  |
| 5. Shoulder joint | e) cruciate ligaments                     | 5. _____  |
| 6. Synarthrosis   | f) turning the sole of the foot laterally | 6. _____  |
| 7. Joint cavity   | g) only on the skull                      | 7. _____  |
| 8. Acetabulum     | h) rotator cuff                           | 8. _____  |
| 9. Eversion       | i) plane joint                            | 9. _____  |
| 10. Suture        | j) condyloid joint                        | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

1. Synovial joints do **not** \_\_\_\_\_.
  - a. include a cavity
  - b. have bones covered in hyaline cartilage
  - c. include elastic cartilage
  - d. have ligaments
  
2. Which of the following is used to reduce friction near joints?
  - a. Bursae
  - b. Synovial fluid
  - c. Accessory ligaments
  - d. Tendon sheaths

3. This is a type of movement where there is a decrease in the angle between articulating bones.
  - a. Flexion
  - b. Extension
  - c. Gliding
  - d. Circumduction
  
4. Synovial joints are examples of \_\_\_\_\_.
  - a. amphiarthroses
  - b. diarthroses
  - c. synarthroses
  - d. synchondroses
  
5. The opposite movement of supination is \_\_\_\_\_.
  - a. abduction
  - b. protraction
  - c. opposition
  - d. pronation
  
6. Ball-and-socket joints are classified as \_\_\_\_\_.
  - a. nonaxial
  - b. uniaxial
  - c. biaxial
  - d. multiaxial
  
7. Which of the following joint is the most complex joint?
  - a. Elbow
  - b. Knee
  - c. Hip
  - d. Shoulder
  
8. The fibrous capsule of a synovial joint is composed of \_\_\_\_\_.
  - a. cartilage
  - b. synovial fluid
  - c. dense connective tissue
  - d. synovial membrane
  
9. A fibrous joint connected by ligaments is classified as a \_\_\_\_\_.
  - a. suture
  - b. syndesmosis
  - c. gomphosis
  - d. symphysis
  
10. The glenoid fossa is part of the \_\_\_\_\_ joint.
  - a. hip
  - b. shoulder
  - c. elbow
  - d. temporomandibular

## Chapter 9 Muscle Tissue

### 9.1 Chapter Outline

Muscle tissue is the only tissue of the body that can convert chemical energy to mechanical energy. Of the three types of muscle tissue (smooth muscle, cardiac muscle, and skeletal muscle), only skeletal muscle tissue is under voluntary control.

### 9.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Name the special characteristics of muscle tissue and the three types of muscle tissue.
- Name important functions of muscle tissue.
- Explain the macroscopic structure of a skeletal muscle.
- Describe the microscopic structure of skeletal muscle tissue.
- Describe the neuromuscular junction and the events taking place there.
- Explain the events of excitation-contraction coupling and the cross bridge cycle.
- Compare isometric contractions with isotonic contractions.
- Discuss the different ways to generate ATP in muscle metabolism.
- Name and compare the different types of skeletal muscle fibers.
- Explain the different effects of endurance and resistance exercises.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 9.3 Combining Forms

Table 9.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 9.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
electr(o)-	electricity	<i>electromyography</i> = recording of the electrical activity of muscles
erg(o)-, -ergy	work or exercise	<i>ergometer</i> = an instrument for measuring the amount of work done by muscles
fasci(o)-	fascia	<i>fasciitis</i> = inflammation of a fascia
-gram	picture, recording	<i>myogram</i> = graphic representation of a muscle contraction
-lysis	breakdown, separation, destruction	<i>rhabdomyolysis</i> = breakdown of skeletal muscle fibers
my(o)-, myos(o)-	muscle (tissue)	<i>myalgia</i> = pain in a muscle
-pathy	disease	<i>myopathy</i> = any disease affecting muscles
rhabdomy(o)-	skeletal muscle	<i>rhabdosarcoma</i> = cancer of skeletal muscle
sarc(o)-	muscle or flesh	<i>sarcolemma</i> = the cell membrane of a muscle fiber
ten(o)-, tend(o)-, tendin(o)-	tendon	<i>tendinitis</i> = inflammation of a tendon (sheath)

## 9.4 Muscle Tissue

Muscle tissue is the only tissue of the human body that can convert chemical energy to mechanical energy. There are three types of muscle tissues:

1. **Smooth muscle** is the oldest muscle tissue. It is found mostly in the walls of hollow organs, such as the urinary bladder, blood vessels, and stomach. Smooth muscle has spindle-shaped cells with central nuclei. The cells are arranged closely to form sheets or muscle tissue. Unlike the other muscle tissue types smooth muscle has no striations. Smooth muscle is involuntary and can even generate its own contraction rhythm
2. **Skeletal muscle** is voluntary and needs signals from the nervous system to contract. It has long, cylindrical cells with many nuclei and shows striations. Skeletal muscles attach to bones or skin and help the body to move and manipulate its environment. They are fast and powerful.
3. **Cardiac muscle** is found in the wall of the heart only. It has branching, striated, usually mononucleate cells that interdigitate at specialized junctions, the so-called intercalated discs. Just like smooth muscle, cardiac muscle is involuntary and can generate its own contraction rhythm. It is faster than smooth muscle, but much slower than skeletal muscle.

The four **special characteristics of muscle tissue** are:

1. **Excitability** (responsiveness or irritability): The ability to receive and respond to stimuli.
2. **Contractility**: The ability to shorten when stimulated.
3. **Extensibility**: The ability to be stretched.
4. **Elasticity**: The ability to recoil to resting length.

## 9.5 Skeletal Muscle Structure

Skeletal muscles have **three connective tissue sheaths**.

1. The innermost sheath consisting of areolar connective tissue surrounds individual muscle fibers is called **endomysium**.
2. The **perimysium** is a fibrous connective tissue sheath surrounding groups of muscle fibers called fascicles.
3. The outermost sheath, called **epimysium**, wraps around the whole muscle and helps transfer the force generated by the contraction of the muscle onto skin or bones.

In order to transfer the force they generate onto other structures, skeletal muscles need to attach firmly to them.

That can be in the form of a **direct attachment** - the epimysium fuses with the periosteum of a bone or the perichondrium of cartilage - or as an **indirect attachment** via a **tendon**.

Tendons may be surrounded by a **tendon sheath** to protect it in places where it runs over bones or joints. Tendon sheaths are similar to bursae in that they have an outer fibrous and an inner synovial layer. The tendon glides frictionless inside the sheath, while the tough outer layer protects the tendon from friction. Tendons can be fairly long, such as the tendons of the flexors and extensor muscles of the fingers. A flat, sheet-like tendon is called an **aponeurosis**.

Figure 9.1 Types of muscle tissue

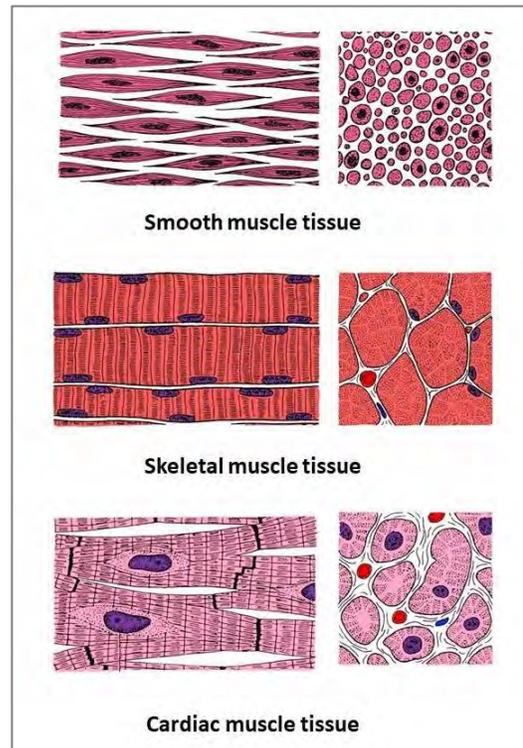
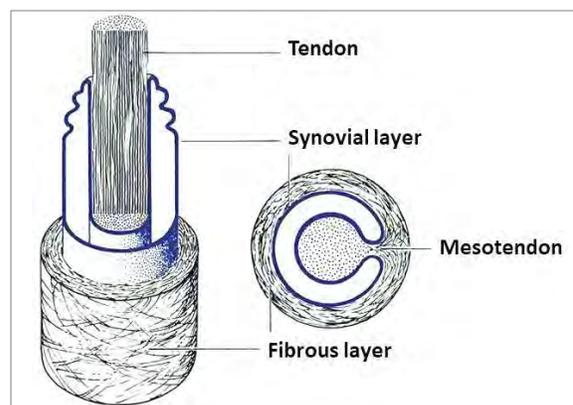


Figure 9.2 Tendon sheath structure



### Microscopic Structure

**Skeletal muscle cells are long** (up to 12 inches or more) and, consequently, are also termed **muscle fibers**. While microscopically small with a diameter of 10 to 100  $\mu\text{m}$ , they come together to form big muscles that can generate a lot of power quickly. Skeletal muscle cells have many **nuclei** that are found directly under the plasma membrane, which is now referred to as **sarcolemma**.

The cytoplasm of muscle cells is called **sarcomplasm** and the endoplasmic reticulum is called **sarcoplasmic reticulum**. Muscle cells require a lot of energy, which is produced in the form of ATP in its many **mitochondria**. There is a special protein for oxygen storage called **myoglobin**, and there are glycogen granules called **glycosomes**.

Skeletal muscle has special structures that are designed to convert chemical energy into mechanical energy, the rod-like **myofibrils**. They make up approx. 80% of the cell volume.

The **sarcoplasmic reticulum (SR)** is a network of smooth endoplasmic reticulum surrounding each myofibril. It functions in the regulation of intracellular  $\text{Ca}^{2+}$  levels. Pairs of **terminal cisternae** form perpendicular cross channels.

**T** (transverse) **tubules** are continuous invaginations of the sarcolemma. They penetrate the cell's interior at each A band–I band junction and associate with the paired terminal cisternae of the SR to form **triads**.

T tubules conduct action potentials deep into muscle fiber. They contain **voltage sensors** that open **gated proteins** leading to the release of  $\text{Ca}^{2+}$  from the SR and the initiation of a muscle contraction.

Because of their regular alignment inside the cells, the myofibrils create a repeating series of **dark A bands** and **lighter I bands** that, together, give skeletal muscle tissue its **striations**.

The **smallest contractile or functional unit** of a muscle fiber is called a **sarcomere**. It is defined as the region of a myofibril between two successive **Z discs**.

The sarcomere is composed of thick and thin myofilaments made of contractile proteins. The **H zone** is the lighter midregion of the sarcomere where myofilaments do not overlap. At its center is the **M line**, which is made of the protein **myomesin** that holds adjacent thick filaments together.

**Thick filaments** run the entire length of an A band, while **thin filaments** stretch the entire length of an I band and partway into an A band. Thick filaments are composed of the protein **myosin**. Each molecule consists of a **tail** made of two interwoven, heavy polypeptide chains, and a **head** made of smaller, lighter polypeptide chains. The head and the tail are connected by a flexible **hinge** region. The head has **binding sites for actin** as well as **ATP** and enzymes (**ATPases**) that can split ATP to release its stored energy.

**Thin filaments** are twisted double strands of a fibrous protein called **F actin**. Each actin strand is made of a chain of globular subunits called **G actin**. These pearl-like subunits have an **active site** to which the head of the thick filament binds during contraction.

Figure 9.3 Skeletal muscle cell

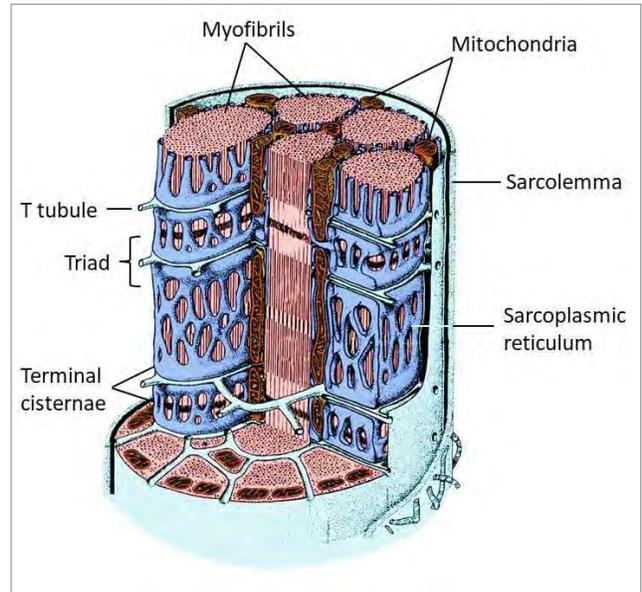
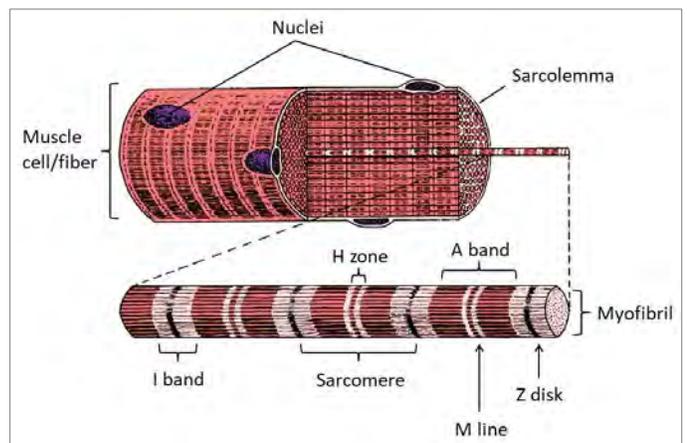


Figure 9.4 Myofibril structure



There are two regulatory proteins on the thin filaments called **troponin** and **tropomyosin**; they help to regulate myosin's access to the active site on actin.

## 9.6 Skeletal Muscle Contraction

**Muscle contraction refers to the generation of force.** The process of contraction is described by the **sliding filament model**. When a muscle is relaxed, the thick and thin myofibrils overlap only slightly. During contraction, the heads of the thick filaments form cross bridges with the actin of the thin filaments, propelling the thin filament towards the M line. Then the heads detach from the thin filament and bind again. This process repeats over and over again. When the filaments slide over each other, the H zones shorten and can even disappear completely.

However, this **generation of force does not always lead to a visible shortening of the muscle fiber**. For example, if we try to lift an object that is too heavy, our muscles will not shorten, no matter how hard we try. Shortening only occurs when the tension or power generated is greater than the forces opposing shortening. For example, when you try to lift a car, the car is too heavy and cannot be lifted. Thus, even though your muscles are working, they are not shortening.

### Activation of Skeletal Muscle Cells

**Skeletal muscle cells do not contract without a signal from their motor neuron in the central nervous system.** Therefore, a nerve signal must activate the muscle fiber to contract.

Neurons have microscopic processes called **axons** that form nerves. Axons are used to send signals to muscles as well as other structures. Each axon forms several branches as it enters a muscle, and each single branch forms an individual **neuromuscular junction** with a single muscle fiber. These junctions are always situated midway along the length of a muscle fiber. Separating the end of the axon and the muscle fiber is a microscopic space called the **synaptic cleft**. Inside the axon are **synaptic vesicles** filled with the neurotransmitter **acetylcholine (ACh)**. The sarcolemma on the other side of the synaptic cleft has receptors for ACh.

When a nerve impulse, or **action potential**, arrives at the axon terminal, **voltage-gated  $Ca^{2+}$  channels** open, leading to an inflow of  $Ca^{2+}$  into the axon. This inflow of  $Ca^{2+}$ , in turn, leads to the release of ACh from the axon terminal into the synaptic cleft. ACh crosses the cleft and binds to **ACh receptors** in the sarcolemma, which are **chemically-gated ion channels**.

Binding of ACh to the receptor, changes its conformation and opens its internal channels, which allows  $Na^+$  and  $K^+$  to move into or out of the muscle cell. As  $Na^+$  has a much higher concentration outside the cell,  $Na^+$  ions move into the cell, whereas  $K^+$  ions moves in the opposite direction, because  $K^+$  has a much lower concentration outside the cell. But, because the cell interior is negatively-charged compared to the outside (resting membrane potential of -90mV), more  $Na^+$  ions move into the cell. This inflow of positively charged  $Na^+$  ions leads to the interior of the cells becoming less negative, causing local depolarization, which is called the **end plate potential**.

The end plate potential spreads to adjacent areas, leading to the opening of voltage-gated  $Na^+$  channels. Influx of  $Na^+$  ions into the cell changes the membrane potential toward zero, i.e., leads to **depolarization**. Once this depolarization reaches a critical threshold, a positive feedback leads to more  $Na^+$  ions flowing into the cell and the generation of an **action potential**. The same process happens in adjacent areas leading to a spread or **propagation of the action potential along the sarcolemma**.

Within less than a millisecond, the  $Na^+$  channels close and **voltage-gated  $K^+$  channels** open, allowing for an outflow of  $K^+$  ions. The exit of positively-charged  $K^+$  ions restores the original polarity with the inside of the muscle cell being negative compared to the outside. This step is called **repolarization**.

$Na^+$  ions that moved into the cell during depolarization and  $K^+$  that moved out during repolarization have to be moved back to their original location to **restore ionic balance**. This task is completed by the  **$Na^+-K^+$  pump** in a process that requires ATP as the ions have to be moved against their concentration gradient.

In the meantime, the ACh released by the axon terminal has to be removed from the synaptic cleft so that the chemically-gated ACh receptor can be reset and be ready for more signals from the motor neuron. ACh is enzymatically split by **acetylcholinesterase**.

### Excitation-Contraction Coupling

Generation and propagation of an action potential is only the first step toward contraction. In the second step, the so-called **excitation-contraction coupling leads to a sliding of myofilaments against each other and the generation of force**.

The time between the arrival of the signal at the neuromuscular junction and the beginning of the contraction is known as the **latent period**. During this time the **AP is propagated along the sarcolemma**, reaches a **T tubule** where it leads to a conformational change of voltage-sensitive proteins, which in turn leads to the **release of  $\text{Ca}^{2+}$  ions from the sarcoplasmic reticulum** into the cytosol.

At **low intracellular  $\text{Ca}^{2+}$  concentration**, the muscle fiber is relaxed as tropomyosin blocks the active sites on actin. When  **$\text{Ca}^{2+}$  is released** from the SR, it **binds to troponin**, which leads to troponin **changing its shape and moving tropomyosin** away from the active sites. This allows the myosin head of the thick filament to attach to the thin filament forming what is called a **cross bridge**. The myosin head automatically pivots and pulls the thin filament toward the M line in what is known as the **power or working stroke**.

The ATPase of the head then splits ATP and the head uses the released energy to detach itself from the actin. This **cross bridge detachment** leads to a **cocking of the myosin head**, which is in a high-energy state and will continue to form cross bridges with active actin sites as long as there is a high level of  $\text{Ca}^{2+}$  and enough ATP present. To stop this cycle from repeating itself,  $\text{Ca}^{2+}$  is pumped back into the sarcoplasmic reticulum and the muscle relaxes again.

If there is no ATP left, the head of the thick filament stays connected to the actin and the muscle fiber remains in a state of permanent contraction. This happens when the body fatigues during work or exercise as a reversible state (**muscle cramps**) and as an irreversible state (**rigor mortis**) after death.

### Check Your Understanding

- Contractility is the ability \_\_\_\_\_.
  - to shorten when stimulated
  - to be stretched
  - to receive nerve stimuli and respond to them
  - to recoil to resting length
- Which muscle type is subject to conscious control?
  - Smooth muscle
  - Skeletal muscle
  - Cardiac muscle
  - All muscle types are subject to conscious control
- Skeletal muscles connect to other structures via \_\_\_\_\_.
  - ligaments
  - bones
  - joints
  - tendons
- Which ion links excitation to contraction?
  - Sodium
  - Potassium
  - Chloride
  - Calcium
- The functional unit of a skeletal muscle fiber is called \_\_\_\_\_.
  - sarcolemma
  - sarcoplasmic reticulum
  - sarcomere
  - sarcoplasm
- During contraction \_\_\_\_\_.
  - $\text{Na}^+$  binds to troponin
  - acetylcholine causes relaxation of thin filaments
  - thick filaments exhibit rigor mortis
  - thin filaments are pulled toward the M line

1.A.2.B.3.D.4.D.5.C.6.D.

### 9.7 Muscle Mechanics

Not all muscle fibers of a muscle are being supplied with signals by the same motor neuron because this would lead to an all-or-nothing situation with either no fiber contracting or all of them contracting at the same time. In order to use the least number of fibers to generate enough force, each neuron supplies only a limited number of muscle fibers. This functional unit of a neuron and the muscle fibers it supplies is called a **motor unit**.

In small motor units, the neuron supplies only a smaller number of fibers; whereas in large motor units, hundreds to thousands of fibers receive their signal from the same neuron. Muscles that control fine movements, such as eye movements, have small motor units; muscles that have to carry a lot of weight against gravity have larger motor units. For example, the bigger leg muscles use large motor units.

When a muscle receives a stimulus from its motor neuron, it will try to use as few fibers as possible in order to be energy efficient. At first, the muscle will use small motor units with small, easily excited fibers. If that doesn't generate enough force, medium sized units with larger fibers will be recruited. If that still isn't sufficient, large units with the largest muscle fibers will be activated. This process is called **recruitment** or **multiple motor unit summation**. It allows the muscle to use the exact number of fibers and to generate the right amount of tension to perform its task.

The response of a single muscle fiber to a single stimulus (action potential) is called **muscle twitch**. It has three phases:

1. The **latent period** is the time from the arrival of the stimulus until the onset of force generation, i.e., the time it takes for excitation-contraction coupling to occur.
2. During the **period of contraction**, force is generated and the fiber shortens.
3. During the **period of relaxation**,  $\text{Ca}^{2+}$  is pumped back into the SR, the tension generated goes down toward zero, and the fiber lengthens.

The duration of the twitch varies from muscle to muscle. Some muscles have fast twitch fibers, e.g., extrinsic eye muscles; others are slower, e.g., calf muscles.

To get the most out of our muscles and to control them properly, we need **graded muscle responses** depending on the strength and frequency of the stimulus. Increases in stimulus frequency leads to increased  $\text{Ca}^{2+}$  release, especially if the muscle doesn't have time to relax completely in between stimuli. Following contractions build on the still existing force and the tension generated increases even more, leading to a so-called **unfused** or **incomplete tetanus**. When the stimulus frequency increases to the point where there is no more relaxation between contractions, a state of **complete** or **fused tetanus** has been reached. If the strength of the stimulus increases, more and more muscle fibers (or motor units) will be recruited until all muscle fibers contract.

A combination of maximum recruitment, i.e., all motor units are activated, and fused tetanus will generate the maximum amount of force a muscle can generate. The more muscle fibers that a muscle has and the bigger the fibers are, i.e., the more myofibrils they have, the more force that a muscle is capable of generating.

If the force generated exceeds the load that the muscle has to move, the muscle will shorten. This is called an **isotonic contraction**, because the tension of the fibers remains constant (*iso-* the same, *-tonic* tone, tension). If the force generated is not sufficient enough to move the load, the muscle will not shorten (stay the same length), and this contraction is called an **isometric** (*iso-* the same, *-metric* length) **contraction**.

Isotonic contractions can be further divided into **concentric contractions** (*con-* together, *centrum* center, middle), during which the muscle shortens and does work, and **eccentric contractions** (*ec-* out, away from, *centrum* center, middle), during which the muscle lengthens while it is generating force. Picking up a tray full of food would be an example of a concentric contraction, putting the tray down again would be an eccentric contraction, and holding the tray at a constant height would be an isometric contraction.

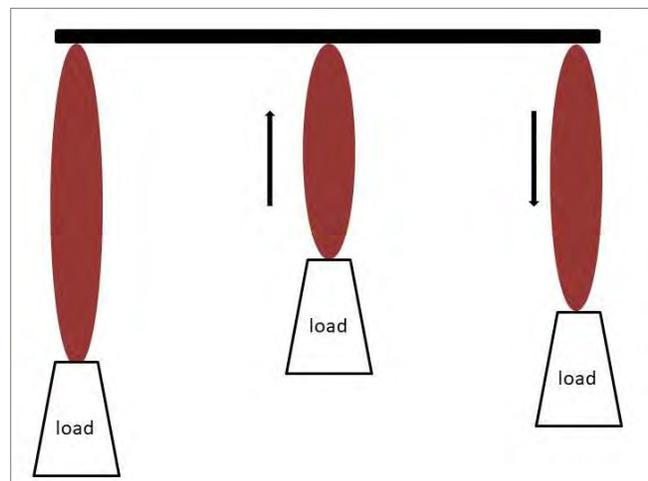
Skeletal muscles are in a constant, slightly contracted state called **muscle tone** due to spinal reflexes that activate groups of motor units alternately in response to input from stretch receptors in muscles. This tone keeps muscles firm, healthy, and ready to respond.

## 9.8 Muscle Metabolism

**The only energy source used directly for muscle contraction is ATP** (adenosine triphosphate). Each muscle cell has to produce its own ATP from nutrients. There are two ways for muscles as well as other body cells to create ATP:

1. Muscles can break down glucose molecules in a process called **glycolysis**, creating two molecules of pyruvic acid for every molecule of glucose. This process does not involve oxygen (**anaerobic**) and occurs quickly. However, it releases far less than 5% of the energy contained in glucose.
2. Muscles can burn glucose and other nutrients, such as fatty acids and amino acids, by adding oxygen. This so-called **aerobic respiration** takes place in the **mitochondria**. It is slower than glycolysis but generates much more ATP. Its waste products are water, carbon dioxide, and heat.

**Figure 9.5 Isometric (left), concentric (middle), and eccentric contraction (right).**



Our muscle cells store a certain amount of **ATP** in order for our skeletal muscles to spring into action immediately. For example, when we are threatened, we can run quickly. The immediately **available stores are used up within 4-6 seconds**; however, the cells do not need to create ATP from scratch, as they contain a substance called **creatine phosphate** that can be used to restore ATP and work our muscle cells for approximately 10-15 seconds.

Once that short time is up, the cells must produce ATP either via **anaerobic glycolysis** or aerobic respiration. Which method the muscle cells choose depends on what we demand from them. If, for example, we are working hard and our muscles are contracting to their maximum, the power generated shuts off blood supply to the muscle tissue. At first, the cells can use oxygen stored in the red pigment **myoglobin**, but this oxygen source will not last long; the muscle's only choice is to switch to glycolysis. The **pyruvic acid** created from glycolysis is turned into **lactic acid** in the absence of oxygen. After approximately 60 seconds, lactic acid levels become too high and the muscle is unable to continue generating the same amount of power. The lactic acid built up in the muscle will cause a feeling of soreness later the same day or the next morning.

The only way for our muscles to work for longer periods of time is to generate less than 70% of their maximum power, which makes sure the cells are supplied with oxygen and, thus, able to generate ATP using **aerobic respiration**. Endurance athletes, such as long-distance runners, are able to keep going for hours using aerobic respiration.

Less than 40% of the energy released during muscle activity is converted into mechanical energy; the rest is lost as **heat** and must be dissipated, or the muscle will overheat and become damaged. Proper hydration keeps up blood flow, and low temperatures help cool down muscles. People violating these rules risk not only muscle damage but further damage to the kidneys and other organs.

**Muscle fibers can be classified depending on the speed of contraction into slow or fast fibers.** They can further be classified **depending on the metabolic pathway used for energy production** into **oxidative fibers** that use the aerobic pathway and **glycolytic fibers** that use glycolysis as their pathway.

- Fibers that use glycolysis generate ATP quickly and, therefore, can contract quickly as well are called **fast glycolytic fibers**.
- Generating ATP using oxygen in the aerobic pathway takes time and, thus, these fibers are called **slow oxidative fibers**.
- Some oxidative fibers can use the ATP faster than other slower oxidative fibers and, thus, are called **fast oxidative fibers**.

In general, humans are slow moving animals, which is why many of our muscles consist mainly of oxidative fibers. Our muscle fibers contain lots of myoglobin for oxygen storage, giving them their red color. The dark meat around the legs of chicken contains oxidative fibers, because chicken walk more slowly than they fly. Myoglobin in cow muscles is also responsible for the red color of rare steaks; they no longer contain blood by the time we cook them.

In point of fact, **most muscles in our body consist of a variety of fiber types**. Muscles around the shoulder and hips that are used to move the limbs quickly have more fast glycolytic and fast oxidative fibers, while the postural muscles in the back are mainly made of slow oxidative fibers.

The **effects of exercise on our muscles** depend on the kind of exercise we engage in:

- **Endurance** or **aerobic exercise** challenges the muscle to increase its blood supply, number of mitochondria, and myoglobin content. These adaptations lead to even greater endurance, strength, and fatigue resistance. Overall, the size of the muscles will barely change.
- **Resistance exercise**, especially if anaerobic, leads to an **increase in muscle size** or **hypertrophy**, as well as more mitochondria.
- To get the muscle to grow even more, it must be pushed beyond the limit of its maximum load; this is known as the **overload principle**. For example, to increase the size of our biceps muscle, we need to do biceps curls with increasingly heavier weights. Using the same weights will maintain the current muscle tone and size but not make it stronger and bigger.

## 9.9 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	work	_____	fasci(o)-
2.	muscle or flesh	_____	-lysis
3.	picture, recording	_____	ten(o)-
4.	breakdown, separation	_____	my(o)-
5.	tendon	_____	sarc(o)-
6.	fascia	_____	erg(o)-
7.	muscle	_____	-gram

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Skeletal muscles need nerve stimulation for contraction to occur. \_\_\_\_\_
- Thick filaments are made of a protein called actin. \_\_\_\_\_
- Lactic acid results from aerobic respiration. \_\_\_\_\_
- Once a motor neuron has fired, all the muscle fibers in a muscle contract. \_\_\_\_\_
- The force of muscle contraction is controlled by multiple motor unit summation or recruitment. \_\_\_\_\_
- A sustained partial contraction of skeletal muscle is called muscle tone. \_\_\_\_\_
- Muscle tissue can convert chemical energy to mechanical energy. \_\_\_\_\_
- Muscle contraction depends on the presence of calcium ions inside the muscle cells. \_\_\_\_\_
- Endurance exercise leads to an increase in muscle size. \_\_\_\_\_
- Extensibility is the ability to shorten when stimulated. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |               |                                      |          |
|---------------|--------------------------------------|----------|
| 1. Endomysium | a) lighter central portion of A band | 1. _____ |
| 2. Sarcomere  | b) used to convert ADP to ATP        | 2. _____ |
| 3. I band     | c) thin and thick filaments          | 3. _____ |

- |     |                        |    |                                       |     |       |
|-----|------------------------|----|---------------------------------------|-----|-------|
| 4.  | H zone                 | d) | distance between two Z discs          | 4.  | _____ |
| 5.  | Acetylcholine          | e) | actual trigger for muscle contraction | 5.  | _____ |
| 6.  | Creatine phosphate     | f) | depend upon anaerobic metabolism      | 6.  | _____ |
| 7.  | A band                 | g) | actin filaments only                  | 7.  | _____ |
| 8.  | Calcium ions           | h) | anaerobic exercise                    | 8.  | _____ |
| 9.  | Fast glycolytic fibers | i) | released at motor end plates          | 9.  | _____ |
| 10. | Lactic acid            | j) | surrounds single muscle fiber         | 10. | _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- This is the property of muscle that gives it the ability to stretch without damage.
  - Electrical excitability
  - Contractility
  - Extensibility
  - Elasticity
- In an isometric contraction, the muscle develops tension but does **not** \_\_\_\_\_.
  - lengthen
  - widen
  - shorten
  - stretch
- These are the contractile structures of the muscle fiber.
  - Myofibrils
  - Myoglobin
  - F actin
  - Sarcomere
- In the sliding filament mechanism, the thin filament is pulled towards the \_\_\_\_\_.
  - Z disc
  - H zone
  - M line
  - I band
- Which of the following are necessary for the contraction cycle to continue?
  - ATP and ACh
  - Ca<sup>2+</sup> and ATP
  - ACh and potassium
  - Water and ATP
- This consists of a somatic motor neuron plus all the skeletal muscle fibers it stimulates.
  - Sarcomere
  - Motor unit
  - Neuromuscular junction
  - Somatic motor neuron

7. Increasing the number of active motor units is called\_\_\_\_\_.
- summation
  - fused tetanus
  - recruitment
  - muscle tone
8. Which of the following muscle fibers is primarily used for endurance-type activities?
- Slow oxidative fibers
  - Fast oxidative fibers
  - Fast glycolytic fibers
  - Slow glycolytic fibers
9. Which of the following is ***not*** a muscle fiber type?
- Fast glycolytic fibers
  - Slow glycolytic fibers
  - Slow oxidative fibers
  - Fast oxidative fibers
10. Which of the following statements is correct?
- Resistance exercise leads to greater endurance.
  - Glycolysis takes place in the mitochondria.
  - At low intracellular  $\text{Ca}^{2+}$  concentration, the muscle fiber is relaxed.
  - Acetylcholine release causes troponin to move tropomyosin off the active site of actin.

## Chapter 10 Muscular System

### 10.1 Chapter Outline

The main functions of muscles are moving bones and fluids, maintaining posture and body position, stabilizing joints, and generating heat. We are able to contract muscles, relax them, or use them to perform certain tasks. Any structural damage or loss of function may have severe local or systemic consequences.

### 10.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Name the functional muscle groups.
- Name the two groups of muscles of the head and their basic functions.
- List and identify on a model the main muscles of facial expression and mastication with origin, insertion and action.
- Name the two groups of muscles of the neck, throat and vertebral column and their basic functions.
- List and identify on a model the main muscles of neck, throat and vertebral column with origin, insertion and action.
- Name the muscles of respiration.
- List and identify on a model the following muscles with origin, insertion, and action:
  - Muscles that form the abdominal wall
  - Muscles that form the pelvic wall and floor
  - Superficial muscles of the thorax
  - Muscles that cross the shoulder joint
  - Muscles that cross the elbow joint
  - Muscles of the forearm
  - Muscles that cross the hip and knee joints
  - Muscles of the leg and foot
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 10.3 Combining Forms

Table 10.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 10.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
ab-	away from	<i>abduct</i> = to move away from the midline of the body
ad-	toward, to, in the direction of	<i>adduct</i> = to move toward the midline of the body
anti-	counteracting, effective against, opposing	<i>antagonist</i> = muscle that reverses or opposes a particular movement
faci(o)-	face	<i>facial</i> = relating to the face
gloss(o)-	tongue	<i>hypoglossal</i> = situated below the tongue
infra-	inferior to, below, or beneath	<i>infrahyoid</i> = situated below the hyoid bone
kines(o)-, kinesi(o)-	movement	<i>kinesiology</i> = the study of the mechanics of

body movements

my(o)-, myos(o)-

muscle (tissue)

*myositis* = inflammation of muscle tissue

supra-

above or over

*suprahyoid* = situated above the hyoid bone

## 10.4 Functional Groups of Skeletal Muscles

To achieve movement, muscles must move bones or other muscles by contracting. Muscles always have a **point of origin** (the immovable bone) and an **insertion**, which is the attachment to the movable bone. Movement can occur along the frontal, sagittal, or transverse plane.

Based on their action, skeletal muscles can be assigned to four functional groups:

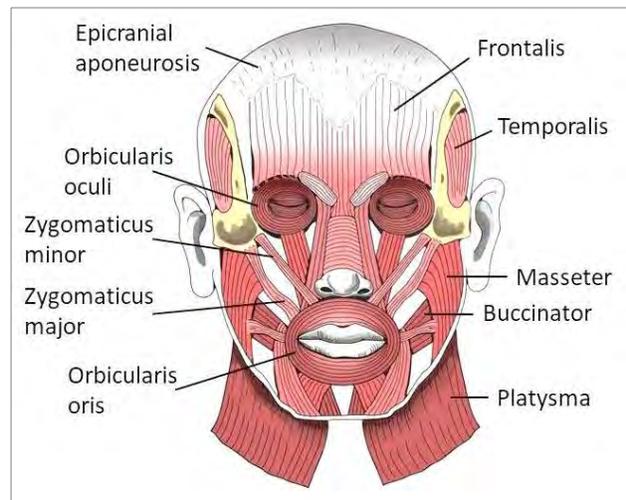
1. **Prime movers** or **agonists** provide most of the force for a specific movement. For example, the biceps brachii and brachialis generate most of the power needed to flex (bend) the elbow joint.
2. **Antagonists** (short for anti-agonists) oppose or reverse a particular movement. For example, the triceps brachii is the antagonist to the biceps brachii and brachialis, because it stretches (extends) the elbow joint.
3. **Synergists** add force to a movement or reduce undesirable or unnecessary movement. For example, the brachioradialis supports the biceps brachii and brachialis muscles in flexing the elbow joint.
4. **Fixators** immobilize a bone or a muscle's origin. For example, the deltoid has to hold the upper arm at a certain angle, while the biceps brachii and brachialis move a glass toward the mouth.

## 10.5 Muscles of the Axial Skeleton

The **muscles of the head** can be subdivided into two groups:

1. The **muscles of facial expression** insert into the skin. The muscle of the scalp is called either the **epicranius**, because it lies on top (*epi-*) of the skull (*cranium*), or the **occipitofrontalis**, because it consists of a frontal and an occipital part. The aponeurosis connecting the two parts is called the **galea aponeurotica**. The two muscles have alternate actions of pulling the scalp forward and backward.
2. The **muscles of mastication** (chewing) and **tongue movement** consists of four muscles involved in chewing (**temporalis**, **masseter**, **medial pterygoid**, **lateral pterygoid**) and three muscles that anchor and move the tongue (**genioglossus**, **hyoglossus**, **styloglossus**).

Figure 10.1 Selected muscles of the head



The **buccinator** muscle is a facial muscles, but also important for chewing as it helps to keep the food between the teeth.

The **temporalis** and **masseter** muscles are the prime movers for jaw closure, while the **medial** and **lateral pterygoid** muscles affect grinding movements while chewing.

Table 10.2 Main Muscles of Facial Expression, Mastication, and Tongue Movement

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Frontalis</b> (frontal belly of occipitofrontalis)	Galea aponeurotica	Skin of forehead/eyebrows	Wrinkles/elevates forehead and eyebrows
<b>Orbicularis oculi</b>	Bones of orbit	Tissue of eyelid, tarsal plate	Closes eyelid
<b>Nasalis</b>	Maxilla	Nasal cartilages	Flares nostrils
<b>Orbicularis oris</b>	Maxilla and mandible	Lips	Closes and purses lips

<b>Levator labii superioris</b>	Upper maxilla	Orbicularis oris and skin of upper lip	Elevates upper lip
<b>Zygomaticus major</b>	Zygomatic bone	Skin and muscle at corner of mouth	Elevates lateral corner of mouth
<b>Risorius</b>	Zygomatic arch	Skin at corner of mouth	Draws corner of lip laterally; tenses lips
<b>Depressor anguli oris</b>	Mandible	Inferior corner of orbicularis oris	Depresses corner of mouth
<b>Depressor labii inferioris</b>	Mandible	Inferior corner of orbicularis oris	Depresses lip
<b>Mentalis</b>	Mandible	Skin of lower lip/chin	Wrinkles chin; protrudes lower lip
<b>Buccinator</b>	Maxilla and mandible	Orbicularis oris at angle of mouth	Compresses cheek to keep food between teeth
<b>Platysma</b>	Fascia of chest	Lower margin of mandible, skin and muscle at corner of mouth	Tenses skin of neck; depresses mandible
<b>Temporalis</b>	Temporal fossa	Coronoid process of mandible	Elevates and retracts mandible; closes jaw
<b>Masseter</b>	Zygomatic arch	Lateral ramus of mandible	Elevates mandible (prime mover); closes jaw
<b>Medial pterygoid</b>	Sphenoid bone	Medial ramus of mandible	Elevates, protracts, and laterally moves mandible
<b>Lateral pterygoid</b>	Sphenoid bone	Condylar process of mandible	Protracts and laterally moves mandible
<b>Genioglossus</b>	Mandible	Tongue	Depresses and protrudes tongue
<b>Hyoglossus</b>	Hyoid	Side of tongue	Retracts and depresses side of tongue
<b>Styloglossus</b>	Styloid process (temporal bone)	Tongue	Retracts tongue

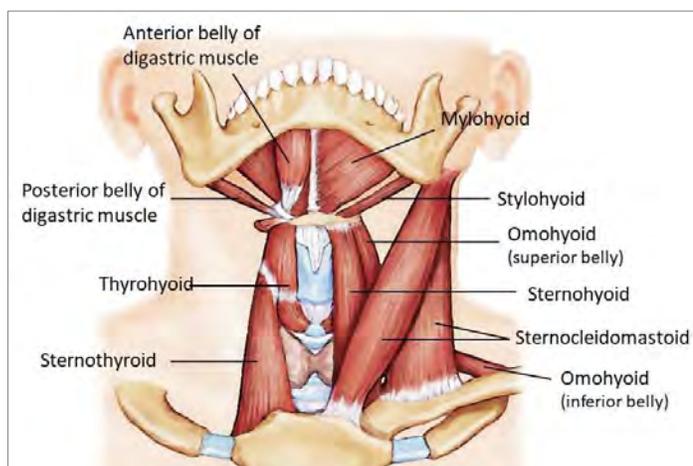
Most of the **muscles of the anterior neck and throat** are involved in swallowing and speech. They are subdivided into two groups, depending on whether they run upward from the hyoid bone (**suprahyoid muscles**) or downward to the larynx (**infrahyoid muscles**).

The four suprahyoid muscles (**digastric**, **stylohyoid**, **mylohyoid**, **geniohyoid**) are mainly involved in swallowing. They form the floor of the mouth, anchor the tongue, and move the larynx (thyroid cartilage) and hyoid bone upward and forward during swallowing.

The strap-like infrahyoid muscles (**sternohyoid**, **sternothyroid**, **omohyoid**, **thyrohyoid**) depress the hyoid bone and larynx (thyroid cartilage) at the end of swallowing and during speaking.

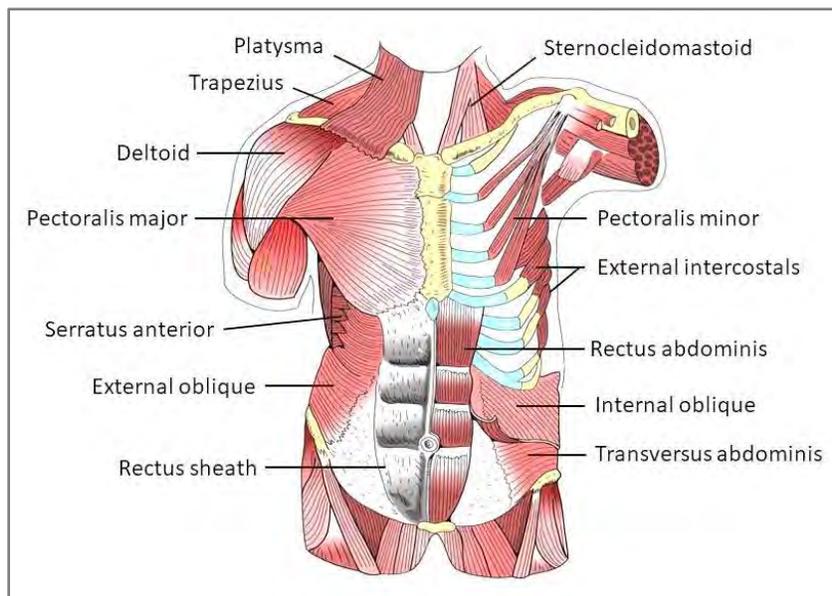
The **muscles of the neck and vertebral column** either move the head or extend the trunk and maintain our posture. The **sternocleidomastoid** muscles are the **prime mover for flexion of the head**, while the **erector spinae** group, consisting of **iliocostalis**, **longissimus**, and **spinalis**, is the **prime mover of back extension and lateral bending of the spine**. The erector spinae forms the deep back muscles together with the **semispinalis** and **quadratus lumborum**, which are synergists in extension and rotation of the back.

**Figure 10.2 Muscles of the anterior neck and throat**



**Table 10.3 Muscles of the Neck, Throat and Vertebral Column**

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Suprahyoid muscles - involved in swallowing (they raise the hyoid bone and larynx)</b>			
<b>Digastric</b>	Inferior border of mandible and mastoid process	Hyoid bone	Depresses mandible; elevates hyoid bone
<b>Stylohyoid</b>	Styloid process of temporal bone	Hyoid bone	Elevates and retracts hyoid bone
<b>Mylohyoid</b>	Inferior border of mandible	Hyoid bone	Elevates hyoid bone and floor of mouth
<b>Geniohyoid</b>	Medial surface of mandible at chin	Hyoid bone and median raphe	Elevates hyoid bone
<b>Infrahyoid muscles - depress the hyoid and larynx as swallowing ends and during speaking</b>			
<b>Sternohyoid</b>	Manubrium	Hyoid bone	Depresses hyoid bone
<b>Sternothyroid</b>	Manubrium	Thyroid cartilage	Depresses thyroid cartilage
<b>Omohyoid</b>	Superior border of scapula	Hyoid bone	Depresses hyoid bone
<b>Thyrohyoid</b>	Thyroid cartilage	Hyoid bone	Depresses hyoid bone; elevates thyroid cartilage
<b>Muscles that move the head</b>			
<b>Sternocleidomastoid</b>	Sternum and clavicle	Mastoid process	Flexes neck; rotates head to opposite side
<b>Suprahyoid and infrahyoid muscles</b> - synergists to head flexion			
<b>Scalene muscles</b> - lateral flexion of the head			
<b>Semispinalis capitis</b> - synergist with sternocleidomastoid			
<b>Splenius</b> (capitis and cervicis portions) - head extension, rotation, and lateral bending to same (ipsilateral) side			
<b>Deep (intrinsic) back muscles</b>			
<b>Erector spinae</b> (sacrospinalis) group [Iliocostalis, Longissimus, Spinalis] - prime movers of back extension and lateral bending			
<b>Semispinalis and quadratus lumborum</b> - synergists in extension and rotation			

**Figure 10.3 Muscles of the anterior trunk**

The primary function of the **deep muscles of the thorax** is to assist in respiration. The most important muscle for inspiration (breathing in) is the **diaphragm**. It separates the thoracic and abdominopelvic cavities. The intercostal muscles connect adjacent ribs and either aid in inspiration (**external intercostals**) or in forced expiration (**internal intercostals**).

There are **four paired muscles that form the lateral and anterior abdominal wall** together with their fasciae and aponeuroses. These muscles are commonly known as your “stomach muscles” or “abs”.

Two of them have oblique fibers that run either downward (**external oblique**) or upward (**internal oblique**). They form the most superficial layer (**external oblique**) and the deeper, second layer (**internal oblique**) on the lateral side.

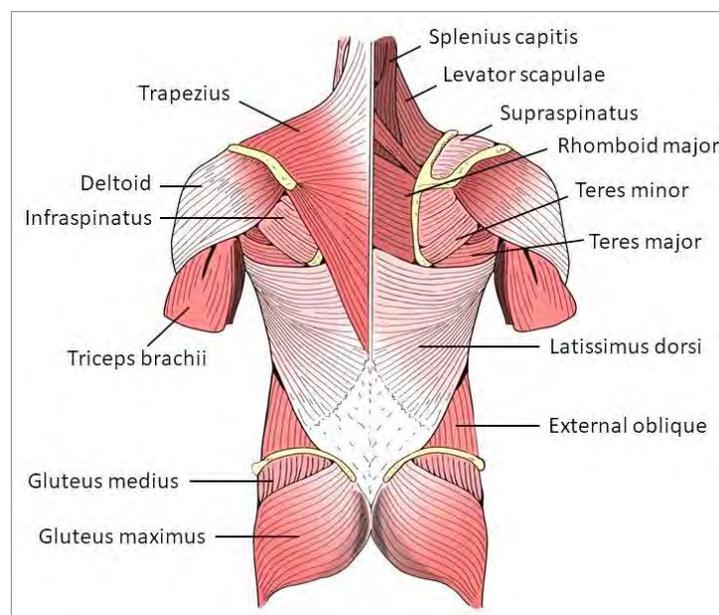
The oblique muscles work together to protect the organs of the abdominal cavity and to flex or rotate the trunk. They also help promote any action that needs an increased intraabdominal pressure, such as defecation, childbirth, or coughing.

The fibers of the other two muscles run horizontally (**transversus abdominis**) or straight up and down (**rectus abdominis**). The **transversus abdominis** forms the inner most layer of the wall. The **rectus abdominis** stretches from the rib cage down to the pubic bone surrounded by the **aponeuroses of the lateral muscles**. It is subdivided by **tendinous intersections** into three segments that form the visible “**six pack**” in athletes.

**Table 10.4 Muscles of the Abdominal Wall**

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>External oblique</b>	Lower eight ribs	Iliac crest and linea alba	Flexes and compresses abdomen; lateral rotation to opposite side
<b>Internal oblique</b>	Iliac crest, lumbodorsal fascia, inguinal ligament	Linea alba and costal cartilages of last 3-4 ribs	Flexes and compresses abdomen; lateral rotation to same side
<b>Transversus abdominis</b>	Iliac crest, lumbodorsal fascia, costal cartilages of last 6 ribs	Xiphoid process, linea alba, pubic bone	Compresses abdomen
<b>Rectus abdominis</b>	Pubic crest and symphysis pubis	Xiphoid process, costal cartilages 5 <sup>th</sup> -7 <sup>th</sup> rib	Flexes vertebral column (prime mover)

**Figure 10.4 Muscles of the posterior trunk**



The **pelvic floor** or **diaphragm** is composed of two muscles called the **levator ani** and **coccygeus**. The main tasks are to support the pelvic organs and seal the inferior outlet of the pelvis.

The **perineal muscles** can be subdivided into muscles that form the **urogenital diaphragm** (deep transverse peri-

neal and external urethral sphincter) and **muscles of the superficial perineal space** (ischiocavernosus and bulbospongiosus). The **external anal sphincter** is also a part of this group.

Two of these muscles control the release of urine from the urethra (**external urethral sphincter**) and the anal canal, respectively (**external anal sphincter**). The **bulbospongiosus** assists in the erection of the penis and clitoris and helps to propel semen out of the urethra during ejaculation. The **ischiocavernosus** helps maintain erection of the penis and clitoris.

**Table 10.5 Muscles of the Pelvic Wall and Floor**

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Obturator internus</b>	Pelvic surface of ilium and ischium, obturator membrane	Greater trochanter	Rotates thigh laterally; assists in holding head of femur in acetabulum
<b>Piriformis</b>	Pelvis surface of S2-S4, superior margin of sciatic notch, sacrotuberous ligament	Greater trochanter	Rotates thigh laterally; abducts thigh; assists in holding head of femur in acetabulum
<b>Levator ani</b> (pubococcygeus, puborectalis, iliococcygeus)	Body of pubic bone, tendinous arch of obturator fascia, ischial spine	Pineal body, coccyx, ano-coccygeal ligament, walls of prostate/vagina, rectum and anal canal	Forms most of pelvic diaphragm
<b>Coccygeus</b>	Ischial spine	Inferior end of sacrum and coccyx	Forms small part of pelvic diaphragm; flexes coccyx

Most of the **superficial muscles of the thorax** are extrinsic shoulder muscles. They **act together to stabilize the shoulder girdle**, especially the scapula, **and move it to increase the range of arm movements**.

They can be subdivided into **anterior** (pectoralis major and minor, serratus anterior, subclavius) and **posterior extrinsic shoulder muscles** (trapezius, levator scapulae, rhomboid major and minor, latissimus dorsi).

**Table 10.6 Superficial Muscles of the Thorax**

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Anterior extrinsic shoulder muscles</b>			
<b>Pectoralis minor</b>	Sternal end of ribs 3-5	Coracoid process of scapula	Pulls scapula forward and downward
<b>Serratus anterior</b>	Upper 8-9 ribs	Anterior medial border of scapula	Rotates scapula upward; prime mover for protraction and fixation against thorax; call boxer's muscle
<b>Subclavius</b>	First rib	Subclavian groove of clavicle	Depresses clavicle
<b>Pectoralis major</b>	Clavicle, sternum costal cartilages 2-6	Greater tubercle of humerus	Flexes, adducts and rotates shoulder medially
<b>Posterior extrinsic shoulder muscles</b>			
<b>Trapezius</b>	Occipital bone and spines of cervical and thoracic vertebrae	Clavicle, acromion, and spine of scapula	Elevates, retracts, rotates, and stabilizes scapula; hyperextends neck; braces shoulder
<b>Levator scapulae</b>	Cervical vertebrae 1-4	Superior border of scapula	Elevates scapula
<b>Rhomboid major</b>	Spines of thoracic vertebrae 2-5	Medial border of scapula	Retracts scapula; stabilizes scapula
<b>Rhomboid minor</b>	Cervical (7 <sup>th</sup> ) and thoracic (1 <sup>st</sup> ) vertebrae	Medial border of scapula	Retracts scapula; stabilizes scapula
<b>Latissimus dorsi</b>	Spines of sacral, lumbar and lower thoracic ribs, lower ribs	Intertubercular groove of humerus	Prime mover of arm extension; adducts and laterally rotates humerus

### Check Your Understanding

1. The prime mover for flexion of the spine is the \_\_\_\_\_.
  - a) trapezius
  - b) erector spinae
  - c) rectus abdominis
  - d) transversus abdominis
2. If you purse your lips and whistle you are using which muscle?
  - a) Frontalis
  - b) Orbicularis oculi
  - c) Orbicularis oris
  - d) Zygomaticus major
3. The \_\_\_\_ helps maintain erection of the penis and clitoris.
  - a) ischiocavernosus
  - b) bulbospongiosus
  - c) levator penis
  - d) coccygeus
4. Which muscle group depresses the hyoid bone and larynx?
  - a) Infrahyoid muscles
  - b) Suprahyoid muscles
  - c) Muscles of mastication
  - d) Sternocleidomastoid

1.C.2.C.3.A.4.A

## 10.6 Muscles of the Upper Limbs

The nine **muscles that cross the shoulder joint** originate from either the axial skeleton or the scapula; they all insert on and move the humerus. They can be subdivided into:

- **Rotator cuff muscles** that reinforce the capsule of the shoulder joint: **supraspinatus, infraspinatus, teres minor, and subscapularis**. They also act as synergists and fixators.
- **Additional synergists**: coracobrachialis and teres major.

The **shoulder** (glenohumeral) **joint** is a multiaxial joint and, therefore, there are **prime movers for flexion** (pectoralis major, deltoid anterior part), **extension** (latissimus dorsi, deltoid posterior part), **abduction** (deltoid, supraspinatus), **adduction** (pectoralis major, latissimus dorsi) as well as **medial** (subscapularis) and **lateral rotation** (infraspinatus, teres minor).

**Table 10.7 Muscles Crossing the Shoulder Joint**

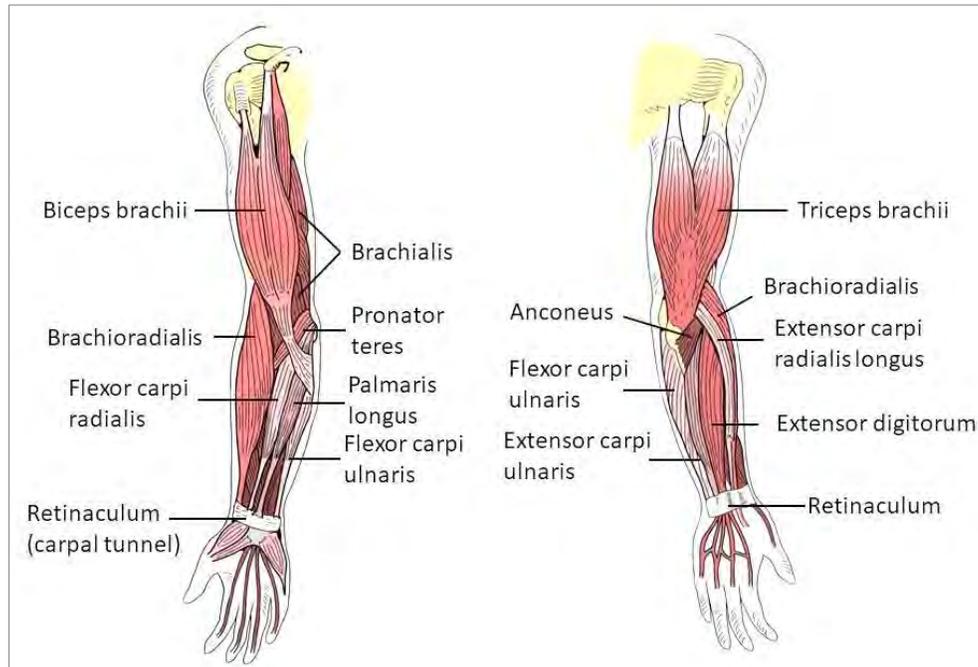
Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Coracobrachialis</b>	Coracoid process of scapula	Body of humerus	Flexes and adducts arm
<b>Teres major</b>	Inferior angle and lateral border of scapula	Intertubercular groove of humerus	Rotates arm medially; assists in keeping humeral head in glenoid cavity
<b>Prime movers of the arm</b>			
<b>Pectoralis major</b>	Clavicle, sternum costal cartilages 2-6	Greater tubercle of humerus	Flexes, adducts and rotates shoulder medially
<b>Latissimus dorsi</b>	Spines of sacral, lumbar and lower thoracic ribs, lower ribs	Intertubercular groove of humerus	Prime mover of arm extension; adducts and laterally rotates humerus
<b>Deltoid</b>	Clavicle, acromion and spine of scapula	Deltoid tuberosity of humerus	Abducts, flexes (anterior part) or extends (posterior part) shoulder joint
<b>Rotator cuff muscles</b>			
<b>Supraspinatus</b>	Supraspinous fossa of scapula	Greater tubercle of humerus	Rotates arm medially; initiates abduction of shoulder joint
<b>Infraspinatus</b>	Infraspinous fossa of scapula	Greater tubercle of humerus	Rotates arm laterally; assists in keeping humeral head in glenoid cavity
<b>Teres minor</b>	Lateral border of scapula	Greater tubercle of humerus	Rotates arm laterally; assists in keeping humeral head in glenoid

			cavity
<b>Subscapularis</b>	Subscapular fossa	Lesser tubercle of humerus	Rotates arm medially; assists in keeping humeral head in glenoid cavity

**Muscles crossing the elbow joint** can either cause flexion or extension, because the joint is a hinge joint. The muscles crossing in front of the joint (anteriorly) cause flexion; the muscles crossing behind the joint (posteriorly) cause extension.

The **prime movers for flexion of the forearm** (elbow joint) are the **brachialis** and **biceps brachii** while the **prime mover for extension** of the forearm is the **triceps brachii**.

**Figure 10.5 Muscles of the upper limb, anterior and posterior view**



The **muscles of the forearm** move the wrist, hand, and fingers. Most **anterior muscles are flexors**, lie in the **anterior compartment**, and insert via the **flexor retinaculum**. Most posterior muscles are **extensors**, lie in the **posterior compartment**, and insert via the **extensor retinaculum**. In addition, the forearm muscles can also pronate or supinate the forearm as well as adduct and abduct the wrist.

**Table 10.8 Muscles Crossing the Elbow Joint and Muscles of the Forearm**

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Anterior flexor muscles</b>			
<b>Biceps brachii</b>	Coracoid process and tuberosity above glenoid fossa	Radial tuberosity	Flexes elbow joint; tendon of long head assists in keeping humeral head in glenoid cavity
<b>Brachialis</b>	Anterior body of humerus	Tuberosity of ulna	Flexes elbow joint
<b>Brachioradialis</b>	Lateral supracondylar ridge of humerus	Proximal to styloid process of radius	Flexes elbow joint; supinates forearm and hand at radioulnar joint
<b>Posterior extensor muscles</b>			
<b>Triceps brachii</b>	Tuberosity below glenoid fossa; lateral and medial surfaces of humerus	Olecranon of ulna	Extends elbow joint
<b>Anconeus</b>	Lateral epicondyle of hu-	Olecranon of ulna	Extends elbow joint

	merus		
<b>Supinator</b>	Lateral epicondyle of humerus and crest of ulna	Lateral surface of radius	Supinates forearm and hand
<b>Pronator teres</b>	Medial epicondyle of humerus	Lateral surface of radius	Pronates forearm and hand
<b>Pronator quadratus</b>	Distal fourth of ulna	Distal fourth of radius	Pronates forearm and hand
<b>Anterior compartment</b>			
<b>Flexor carpi radialis</b>	Medial epicondyle of humerus	Base of metacarpal bone 2 and 3	Flexes and abducts wrist
<b>Palmaris longus</b>	Medial epicondyle of humerus	Palmar aponeurosis	Flexes wrist
<b>Flexor carpi ulnaris</b>	Medial epicondyle of humerus and olecranon of ulna	Carpal and metacarpal bones	Flexes and adducts wrist
<b>Flexor digitorum superficialis</b>	Medial epicondyle of humerus and coronoid process of ulna	Middle phalanges of digits 2-5	Flexes wrist and digits
<b>Flexor digitorum profundus</b>	Proximal 2/3 of ulna and interosseous membrane	Distal phalanges of digits 2-5	Flexes wrist and digits
<b>Flexor pollicis longus</b>	Body of radius and coronoid process of ulna	Distal phalanx of thumb	Flexes thumb
<b>Posterior compartment</b>			
<b>Extensor carpi radialis longus</b>	Lateral supracondylar ridge of humerus	2 <sup>nd</sup> metacarpal bone	Extends and abducts wrist
<b>Extensor carpi radialis brevis</b>	Lateral epicondyle of humerus	3 <sup>rd</sup> metacarpal bone	Extends and abducts wrist
<b>Extensor digitorum</b>	Lateral epicondyle of humerus	Posterior surfaces of digits 2-5	Extends wrist and phalanges
<b>Extensor carpi ulnaris</b>	Lateral epicondyle of humerus and olecranon of ulna	Base of 5 <sup>th</sup> metacarpal bone	Extends and adducts wrist
<b>Extensor pollicis brevis</b>	Distal body of radius and interosseous membrane	Base of proximal phalanx of thumb	Extends thumb; abducts hand
<b>Extensor pollicis longus</b>	Lateral and posterior surface of ulna	Base of distal phalanx of thumb	Extends thumb; abducts hand
<b>Extensor indicis</b>	Posterior surface of ulna and interosseous membrane	2 <sup>nd</sup> digit	Extends index
<b>Abductor pollicis longus</b>	Distal radius and ulna and interosseous membrane	Base of 1 <sup>st</sup> metacarpal bone	Abducts thumb and hand

**Intrinsic muscles of the hand** are located in the palm of the hand. They are fairly small and weak as their main task is control precise movements of the first metacarpal and fingers. They can be subdivided into three groups: the thenar muscles, the hypothenar muscles and the midpalmar muscles.

- The **thenar eminence** (ball of the thumb) and the **hypothenar eminence** (ball of the little finger) have a flexor, an abductor, and an opponens muscle each.
- **Midpalmar muscles:** lumbricals and palmar and dorsal interossei extend the fingers; interossei muscles also abduct and adduct the fingers.

### Check Your Understanding

- Muscles crossing the elbow joint in front of the joint cause \_\_\_ of the joint.
  - extension
  - flexion
  - pronation
  - supination
- Which muscles reinforce the shoulder joint?
  - hamstrings
  - pectoralis minor and major
  - rotator cuff
  - latissimus dorsi
- The \_\_\_ is a prime mover for flexion of the arm.
  - biceps brachii
  - latissimus dorsi
  - pectoralis major
  - triceps brachii
- Which muscle is **not** a flexor of the wrist?
  - Flexor carpi radialis
  - Flexor carpi ulnaris
  - Palmaris longus
  - Pronator quadratus

1.B.2.C.3.C.4.D

### 10.7 Muscles of the Lower Limbs

All three groups of **muscles that cross the hip and knee joint** are surrounded by the **fascia lata**. As a rule, most **anterior muscles** flex the femur at the hip and extend the leg at the knee, leading to a foreswing as we walk; **posterior muscles** extend the thigh and flex the knee, creating a backswing when we walk; **medial muscles** pull the thigh inside, i.e., they are adductors.

Just like the shoulder joint, the **hip joint is a ball-and-socket joint** and thus has six major actions; flexion, extension, abduction, adduction, and medial and lateral rotation.

Thigh flexors pass in front of the hip joint. The **iliopsoas** muscle, consisting of iliacus and psoas major, is the **prime mover for flexion**. The thigh extensors consist of the **hamstring muscles**, which are the **prime movers for extension**, and the **gluteus maximus**, which takes over as **prime mover for forceful extension**. All **adductors** also **rotate the thigh medially**, whereas abductors can either support lateral (most of them) or medial rotation.

There are only two muscles of the thigh that move the **knee joint**. The **quadriceps femoris is the sole extensor** of the knee and the **hamstring muscles are the sole flexors** of the knee.

Figure 10.6 Muscles of the lower limb, anterior and posterior view

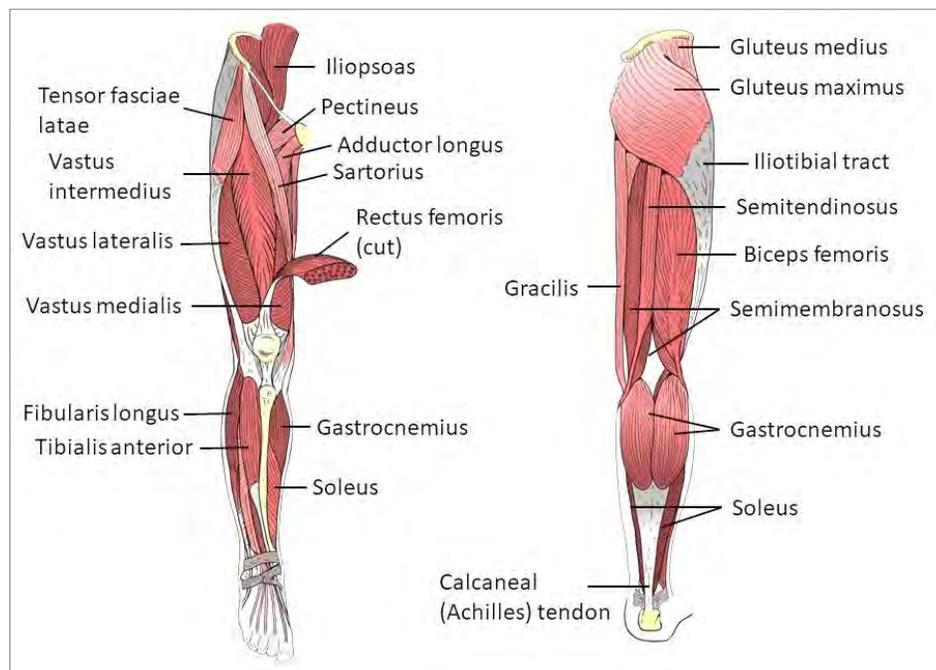


Table 10.9 Muscles Crossing the Hip and Knee Joint

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Thigh flexors pass in front of the hip joint; assisted by medial adductors</b>			
<b>Iliopsoas</b> (iliacus and psoas major)	Iliac fossa (iliacus) and transverse processes of lumbar vertebrae (psoas major)	Lesser trochanter of femur	Prime mover of hip flexion; flexes joints of vertebral column
<b>Tensor fasciae latae</b>	Anterior border of ilium and iliac crest	Iliotibial tract	Abducts and rotates thigh medially
<b>Rectus femoris</b>	Anterior inferior iliac spine	Tibial tuberosity via patellar tendon/ligament	Flexes hip joint; extends leg at knee joint
<b>Sartorius</b>	Anterior superior iliac spine	Medial surface of tibia	Flexes leg and thigh; abducts and rotates thigh laterally
<b>Thigh extensors</b>			
<b>Hamstring muscles</b>	Ischial tuberosity and linea aspera of femur (short head of biceps)	Head of fibula and proximal lateral part of tibia (biceps) or proximal medial surface of tibia	Prime mover for extension of thigh at hip joint and flexion of leg at knee joint
<b>Gluteus maximus</b>	Iliac crest, sacrum, coccyx and aponeurosis of lumbar region	Gluteal tuberosity and iliotibial tract	Prime mover during forceful extension of thigh at hip joint; rotates thigh laterally
<b>Adductors</b>			
<b>Adductor magnus</b>	Inferior rami of ischium and pubis	Linea aspera and medial epicondyle of femur	Adducts thigh at hip joint; rotates thigh medially
<b>Adductor longus</b>	Pubis below pubic crest	Linea aspera	Adducts thigh at hip joint; rotates thigh medially
<b>Adductor brevis</b>	Inferior ramus of pubis	Linea aspera	Adducts thigh at hip joint; rotates thigh medially
<b>Pectineus</b>	Pectineal line of pubis	Distal to lesser trochanter of femur	Adducts and flexes thigh at hip joint; rotates thigh medially
<b>Gracilis</b>	Inferior edge of symphysis pubis	Proximal medial surface of tibia	Adducts thigh at hip joint; flexes leg at knee joint; rotates thigh medially
<b>Abductors</b>			
<b>Gluteus medius</b>	Lateral surface of ilium	Greater trochanter	Abducts and medially rotates thigh
<b>Gluteus minimus</b>	Lateral surface of the lower half of ilium	Greater trochanter	Abducts and medially rotates thigh
<b>Piriformis</b>	Anterior surface of sacrum and sacrotuberous ligament	Greater trochanter	Rotates thigh laterally; abducts thigh; assists in holding head of femur in acetabulum
<b>Obturator externus</b>	Obturator foramen and membrane	Trochanteric fossa of femur	Rotates thigh laterally; abducts thigh; assists in holding head of femur in acetabulum
<b>Obturator internus</b>	Pelvic surface of obturator membrane	Greater trochanter	Rotates thigh laterally; abducts thigh; assists in holding head of femur in acetabulum
<b>Gemellus superior and inferior</b>	Ischial spine and tuberosity	Greater trochanter	Rotates thigh laterally; abducts thigh; assists in holding head of femur in acetabulum
<b>Thigh muscles that move the knee joint</b>			
<b>Quadriceps femoris</b> (rectus femoris, vastus lateralis, intermedius and medialis)	Anterior inferior iliac spine (rectus femoris), femur	Tibial tuberosity via patellar tendon/ligament	Prime mover for extension of the leg at knee joint

<b>Hamstring muscles</b> (biceps femoris, semitendinosus, semimembranosus)	Ischial tuberosity and linea aspera of femur (short head of biceps femoris)	Head of fibula and proximal lateral part of tibia (biceps) or proximal medial surface of tibia	Prime mover for extension of thigh at hip joint and flexion of leg at knee joint
--	---	--	--

The fascia lata of the thigh continues as the **deep fascia of the leg**, which separates the leg into an **anterior, lateral, and posterior compartment**. Distally, the fascia thickens, forming the **flexor, extensor, and fibular (or peroneal) retinacula**.

The **muscles of the anterior compartment** are primary movers for toe extension and ankle dorsiflexion, while the **muscles of the posterior compartment** accomplish flexion of the toes and plantar flexion of the ankle. **Lateral compartment muscles** can cause plantar flexion as well as eversion of the foot.

The **prime mover for dorsiflexion** of the foot is the **tibialis anterior**, whereas the **extensor digitorum longus** is the **prime toe extensor**.

The **triceps surae** refers to the **gastrocnemius** and the **soleus** muscles together. It is the **prime mover for plantar flexion**; its tendon, the so-called **calcaneal** or **Achilles tendon**, is the largest and strongest tendon in the body.

Foot **inversion** is mainly accomplished by contraction of the **tibialis posterior**.

**Table 10.10 Muscles of the Leg**

Muscle	Origin(s)	Insertion(s)	Action(s)
<b>Anterior compartment - Primary toe extensors and ankle dorsiflexors</b>			
<b>Tibialis anterior</b>	Lateral condyle and body of tibia	1st metatarsal bone and 1st cuneiform bone	Dorsiflexes ankle; inverts foot and ankle
<b>Extensor digitorum longus</b>	Lateral condyle of tibia and anterior surface of fibula	Middle and distal phalanges of digits 2-5	Extends digits 2-5; dorsiflexes ankle
<b>Extensor hallucis longus</b>	Anterior surface of fibula and interosseous membrane	Distal phalanx of hallux	Extends hallux; dorsiflexes ankle
<b>Fibularis tertius</b> (not always present)	Anterior surface of fibula and interosseous membrane	Dorsal surface of 5th metatarsal bone	Dorsiflexes ankle; everts foot and ankle
<b>Lateral compartment - Plantar flexion and eversion of the foot</b>			
<b>Fibularis longus</b>	Lateral condyle of tibia and head and shaft of fibula	Medial cuneiform and 1 <sup>st</sup> metatarsal bone	Plantar flexes and everts foot
<b>Fibularis brevis</b>	Inferior 2/3 of fibula	5 <sup>th</sup> metatarsal bone	Plantar flexes and everts foot
<b>Posterior compartment - Flexors of the foot and the toes</b>			
<b>Gastrocnemius</b>	Lateral and medial condyle of femur	Calcaneus via calcaneal tendon	Plantar flexes foot at ankle; raises heel during walking; flexes leg at knee joint
<b>Soleus</b>	Posterior aspect of fibula and tibia	Calcaneus via calcaneal tendon	Plantar flexes foot at ankle
<b>Plantaris</b>	Supracondylar ridge of femur	Calcaneus	Plantar flexes foot at ankle
<b>Popliteus</b>	Lateral condyle of femur	Upper posterior aspect of tibia	Flexes and medially rotates knee joint
<b>Tibialis posterior</b>	Tibia, fibula and interosseous membrane	Navicular, cuneiform, cuboid and metatarsal bones 2-4	Plantar flexes and inverts foot at ankle; supports arches of foot
<b>Flexor digitorum longus</b>	Posterior surface of tibia	Distal phalanges digits 2-5	Plantar flexes foot at ankle; flexes digits 2-5; supports longitudinal arches of foot
<b>Flexor hallucis longus</b>	Posterior surface of tibia	Distal phalanx of hallux	Plantar flexes foot at ankle; flexes hallux; supports medial longitudinal arch of foot

The **intrinsic muscles of the foot** help to flex, extend, adduct, and abduct the toes. They also support the arches of the foot together with tendons of the leg muscles. The extensor digitorum brevis is the only muscle on the dorsal side of the foot; all others are on the plantar side.

### 10.8 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	toward	_____	kinesi(o)-
2.	tongue	_____	supra-
3.	movement	_____	quadr(i)-
4.	above	_____	anti-
5.	away from	_____	ad-
6.	opposing	_____	gloss(o)-
7.	four	_____	ab-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Muscles are only able to pull, they never push. \_\_\_\_\_
- The deltoid is a prime mover for adduction of the arm. \_\_\_\_\_
- Muscles connecting to the hyoid bone are important for swallowing and speech. \_\_\_\_\_
- The biceps brachii inserts on the ulna. \_\_\_\_\_
- The soleus is a synergist of the gastrocnemius during plantar flexion. \_\_\_\_\_
- Movements of the thigh are accomplished by muscles anchored to the pelvic girdle. \_\_\_\_\_
- Severing of the patellar tendon would inactivate the hamstring group. \_\_\_\_\_
- The orbicularis oris closes the eyelid. \_\_\_\_\_
- The buccinator is important for chewing as it helps to keep the food between the teeth. \_\_\_\_\_
- The triceps brachii is the prime mover for extension of the arm at the elbow. \_\_\_\_\_

#### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                    |   |          |
|--------------------|---|----------|
| 1. Synergist       | a) broadest muscle of the back              | 1. _____ |
| 2. Achilles tendon | b) prime mover for flexion of the hip joint | 2. _____ |

- |     |                   |    |  |     |       |
|-----|-------------------|----|--|-----|-------|
| 3.  | Latissimus dorsi  | c) | bends the spine                                    | 3.  | _____ |
| 4.  | Hamstrings        | d) | boxer's muscle                                     | 4.  | _____ |
| 5.  | Iliopsoas         | e) | largest, strongest tendon in the body              | 5.  | _____ |
| 6.  | Triceps brachii   | f) | has two bellies                                    | 6.  | _____ |
| 7.  | Serratus anterior | g) | aids another muscle by promoting the same movement | 7.  | _____ |
| 8.  | Rectus abdominis  | h) | closes the mouth                                   | 8.  | _____ |
| 9.  | Digastric muscle  | i) | prime mover for flexion of the knee joint          | 9.  | _____ |
| 10. | Orbicularis oris  | j) | Inserts on the olecranon of ulna                   | 10. | _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Most muscles cross at least one \_\_\_\_\_.
  - tendon
  - joint
  - bone
  - body plane
- This type of muscle works by stabilizing the origin of a prime mover so that it can act more efficiently.
  - Synergist
  - Agonist
  - Antagonist
  - Fixator
- Which group of muscles flexes and rotates the neck?
  - Iliocostalis
  - Spinalis
  - Scalene
  - Splenius
- Which of the following muscles inserts via the calcaneal (Achilles) tendon?
  - Gastrocnemius
  - Semitendinosus
  - Sartorius
  - Tibialis anterior
- Which of the choices below is the major muscle for breathing?
  - Temporalis
  - Rectus abdominis
  - Diaphragm
  - Latissimus dorsi
- Adductor magnus, adductor longus, and adductor brevis are parts of a large muscle mass of the \_\_\_\_\_.
  - medial compartment of the thigh
  - lateral rotators
  - posterior muscle group of the thigh
  - anterior compartment of the thigh

7. Paralysis of which of the following muscles would make an individual unable to extend the knee?
  - a. Hamstrings
  - b. Quadriceps
  - c. Brachioradialis
  - d. Soleus
  
8. The pectoralis major \_\_\_\_.
  - a. closes the jaw
  - b. pulls the arm across the chest
  - c. is the prime mover for flexion of the thigh
  - d. plantar flexes the foot at the ankle
  
9. Which muscle is used in pull-ups, climbing and swimming?
  - a. Latissimus dorsi
  - b. Rectus abdominis
  - c. Trapezius
  - d. Biceps brachii
  
10. If you purse your lips and whistle you are using which muscle?
  - a. Frontalis
  - b. Orbicularis oculi
  - c. Orbicularis oris
  - d. Zygomaticus major



## Chapter 11 Nervous Tissue

### 11.1 Chapter Outline

Nervous tissue consists of highly excitable nerve cells, the so-called neurons, in addition to supporting cells. It is composed of the central and the peripheral nervous systems, which together make up the fast-acting control system of the body.

### 11.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Name the basic functions of the nervous system.
- Explain the structural and functional divisions of the nervous system.
- Describe the histology of nervous tissue and the different glial cells.
- Describe a neuron and its different parts.
- Define nucleus, ganglion, tract and nerve.
- Explain the myelin sheath and its function.
- Classify neurons by their structure and their function.
- Describe a chemical synapse and name the most important neurotransmitters.
- Discuss direct and indirect action of neurotransmitters and receptors involved.
- Explain what postsynaptic potentials are and how are they are integrated and modified.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 11.3 Combining Forms

Table 11.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 11.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
cephal(o)-	head	<i>cephalgia</i> = headache
crani(o)-	skull (cranium)	<i>craniospinal</i> = relating to cranium and spinal column
encephal(o)-	brain	<i>encephalitis</i> = inflammation of the brain (tissue)
glio(o)-	nervous tissue	<i>glioma</i> = tumor arising from glial cells
ment(o)-	mind	<i>mental</i> = relating to the mind or to disorders of the mind
myel(o)-	spinal cord or myelin	<i>myelopathy</i> = disease affecting the spinal cord
neur(i)-, neur(o)-	nerve or nervous system	<i>neural</i> = relating to nerves or the nervous system
poli(o)-	gray matter	<i>poliomyelitis</i> = viral infection affecting the gray matter of the spinal cord
psych(o)-	mind	<i>psychology</i> = study of the human mind and its function

### 11.4 Overview

Our nervous system has **three basic functions**:

1. **Sensory input:** Gather information via sensory receptors about both our internal and external environment.

- 2. Integration:** Analyze gathered information by using previously stored information.
- 3. Motor output:** Activate effector organs in response to the information gathered and the evaluation of this information.

The two major subdivisions of the nervous system are the **central nervous system (CNS)** and the **peripheral nervous system (PNS)**. The **CNS** is the integration and command center. It consists of two parts: the **brain** and the **spinal cord**. The **PNS** is made up of the **cranial** and **spinal nerves** that convey messages to or from the CNS. It has two functional divisions: the sensory or afferent division and the motor or efferent division.

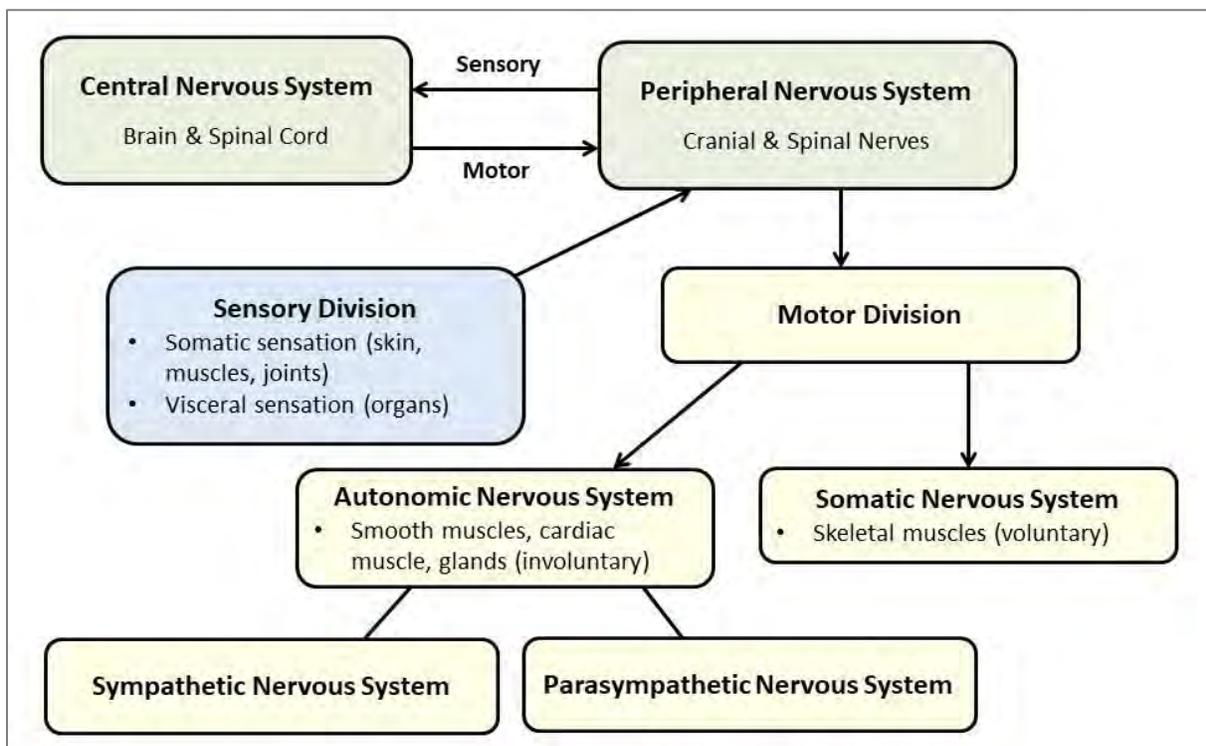
The **sensory division** carries impulses from the skin, muscles, and joints (**somatic sensation**) or internal organs (**visceral sensation**) to the central nervous system.

The **motor division** connects the CNS to peripheral motor organs. Fibers giving us conscious control of skeletal muscles form the **somatic (or voluntary) nervous system**.

The **autonomic (or involuntary) nervous system (ANS)** consists of nerve fibers that innervate structures we have no conscious control over (smooth muscle, cardiac muscle, and glands).

The ANS is further subdivided into a **sympathetic** and a **parasympathetic division**.

Figure 11.1 Overview over the nervous system



## 11.5 Histology of Nervous Tissue

Nervous tissue consists of two principal cell types: **Neurons** (or **nerve cells**) are excitable cells that generate, receive, and transmit electrical signals. The **neuroglia** (or **glial cells**) are primarily supporting cells.

There are **six different glial cells**. Four of them are found in the CNS only (astrocytes, microglia, ependymal cells, oligodendrocytes); the other two (Schwann cells, satellite cells) are found in the PNS only.

Table 11.2 Neuroglia

<b>Astrocytes</b>	<ul style="list-style-type: none"> <li>• Most abundant, versatile, and highly branched glial cells</li> <li>• Cling to neurons, synaptic endings, and capillaries</li> <li>• Support and brace neurons</li> <li>• Help determine capillary permeability</li> <li>• Guide migration of young neurons</li> </ul>
-------------------	--

	<ul style="list-style-type: none"> <li>• Control the chemical environment</li> <li>• Participate in information processing in the brain</li> </ul>
<b>Microglia</b>	<ul style="list-style-type: none"> <li>• Small, ovoid cells with thorny processes</li> <li>• Migrate toward injured neurons</li> <li>• Phagocytize microorganisms and neuronal debris</li> </ul>
<b>Ependymal cells</b>	<ul style="list-style-type: none"> <li>• Line the central cavities of the brain and spinal column; may be ciliated</li> <li>• Separate the CNS interstitial fluid from the cerebrospinal fluid in the cavities</li> </ul>
<b>Oligodendrocytes</b>	<ul style="list-style-type: none"> <li>• Processes wrap CNS nerve fibers, form myelin sheaths</li> </ul>
<b>Satellite cells</b>	<ul style="list-style-type: none"> <li>• Surround neuron cell bodies in the PNS</li> </ul>
<b>Schwann cells (neurolemmocytes)</b>	<ul style="list-style-type: none"> <li>• Surround peripheral nerve fibers and form myelin sheaths</li> <li>• Vital to regeneration of damaged peripheral nerve fibers</li> </ul>

**Neurons** are excitable cells that transmit electrical signals. They are long-lived, amitotic (with a few exceptions), and have a high metabolic rate, i.e., have a high energy use. Consequently, they depend on a continuous supply of oxygen and glucose. Neurons are the first cells to die when the cardiovascular system stops supplying sufficient amounts of oxygen.

The cell body of a neuron is also called the **perikaryon** or **soma**. It is the biosynthetic center of the neuron with a spherical **nucleus** and a well-developed Golgi apparatus.

The rough endoplasmic reticulum is called **Nissl bodies** or **chromatophilic substance**.

Nerve cells have two types of processes: dendrites and axons. **Dendrites** are short, tapering, and diffusely branched processes resembling tree branches. Some nerve cells have just a few dendrites; others may have hundreds to thousands of them.

The dendrites are the antennae of the nerve cells. They are the region where the cells receive signals from other cells, which they then convey toward the cell body.

Each nerve cell has one long process called the **axon**, which carries signals away from the cell body. Axons can form very long nerve fibers; some travel 4-5 feet or more from our spinal cord to our toes. Axons arise from a cone-shaped area called the **axon hillock**.

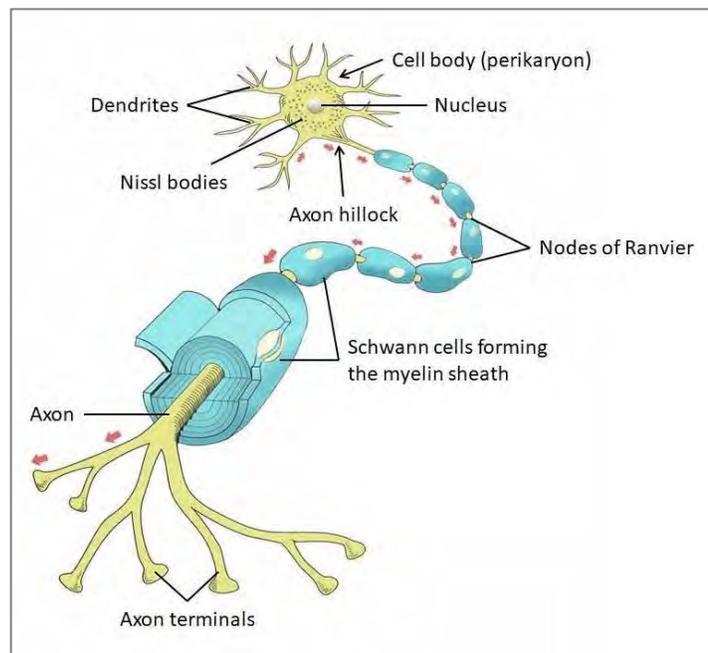
Axons may form occasional branches which we would refer to as **axon collaterals**. Before they reach their target area, axons can form numerous **terminal branches** (or **telodendria**). Each terminal branch has knob-like terminals called **synaptic knobs** (or **boutons**) that store and release messenger substances (so-called neurotransmitters) to excite or inhibit other cells.

The axon is the conducting region of a neuron; it generates and transmits nerve impulses (action potentials) away from the cell body. Molecules and organelles are moved along axons by motor molecules in two directions:

1. **Anterograde** (*antero-* forwards) **transport** refers to the movement of substances from the cell body toward the axon terminal; this type of transport moves mitochondria, membrane components, and enzymes, for example.
2. **Retrograde** (*retro-* backwards) **transport** refers to the movement of substances from the axon towards the cell body; this type of transport moves, for example, organelles to be degraded, signal molecules, viruses, and bacterial toxins.

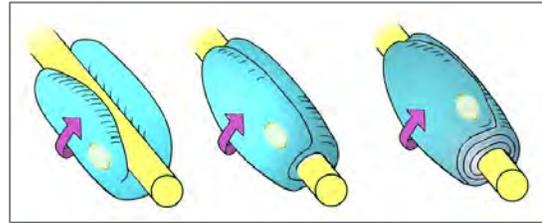
Both anterograde and retrograde transport are fairly slow process, which is one of the reasons why regeneration of damaged nerves may take weeks to months to years (see **Chapter 13 Peripheral Nervous System & Reflexes**).

**Figure 11.2 Multipolar neuron with myelinated axon**



A special feature of nervous tissue is the formation of a segmented protein-lipoid sheath around axons called the **myelin sheath**. The main functions of the myelin sheath are protection of the delicate axon, electric insulation (the axons are like electric wires that must be insulated to prevent short-circuiting), and acceleration of the conduction of electric signals. This myelin sheath is formed by glia cells: Schwann cells in the peripheral nervous system and oligodendrocytes in the central nervous system.

Figure 11.3 Schwann cell forming the myelin sheath



In the PNS, **Schwann cells** (or **neurolemmocytes**) wrap themselves around the axon forming concentric layers. The gaps between adjacent Schwann cells are called the **nodes of Ranvier**. These nodes are areas where axons can sprout new collaterals to connect with other neurons, for example, when we learn a new motor skill.

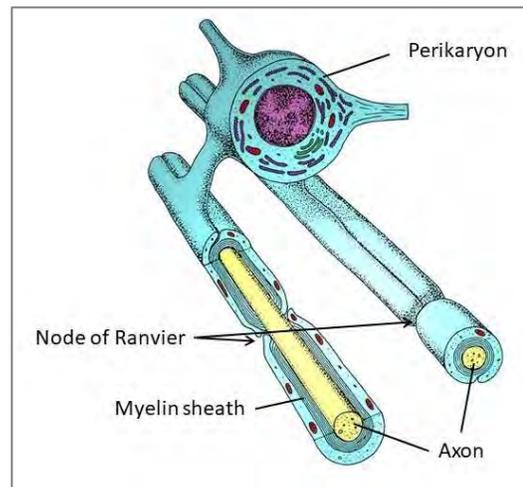
**Oligodendrocytes** function differently than the Schwann cells. They don't wrap themselves around the axon; rather they form a number of processes (*oligo* = few) that form the myelin sheath around several axons.

Fibers that are surrounded by a myelin sheath are called **myelinated fibers**, whereas those without a sheath are called **unmyelinated**. **Myelinated fibers appear white** because of the protein-lipoid sheath.

**Unmyelinated fibers** are thin because of a lack of myelin. They are **gray** because there is no protein-lipoid sheath surrounding the axon.

Because myelin is mainly made of white fat, areas of the brain and spinal cord that contain myelinated fibers form the so-called **white matter**. Non-myelinated fibers, dendrites, and cell bodies appear dark and form the **gray matter** of brain and spinal cord.

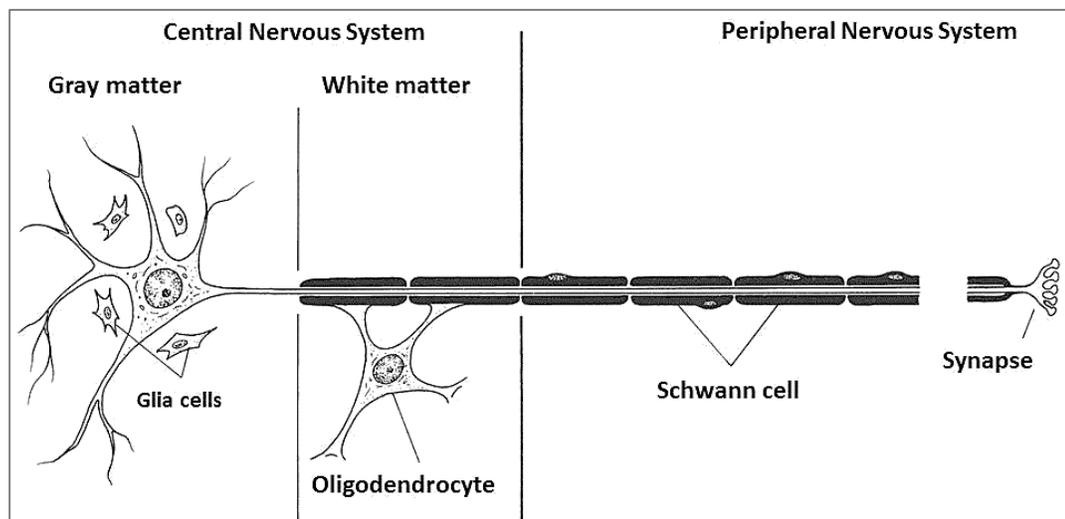
Figure 11.4 Oligodendrocyte forming myelin sheaths around two axons



#### Key Vocabulary

- **Clusters of cell bodies** are called **nuclei** in the CNS and **ganglia** in the PNS.
- **Bundles of processes** are called **tracts** in the CNS and **nerves** in the PNS.
- **White matter**: Dense collections of myelinated fibers in the CNS.
- **Gray matter**: Mostly neuron cell bodies and unmyelinated fibers in the CNS.

Figure 11.5 Myelin sheath in the CNS and PNS



Neurons can be **classified according to their structure** into three types:

- **Multipolar neurons** have one axon and several dendrites. They are the most abundant neuron type forming motor neurons and interneurons.
- **Bipolar neurons** have one axon and one dendrite only, e.g., retinal neurons of the eye are bipolar. Bipolar neurons are rare in humans.
- **Unipolar (pseudounipolar) neurons** have a single, short process that has two branches. The peripheral process is the more distal branch; it is often associated with a sensory receptor. The central process is the branch entering the CNS.

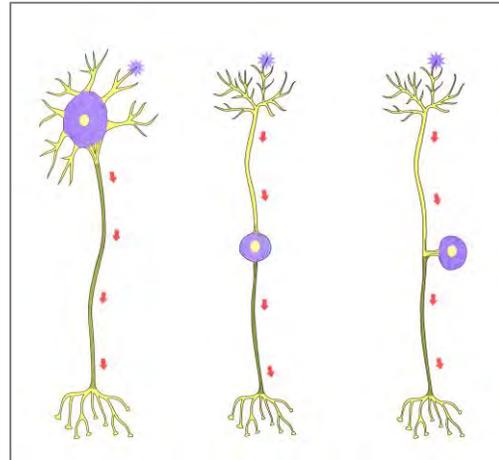
The **SAM** (or **ACE**) classification is based on the function of neurons:

- **Sensory (Afferent) neurons** transmit impulses from sensory receptors *toward* the CNS.
- **Association (Connecting) neurons** link sensory and motor neurons. Association neurons are sometimes also referred to as **interneurons**.
- **Motor (Efferent) neurons** carry impulses *away* from the CNS to muscles and glands.

The **conduction velocity of neurons** varies widely. The two main factors are axon diameter and degree of myelination.

- **Axon diameter:** Larger diameter fibers have less resistance to local current flow and have faster impulse conduction.
- **Myelination:** Continuous conduction in unmyelinated axons is slower than **saltatory conduction** in myelinated axons. Myelin sheaths insulate and prevent leakage of electric charges. Voltage-gated  $\text{Na}^+$  channels are located at the nodes. APs to jump rapidly from node to node, making saltatory conduction in myelinated axons up to 100 times faster than signal conduction in non-myelinated fibers.

Figure 11.6 Multipolar (left), bipolar (middle), and pseudounipolar neuron (right)



### Check Your Understanding

- Which of the following is not a division of the nervous system?
  - Motor division
  - Sensory division
  - Special senses
  - Somatic nervous system
- The meaning of the combining form "cephal(o)-" is \_\_\_\_\_.
  - brain
  - head
  - spine
  - cord
- Dendrites \_\_\_\_\_.
  - are the antennae of nerve cells
  - form the white matter
  - are surrounded by myelin
  - are rarely found on nerve cells
- Which of the following is not a neuron of the ACE classification?
  - Afferent neuron
  - Connecting neuron
  - Electric neuron
  - Efferent neuron
- Which glia cells are also called neurolemmocytes?
  - Oligodendrocytes
  - Satellite cells
  - Microglia
  - Schwann cells
- White matter \_\_\_\_\_.
  - is found in the PNS and CNS
  - is found in ganglia only
  - forms nuclei inside the CNS
  - is found in the CNS only

1.C 2.B 3.A 4.C 5.D 6.D

## 11.6 Neuron Function

Neurons are highly irritable cells, meaning that they are excitable. The excitable nature of neurons is one of their key functions. They have a **resting membrane potential (RMP)**, which enables them to respond to adequate stimuli by generating an **action potential** (the nerve impulse).

The resting membrane potential is a potential difference across the membrane of a resting cell caused by differences in the ionic makeup of extracellular and intracellular fluid and the presence of more leakage channels for  $K^+$  than  $Na^+$ . It is approximately  $-70$  mV in neurons, i.e., the cytoplasmic side of the membrane is negatively charged relative to the outside (see also **Chapter 2 Basic Sciences Review**).

### Synapses

A synapse is the junction that mediates information transfer from one neuron to another neuron or to an effector cell, such as a muscle or gland cell. This interaction with neighboring cells may cause the effector cell either to become excited and send out their own message or to stop sending out signals (inhibition). Neurons are able to connect with hundreds or thousands of other nerve or muscle cells via their axon terminals.

The first neuron at a synapse is called the presynaptic neuron, while the second neuron is called the postsynaptic neuron. Inside the nervous system, the **presynaptic neuron** conducts impulses toward the synapse and the **postsynaptic neuron** transmits impulses away from the synapse. An **axodendritic synapse** connects the axon of one neuron and the dendrite of another, while an **axosomatic synapse** is between the axon of one neuron and the soma of another.

There are two types of synapses: **electrical** and **chemical synapses**. In **electrical synapses**, neurons are connected via **gap junctions**, which allow for a free flow of ions between the neurons. Communication is fast and the signals can move in both directions. They are rare in the human body.

In contrast, **chemical synapses** are designed for the release and reception of neurotransmitters. The axon of the presynaptic neuron forms **axon terminals** that contain **synaptic vesicles** filled with **neurotransmitter**, while the postsynaptic neuron has receptor regions for the chemical messenger. The neuromuscular junction of skeletal muscle is a chemical synapse.

The gap between the axon terminal and the postsynaptic membrane is called the **synaptic cleft**. It is a fluid-filled space separating the presynaptic and postsynaptic neurons. The neurotransmitters have to cross this gap to reach their respective **receptors** on the postsynaptic membrane. This process ensures **unidirectional communication**, i.e., the signal cannot return to the presynaptic neuron.

**Postsynaptic receptors** are **chemically-gated receptors** that change their conformation after binding of the transmitter substance. When the AP coming along the presynaptic axon reaches the axon terminal, **voltage-gated channels** open and allow  $Ca^{2+}$  ions to flow into the terminal. This inflow leads to the synaptic vesicles fusing with the axon membrane and the neurotransmitter is released into the synaptic cleft.

The **effect of the neurotransmitter at the synapse has to be terminated immediately**. Otherwise, no second signal can be transmitted. There are three mechanisms for the removal of a neurotransmitter:

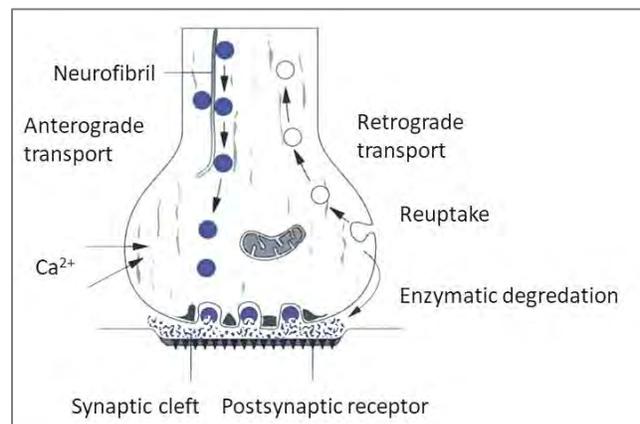
1. Degradation by enzymes.
2. Reuptake by astrocytes or via the axon terminal.
3. Diffusion away from the synaptic cleft.

**Synaptic delay** is the time needed for the release of the neurotransmitter, diffusion across the synaptic cleft, and binding to a receptor. It is the rate-limiting step of neural transmission (0.3–5.0 ms).

### Neurotransmitters

Neurotransmitters are chemicals released by neurons that act on effector cells via receptors. There are more than 50

Figure 11.7 Chemical synapse



known neurotransmitters. Some of them are also used as hormones by the endocrine system (see also **Chapter 15 Endocrine System**). Neurotransmitters play a major role in shaping our everyday lives. For example, cocaine increases the amount of dopamine and norepinephrine at the synaptic cleft. Neurotransmitters can be classified either by their chemical structure or their function:

#### Chemical classification

- **Acetylcholine** (ACh) is the most common neurotransmitter in the human body. It is released at neuromuscular junctions and by some neurons of the autonomic nervous system (ANS). It is degraded by **acetylcholinesterase** (AChE).
- **Biogenic amines** include **catecholamines**, for example, dopamine, norepinephrine (NE), and epinephrine, and **indolamines**, such as serotonin and histamine.
- **Amino acids** include GABA (gamma ( $\gamma$ )-aminobutyric acid), glycine, aspartate, and glutamate.
- **Peptides** (neuropeptides) include substance P (a mediator of pain signals), **endorphins** (act as natural opiates and reduce pain perception), and gut-brain peptides, such as somatostatin and cholecystokinin.
- **Purines** such as ATP act both in the CNS and PNS. They can produce fast or slow responses and provoke pain sensation.
- **Gases: Nitric oxide** (NO) is involved in learning and memory, **carbon monoxide** (CO) is a regulator of cGMP in the brain.
- **Endocannabinoids** are involved in learning and memory.

#### Functional classification

- Neurotransmitter effects may be **excitatory** (depolarizing) **and/or inhibitory** (hyperpolarizing). This effect is **determined by the receptor type** of the postsynaptic neuron. For example, **acetylcholine** is excitatory at neuromuscular junctions in skeletal muscle and inhibitory in cardiac muscle.
- **Neurotransmitter may have a direct effect or an indirect effect.** In **direct action**, the neurotransmitter, e.g., ACh and amino acids, binds to **channel-linked receptor** and opens ion channels. The action is immediate and short, which promotes rapid responses.
- In **indirect action**, the neurotransmitter binds to a **G protein-linked transmembrane receptor** and acts through an **intracellular second messenger**. The responses are indirect, slow, complex, and often prolonged and widespread.

#### Postsynaptic Potentials

**Changes in the resting membrane potential** are signals used to receive, integrate and send information. **Action potentials** are long-distance signals of axons (**See Chapter 2 Basic Sciences Review**); **graded potentials** are incoming short-distance signals.

Postsynaptic potentials are **graded potentials** that decay and, therefore, can only be used as short-distance signals. Their strength is determined by the amount of neurotransmitter released, the number of available receptors, and the time the neurotransmitter spends in the synaptic cleft.

The two types of postsynaptic potentials are **excitatory postsynaptic potentials (EPSP)** and **inhibitory postsynaptic potentials (IPSP)**.

**EPSPs** lead to a **local depolarization** of the membrane potential, i.e., the membrane potential becomes less negative, making it easier for a postsynaptic neuron to reach its threshold for generation of an action potential. The neurotransmitter binds to and opens chemically-gated channels that allow simultaneous flow of  $\text{Na}^+$  and  $\text{K}^+$  in opposite directions. However,  $\text{Na}^+$  influx is greater than  $\text{K}^+$  efflux, causing a net depolarization.

**IPSPs** have the exact opposite effect. The neurotransmitter binds to and opens channels for  $\text{K}^+$  or  $\text{Cl}^-$ , which leads to the interior of the cell becoming more negative and, thus, a local **hyperpolarization** occurs. This reduces the postsynaptic neuron's ability to produce an action potential.

Interestingly enough, **a single EPSP cannot induce an action potential!** To reach the threshold for an action potential, EPSPs have to add up (summate). This can be achieved by many graded potentials happening at the same time but at different locations (**spatial summation**) or by potentials being elicited in quick succession (**temporal summation**). Multiple IPSPs can also negate multiple EPSPs, canceling each other out and, consequently, the neuron does not respond.

### 11.7 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	head	_____	ment(o)-
2.	brain	_____	glio(o)-
3.	mind	_____	myel(o)-
4.	gray matter	_____	neur(o)-
5.	nervous tissue	_____	encephal(o)-
6.	spinal cord	_____	cephal(o)-
7.	nervous system	_____	poli(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

1. Oligodendrocytes can myelinate several axons. \_\_\_\_\_
2. The nodes of Ranvier are found only on myelinated, peripheral neuron processes. \_\_\_\_\_
3. Myelination of nerve fibers in the PNS is the job of the Schwann cells. \_\_\_\_\_
4. Efferent nerve fibers may be described as motor nerve fibers. \_\_\_\_\_
5. Catecholamines are peptides that act like morphine. \_\_\_\_\_
6. If bacteria invaded the CNS, microglia would migrate to the area to destroy them. \_\_\_\_\_
7. Glial cells are excitable cells that generate, receive, and transmit electrical signals. \_\_\_\_\_
8. The CNS is the integration and command center of the nervous system. \_\_\_\_\_
9. Dendrites are diffusely branched processes that resemble tree branches. \_\_\_\_\_
10. Non-myelinated fibers, dendrites, and cell bodies form the white matter. \_\_\_\_\_

#### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                      |  |          |
|----------------------|--|----------|
| 1. Repolarization    | a) area where a nerve impulse is generated | 1. _____ |
| 2. Spatial summation | b) natural opiates that inhibit pain       | 2. _____ |
| 3. Dendrite          | c) control chemical environment in CNS     | 3. _____ |
| 4. Axon hillock      | d) interpretation of sensory input         | 4. _____ |

- |     |                |    |  |     |       |
|-----|----------------|----|--|-----|-------|
| 5.  | Endorphins     | e) | impulses arriving at many terminals at the same time | 5.  | _____ |
| 6.  | Acetylcholine  | f) | nerve cell body                                      | 6.  | _____ |
| 7.  | Sensory neuron | g) | receives stimuli                                     | 7.  | _____ |
| 8.  | Astrocytes     | h) | transmits impulses towards CNS                       | 8.  | _____ |
| 9.  | Integration    | i) | most common neurotransmitter                         | 9.  | _____ |
| 10. | Perikaryon     | j) | interior of the cell becomes negative again          | 10. | _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- The brain and spinal cord form the \_\_\_\_\_.
  - somatic nervous system
  - autonomic nervous system
  - peripheral nervous system
  - central nervous system
- The S in the SAM classification stands for \_\_\_\_\_.
  - short
  - supporting
  - sensory
  - synaptic
- If a neurotransmitter depolarizes the postsynaptic membrane it is considered a(n) \_\_\_\_\_ neurotransmitter.
  - excitatory
  - inhibitory
  - catecholamine
  - indirect
- IPSP stands for \_\_\_\_\_.
  - instant presynaptic summation potential
  - inhibitory postsynaptic summation potential
  - inhibitory postsynaptic potential
  - inhibitory presynaptic potential
- Diffusion, enzymatic degradation, and uptake by cells are all ways to \_\_\_\_\_.
  - remove a neurotransmitter
  - stop spatial summation
  - inhibit a presynaptic potential
  - excite a presynaptic potential
- Myelin sheaths in the CNS are produced by \_\_\_\_\_.
  - astrocytes
  - microglia
  - oligodendrocytes
  - Schwann cells
- The neuroglial cells that line the ventricles of the brain are the \_\_\_\_\_.
  - astrocytes
  - ependymal cells
  - microglia
  - Schwann cells

8. \_\_\_\_\_ occurs when a neuron is stimulated by more than one stimulus at the same time.
- Temporal summation
  - Spatial summation
  - Synaptic delay
  - Synaptic potentiation
9. The nodes of Ranvier are found \_\_\_\_\_.
- in the CNS only
  - on dendrites
  - on neuroglia cells
  - on myelinated axons
10. Which of the following is **not** a function of the nervous system?
- Sensory function
  - Integrative function
  - Motor function
  - All are functions of the nervous system

## Chapter 12 Central Nervous System

### 12.1 Chapter Outline

The central nervous system is the integration and command center of the nervous system. The brain is responsible for our intellect, memory, creativity, and behavior. The spinal cord transmits sensory information up to the brain and motor signals down to motor neurons and mediates spinal reflexes. In addition, the spinal cord coordinates spinal reflexes.

### 12.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Name the major regions of the adult brain and the ventricles as well as the five lobes of the cerebral cortex and the three most important sulci and fissures.
- Explain the structure and function of the cerebral cortex, including the five motor areas and eight sensory areas.
- Describe the function of multimodal association areas.
- Define commissural, association and projection fibers.
- Name the three parts of the diencephalon and their major functions.
- Name the three parts of the brain stem and their major functions.
- Describe the structure and function of the cerebellum.
- Explain functional brain systems, such as the limbic and the reticular system.
- Describe the different sleep stages and their function.
- Define and compare short-term and long-term memory.
- Discuss the differences between declarative and nondeclarative memory.
- Describe the macroscopic and cross-sectional structure of the spinal cord.
- Name the different parts of the gray matter and their function.
- Discuss the function and major tracts of the white matter.
- Name and describe the structures that protect the brain and the spinal cord.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 12.3 Combining Forms

Table 12.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 12.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
-algia	pain or painful condition	<i>cephalgia</i> = headache
cerebell(o)-	cerebellum	<i>cerebellar</i> = relating to the cerebellum
cerebr(o)-	cerebrum	<i>cerebrovascular</i> = relating to the blood vessels of the brain
-dural	dura mater	<i>subdural</i> = located below the dura mater
encephal(o)-	brain	<i>encephalitis</i> = inflammation of the brain
mening(o)-	meninges or membranes	<i>meningioma</i> = tumor arising from the meninges
myel(o)-	spinal cord or myelin	<i>myelopathy</i> = disease affecting the spinal cord

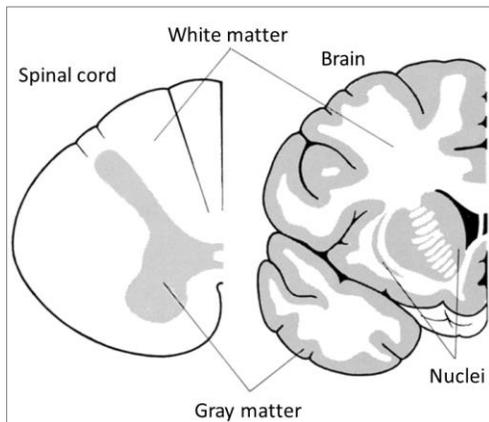
-plegia	paralysis or stroke	<i>quadriplegia</i> = paralysis of all four limbs
spin(o)-	spine or spinal cord	<i>spinal</i> = relating to the spine or the spinal cord
thalam(o)-	thalamus	<i>thalamic</i> = relating to the thalamus

## 12.4 Overview

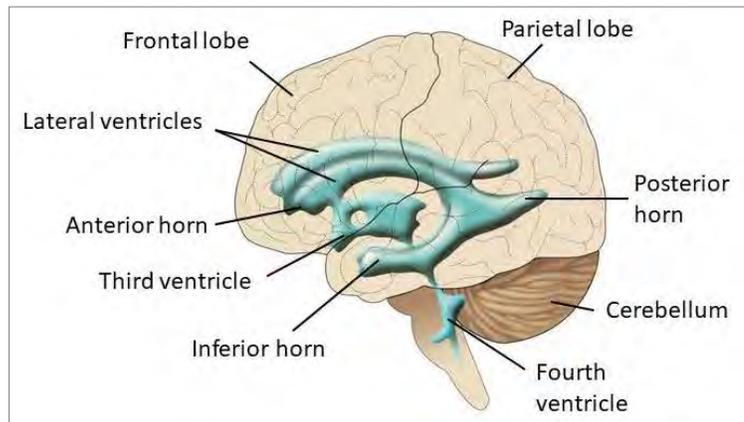
The central nervous system **consists of the brain and spinal cord**. By definition, the **brain** is the part of the CNS inside the cranial cavity of the skull, and the **spinal cord** is the part of the CNS inside the vertebral canal of the spine. Both parts consist of **white matter** (myelinated axons) and **gray matter** (mainly the cell bodies of neurons).

During evolution, the rostral (cranial) part of the CNS increased its number of neuron in a process called **cephalization**, which reached its peak in the human brain and makes humans uniquely intelligent.

**Figure 12.1 Gray and white matter**



**Figure 12.2 Ventricles of the brain**



Embryonic development of the CNS starts with a **neural plate** forming from ectoderm, the outer tissue layer of the embryo. This plate invaginates to form a **neural groove** and **neural folds**. These folds fuse dorsally to form the **neural tube**, which gives rise to the brain and spinal cord. The anterior end of the tube grows bigger and forms brain vesicles that develop into the brain regions.

Inside the brain are four fluid-filled **ventricles** that are connected with each other and to the **central canal** in the **spinal cord**. The two C-shaped **lateral ventricles** are located in the cerebral hemispheres, the **third ventricle** is located in the **diencephalon**, and the **fourth ventricle** is located dorsal to the **pons**.

The ventricles are lined by ependymal cells and contain **cerebrospinal fluid** (see below).

A cross section of the brain shows a similar pattern with additional areas of **gray matter** as **nuclei** in cerebellum and cerebrum, and, especially, as a **cortex** of cerebrum and cerebellum.

In order to accommodate the increasing number of neurons during evolution, the two cerebral hemispheres folded their outer layers during to increase the brain's surface area. This led to visible markings of the cerebral surface called **gyri** (ridges), **sulci** (shallow grooves), and **fissures** (deep grooves).

There are three main grooves:

1. The **central sulcus** is located between the precentral gyrus of the frontal lobe and the postcentral gyrus of the parietal lobe.
2. The **longitudinal fissure** separates the two hemispheres.
3. The **transverse cerebral fissure** separates the cerebrum and the cerebellum.

## 12.5 The Brain

When comparing the ratio of the average brain weight to the average body weight of animal and humans, we find that the human brain is seven times heavier than the average animal brain. To fit billions of nerve cells into our brain without the brain becoming too large for our skull, the neurons moved during evolution from the center of the brain to the outer layer, the **cortex**. Thus, the cortex contains the majority of cerebral gray matter. We also find gray matter in separated, deep **nuclei** of the cerebrum.

The brain has four regions called the **cerebrum**, **diencephalon**, **brain stem**, and **cerebellum**. The newest part, in evolutionary terms, is the **cerebrum** with its two cerebral hemispheres. The **cerebral hemispheres** each have **five lobes** known as the **frontal**, **parietal**, **temporal**, and **occipital lobe**. The fifth lobe, the **insula**, is hidden under the temporal lobe.

Each hemisphere connects to the contralateral side of the body.

There is **lateralization** of cortical function in the hemispheres, i.e., each side has its main functions.

The **cerebral cortex** is a thin (2-4 mm) superficial layer of gray matter, but because of its many cell bodies makes up 40% of the mass of the brain. It is the site of conscious mind: awareness, sensory perception, voluntary motor initiation, communication, memory storage, and understanding. Thus, most of the brain's work is fulfilled by the cerebral cortex.

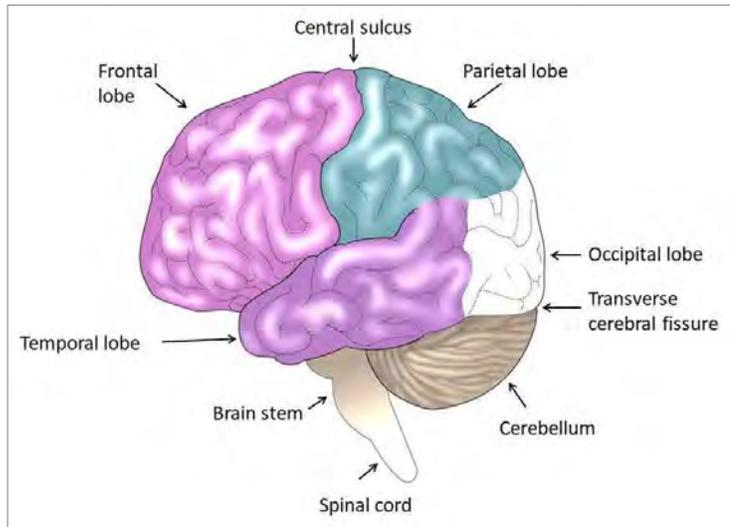
The cerebral cortex has three **functional areas (SAM)**, although conscious behavior involves all areas of the cortex.

**Sensory areas** give us conscious awareness of sensation. There are **eight areas** that receive and process signals from the **special senses**, our skin, muscles, and joints (**somatosensation**), as well as internal organs, such as stomach and bladder (**visceral sensation**).

1. The **primary somatosensory cortex** in the postcentral gyrus receives sensory information from the skin, muscles, and joints. It possesses **spatial discrimination**, i.e., it can identify body regions that are being stimulated.
2. The **somatosensory association cortex**, posterior to the primary somatosensory cortex, helps us to integrate sensory input from the primary somatosensory cortex and to determine the size, texture, and relationship of parts of objects being felt.
3. There are **two visual areas**. The first one is the **primary visual cortex (or striate cortex)** at the extreme posterior tip of the occipital lobe deep in the calcarine sulcus. It receives visual signal from the retina of the eye. If the signal doesn't get to the primary visual cortex, we are blind. The surrounding area is called the **visual association area**. Its task is to help us make sense of what we see by using past visual experiences. This is a very complex process involving the entire posterior half of the cerebral cortex.
4. There are also **two auditory areas**. The **primary auditory area**, at the upper margin on the temporal lobe, interprets the signals received from receptors in the inner ear. If the signals don't arrive at the primary auditory area, we are deaf. The **auditory association area** is located posteriorly. It stores memories of sounds and permits perception and analysis of sound.
5. The **olfactory cortex**, in the piriform lobe of the temporal lobe, is the region of our conscious awareness of smells (odors). It is part of the limbic system (see below), which enables us to have emotions associated with smells.
6. The **gustatory cortex**, in the insula, is the region of our conscious awareness of taste.
7. The **vestibular cortex**, in the posterior part of the insula and nearby parts of the parietal lobe, is in charge of conscious awareness of balance (position of the head in space at rest and when moving it around).
8. The **visceral sensory area**, posterior to the gustatory cortex, gives us a conscious perception of sensations coming from our internal organs, such as the feeling of a full bladder.

**Association areas** integrate diverse information. Cerebral areas that receive input from multiple sensory areas and send output to multiple areas, including the premotor cortex, are called **multimodal association areas**. They make up most of the lower and anterior areas of the cortex. Association areas allow us to give meaning to information received, store it as memory, compare it to previous experience, and decide on which action to take.

Figure 12.3 Regions of the brain



- The **anterior association area**, also known as the **prefrontal cortex**, is the most complicated cortical region. It is involved with intellect, cognition, recall, and personality. It contains working memory needed for judgment, reasoning, persistence, and conscience. Its development depends on feedback from our social environment. The fact that it matures last explains why teenagers and young adults act differently than older adults.
- The **posterior association area** is a large region in the temporal, parietal, and occipital lobes. It plays a role in recognizing patterns and faces as well as understanding spoken and written language (**Wernicke's area**).
- The **limbic association area** provides emotional impact that helps establish memories.

**Motor areas** control voluntary movement. Of the **four motor areas**, the primary motor cortex is the most important:

1. The **primary** or **somatic motor cortex (PMC)** is located in the **precentral gyrus** in front of the central gyrus. It consists of large pyramidal cells, whose long axons form the **pyramidal** or **corticospinal tract**. It is in charge of our conscious control of precise, skilled, voluntary movements.
2. The **premotor cortex** is located anterior to the PMC. It coordinates simultaneous or sequential actions and controls learned, repetitious, and patterned motor skills. It is involved in the planning of movements that depend on sensory feedback; the so-called "*muscle memory*" is information stored here.
3. The area anterior to the inferior region of the premotor area is considered a **motor speech area** as it directs muscles of the tongue. It is called **Broca's area** and is found in one hemisphere only, most of the time on the left side, which is then considered the dominant hemisphere (see below).
4. The **frontal eye field (FEF)** directs voluntary eye movements. It is found anterior to the premotor cortex and superior to Broca's area.

The term **lateralization** describes the division of labor between the two hemispheres. The **left hemisphere** controls language, math, and logic, while the **right hemisphere** provides insight, visual-spatial skills, intuition, and artistic skills. **Cerebral dominance** designates the hemisphere dominant for language, which is the left hemisphere in 90% of people.

The **white matter of the cerebrum** is deep to the cortical areas discussed above (SAM). What makes the deeper areas of the brain "white" is that it is composed of myelinated fibers. These fibers are responsible for communication between cells. **Commissures** connect gray matter of the two hemispheres. These fibers cross in the **corpus callosum** from one side to the other. **Association fibers** connect different parts of the same hemisphere, while **projection fibers** connect the cortex with lower parts of the brain or the spinal cord.

The **basal nuclei** (ganglia) are subcortical nuclei at the base of the cerebrum. They make up the **corpus striatum**, which consists of **caudate nucleus** and **lentiform nucleus**. The basal nuclei are functionally associated with nuclei in the diencephalon and the substantia nigra in the midbrain. They influence motor control, help regulate the intensity of slow or stereotyped movements, inhibit antagonistic and unnecessary movements, and are important for attention and cognition.

### Check Your Understanding

1. The part of the central nervous system inside the vertebral canal is called \_\_\_\_.
  - a) spinal cord
  - b) brain
  - c) brain stem
  - d) cerebellum
2. The \_\_\_\_ cortex is the region of conscious awareness of taste.
  - a) limbic
  - b) motor
  - c) gustatory
  - d) olfactory
3. The cerebrum has \_\_\_\_ lobes.
  - a) 4
  - b) 5
  - c) 3
  - d) 2
4. Which part of the brain is the site of our conscious mind?
  - a) Cerebrum
  - b) Cerebellum
  - c) Diencephalon
  - d) Brain stem

1A.2.C.3B.4.A

## Diencephalon

From an evolutionary point of view, the **diencephalon** (sometimes also called the **“tweenbrain”**) is the second youngest part of the brain. However, we are not aware of the signals coming into the diencephalon until they are relayed to the sensory cortex. The diencephalon is connected to the first two cranial nerves (olfactory and optic nerve). It consists of **three paired structures** that together enclose the third ventricle:

1. The **thalamus** makes up 80% of the diencephalon. It is the **gateway to the cerebral cortex**. For us to be aware of a sensation, the signal has to be passed on from the thalamus to the cerebral cortex. The thalamus sorts, edits, and relays information; it mediates sensation, motor activities, cortical arousal, and is important for learning and memory. The two thalami are located near the walls of the third ventricle and are connected by the **interthalamic adhesion**.
2. The **hypothalamus** is the **center for our emotional response** and is the **autonomic control center** for functions such as blood pressure, body temperature, and water balance. It **controls the release of hormones from the anterior pituitary** and **produces two hormones** (oxytocin, antidiuretic hormone) that are stored in and **released from the posterior pituitary**. The stalk that connects the hypothalamus to the pituitary below is called **infundibulum**. The **hypothalamus is the interface between nervous and endocrine system**; its task is to coordinate and synchronize the functions of these two systems. Tasks that need to be undertaken immediately, such as blood pressure regulation, will be handed on to the autonomic nervous system, while adjustments that are less urgent, e.g., control of our reproductive cycles, will be handled by the endocrine system.
3. The dorsal part of the diencephalon, the **epithalamus**, forms the roof of the third ventricle. It contains an endocrine gland (**pineal gland**), which produces **melatonin**, the hormone that helps regulate our sleep-wake cycle (see below).

## Brain Stem

The brain stem is the **oldest part of the central nervous system**. Its **structure**, especially in its lower parts, is **similar to that of the spinal cord**. The main difference is the presence of **nuclei embedded in the white matter**. They control automatic behaviors necessary for survival and are associated with 10 of the 12 cranial nerves. The white matter of the brain stem mainly consists of **fiber tracts** that connect higher and lower neural centers.

The upper most part of the brain stem, the **midbrain**, is located between the diencephalon and the pons. Brain stem **nuclei** control **cranial nerves III** (oculomotor nerve) and **IV** (trochlear nerve). The **cerebral peduncles** contain pyramidal motor tracts coming down from the cerebral cortex. The **cerebral aqueduct** is a channel that connects the third and fourth ventricle. The **corpora quadrigemina** are dome-like dorsal protrusions that are visual reflex and auditory relay centers. The dark **substantia nigra** is functionally linked to the basal nuclei of the cerebrum. Lack of dopamine in this area is part of the pathophysiology in Parkinson disease. The **red nucleus** is a relay station for some descending motor tracts and forms part of the reticular formation.

The middle part of the brain stem is called the **pons**. It is bridge-shaped and forms part of the anterior wall of the fourth ventricle. Its fibers connect higher brain centers and the spinal cord and relay impulses between the motor cortex and the cerebellum. The **nuclei of cranial nerves V** (trigeminal nerve), **VI** (abducens nerve), and **VII** (facial nerve) are embedded in the pons. Its nuclei are part of the respiratory control system and of the reticular formation.

The last part of the brain stem, the **medulla oblongata**, transcends into the spinal cord at the **foramen magnum**. The **nuclei of cranial nerves VIII** (vestibulocochlear nerve), **X** (vagus nerve), and **XII** (hypoglossal nerve) are associated with the medulla oblongata. The so-called **pyramids** are two ventral longitudinal ridges formed by pyramidal tracts that cross over to the contralateral side in the **decussation of the pyramids**. The **vestibular nuclear complex** mediates responses that maintain equilibrium. The **medulla contains important survival centers**; the **cardiovascular center**, for example, adjusts the force and rate of heart contraction and blood vessel diameter for blood pressure regulation, and the **respiratory centers** generate the respiratory rhythm and control rate and depth of breathing. There are **additional centers** that regulate vomiting, hiccupping, swallowing, coughing, and sneezing. Because of these centers, we usually cannot survive if the medulla oblongata is damaged.

## Cerebellum

The cerebellum makes up approximately 11% of the overall brain mass. Its name means *“little cerebrum”* as it has a similar structure and appearance to the cerebrum, just smaller. The cerebellum is located dorsal to the pons and medulla. Three pairs of fiber tracts called **cerebellar peduncles** connect the cerebellum to the brain stem. The cerebellum also has two **hemispheres** that are connected by the **vermis** (so called because it resembles a worm). Each

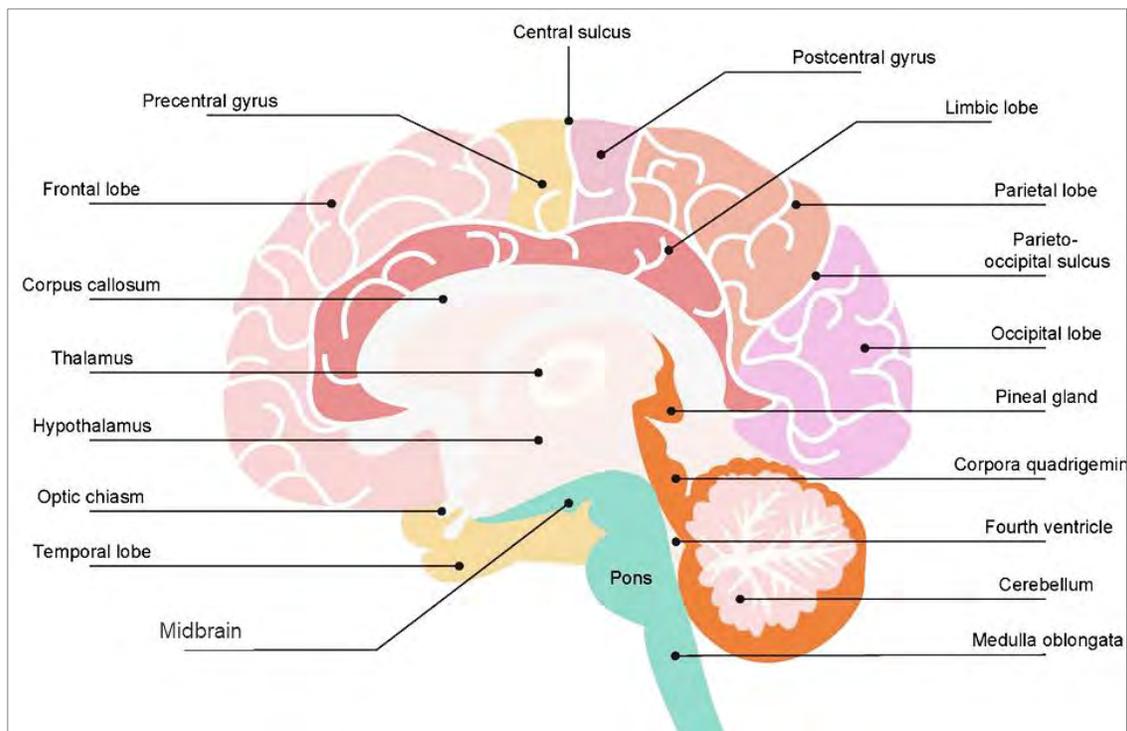
hemisphere has three lobes called the **anterior**, **posterior**, and **flocculonodular lobe**. The transversely oriented gyri of the hemispheres are called **folia**. The distinctive tree-like pattern of the cerebellar white matter is called the **arbor vitae** or “*tree of life*” because of its appearance.

The cerebellum provides **subconscious precise timing and appropriate patterns of skeletal muscle contraction**. It receives impulses from the cerebral cortex of our body’s intent to initiate voluntary muscle contraction. Signals from proprioceptors and visual and equilibrium pathways keep the cerebellum continuously informed about the body’s position and momentum. The **cerebellar cortex calculates the best way to smoothly coordinate muscle contraction**, i.e., a blueprint of the coordinated movement is sent to the cerebral motor cortex and brain stem nuclei.

The cerebellum is also involved in **cognitive functions**. It recognizes and predicts sequences of events during complex movements and plays a role in nonmotor functions such as word association and puzzle solving.

Its **main function**, however, **is maintaining our balance**. Because the cerebellum knows at any time what our muscles are doing, which ones are relaxed and which ones are contracting, and the position of all our joints, the cerebellum keeps us standing still and upright with our eyes closed. Patients with damage to the cerebellum will start swaying or even fall over when they close their eyes or stand in the dark.

**Figure 12.4 Brain, midsagittal section**



### Functional Brain Systems

Functional brain systems are networks of neurons that work together across anatomical boundaries and span wide areas of the brain. Two important brain systems are the limbic system and the reticular formation.

The **limbic system** is our **emotional** or **affective brain**. It includes structures from the **diencephalon** as well as **cerebral structures**, such as the **amygdala** (recognizes angry or fearful facial expressions, assesses danger, and elicits the fear response) and the **cingulate gyrus** (plays a role in expressing emotions via gestures, and resolves mental conflict). The limbic system gives us the ability to react emotionally to things we consciously understand to be happening and plays an **important role in memory formation and recall** via the hippocampus and amygdala.

The **reticular formation** is important for keeping us conscious and alert, e.g., the **reticular activation system (RAS)**, and has autonomic centers, such as vasomotor, cardiac, and respiratory center that regulate visceral motor functions.

### 12.6 Memory

**Memory is the storage and retrieval of information**. There are different kinds of memory, such as taste memories, visual memories, and language memories. Many theories try to explain how the brain stores and retrieves infor-

mation. Although it is tempting to compare the brain to a computer system, our brain is much more complex and overall far superior to any machine.

The two stages of memory are **working** or **short-term memory (STM)** and **long-term memory (LTM)**. The STM is a temporary holding area (30-60 seconds) for a very limited amount of information ( $7 \pm 2$  pieces of information), while the LTM has a limitless capacity and can store the information for as long as we live. The **transfer of information from the STM to the LTM** is influenced by our emotional state (best if motivated, surprised, and aroused), rehearsal (practice makes perfect), and association with already learned/memorized information.

Once any learned information has been transferred to our LTM, our brain needs time to store it where it can find it again, which explains the importance of sleep for learning (see below). Review of the learned material at regular intervals, such as 1 day, 1 week, 1 month, and 1 year, helps to build stronger and more easily accessible memories.

The two categories of memory are **declarative memory**, which contains **factual knowledge**, and **nondeclarative memory**, which includes **procedural, motor, and emotional memory**.

**Declarative memory contains explicit information related to our conscious thoughts and our language ability.** It is stored in the LTM with the context in which it was learned. It is easier to forget or more difficult to access if not used regularly than nonfactual (or nondeclarative) knowledge. Brain structures involved in declarative memory are the **hippocampus** and parts of the surrounding temporal lobes. They function in consolidation and access to memory. Acetylcholine from the basal forebrain is necessary for memory formation and retrieval.

**Nondeclarative memory is less conscious or unconscious.** It is acquired through experience and repetition and best remembered by doing, such as riding a bike. It is much harder to forget or unlearn than factual knowledge. The **cerebellum** plays an important part in **motor memory** and the **amygdala** in **emotional memory**. Procedural memory is dependent on **basal nuclei** relaying sensory and motor inputs to the thalamus and premotor cortex, and on **dopamine** from the substantia nigra.

## 12.7 Sleep

**Sleep is defined as a state of partial unconsciousness from which a person can be aroused by stimulation.** Based on electroencephalographic (EEG) results and eye movement pattern, **two basic types of sleep** can be defined:

1. Nonrapid eye movement (**NREM**) sleep
2. Rapid eye movement (**REM**) sleep

The importance of sleep for the different physical and mental functions is still not completely understood. Nevertheless, we know that **NREM sleep is important for recovery of our organs and muscles** and that **REM sleep is important for learning and our mental health**.

- Slow-wave sleep (NREM stages 3 and 4) is presumed to be the restorative stage.
- **REM sleep may be a reverse learning process where superfluous information is purged from the brain.** People deprived of REM sleep become moody and depressed.

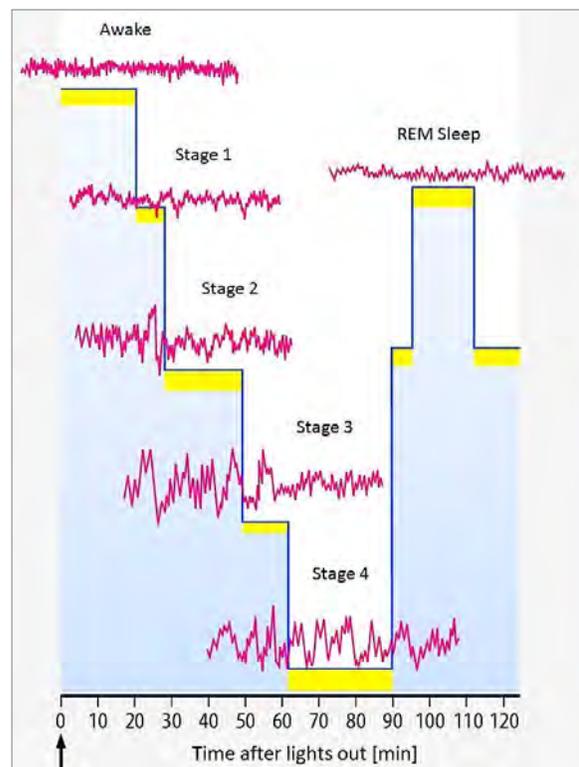
Daily sleep requirements decline with age. Stage 4 sleep declines steadily and may disappear after age 60.

A typical sleep pattern alternates between REM and NREM sleep. The first two stages of NREM occur during the first 30–45 minutes of sleep. Stage 4 is achieved in about 90 minutes, and then REM sleep begins abruptly.

Alternating cycles of sleep and wakefulness reflect a natural **circadian** (24-hour) **rhythm**.

- **Melatonin** has an influence on our sleep/wake cycle as well. Its blood level is highest at around 9-10 pm at

Figure 12.5 Sleep stages



night making us sleepy and at its lowest level early in the morning so we can get up and start our day.

- The **reticular activation system** (RAS) regulates how deep asleep we are. If it puts us on alert, we may not descend into stage 4 and are easily aroused by sensory input, such as the crying of a baby or noise outside. However, if the RAS is not functioning correctly, it can put us in a state of permanent unconsciousness (coma).

### Check Your Understanding

1. The \_\_\_ is the autonomic control center for functions such as blood pressure.
  - a) diencephalon
  - b) hypothalamus
  - c) cerebrum
  - d) cerebellum
2. The main function of the cerebellum is \_\_\_\_.
  - a) motor memory
  - b) word association and puzzle solving
  - c) maintaining balance
  - d) sleep regulation
3. Which of the following statements about memory and sleep is correct?
  - a) Short-term memory has a limitless capacity.
  - b) NREM sleep is important for learning.
  - c) Melatonin is important for our sleep/wake cycle.
  - d) Rehearsal has no influence on the transfer of information to the long-term memory.
4. Reflex centers that control adjustments and behavior necessary for our survival are located in the \_\_\_\_.
  - a) cerebrum
  - b) cerebellum
  - c) diencephalon
  - d) brain stem

1.B.2.C.3.C.4.D

## 12.8 The Spinal Cord

The spinal cord is **the part of the central nervous system inside the vertebral canal below the foramen magnum**. It contains reflex centers in its butterfly or H-shaped **gray matter** core that help with motor functions such as walking and keeping our balance. All higher functions, including automatic behaviors necessary for survival, are regulated by areas of the brain (see above).

The spinal cord has two enlargements created by neurons and axons that serve the upper (**cervical enlargement**) and lower limbs (**lumbar enlargement**). Its lower end at the level of L<sub>1</sub> is called **conus medullaris**. The **filum terminale** is a fibrous extension of the conus medullaris that anchors the spinal cord to the coccyx. The spinal cord is also secured by the **denticulate ligaments**, which are extensions of the pia mater to the dura mater.

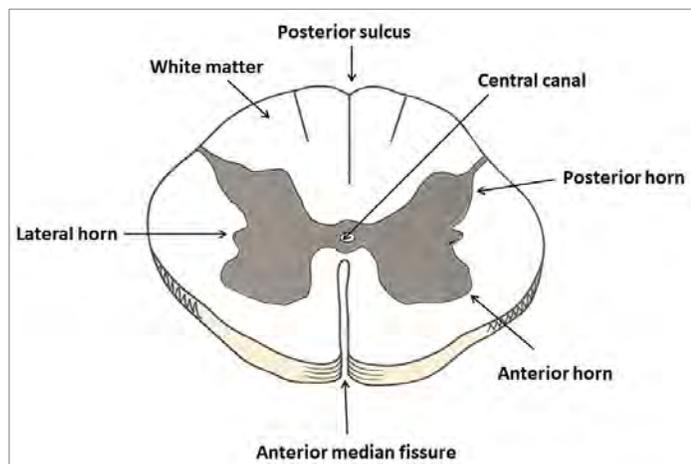
A cross-section of the spinal cord shows two lengthwise grooves called the **ventral** or **anterior median fissure** in the front and the **dorsal** or **posterior median sulcus** in the back. The **gray matter** has a central **gray commissure** that connects the bilateral areas of gray matter from the right and left sides of the spinal cord. The gray commissure encloses the **central canal** that contains cerebrospinal fluid.

The gray matter is subdivided into three horns:

1. The **anterior** or **ventral horns** contain **somatic motor neurons** that send axons to voluntary skeletal muscles.
2. The **posterior** or **dorsal horns** contain **interneurons** that receive visceral and somatic **sensory input**.
3. **Lateral horns** are found in the **thoracic and lumbar regions** only. They contain **motor neurons of the sympathetic nervous system**.

The spinal cord gives off **31 pairs of spinal nerves** (see **Chapter 13 Peripheral Nervous System & Reflexes**). The lower spinal nerves form the “horsetail” or **cauda equina**, which comes off the conus medullaris.

Figure 12.6 Spinal cord, cross-section



The **white matter** of the spinal cord consists of fibers that provide a two-way communication to and from the brain. **Ascending** or **sensory tracts** connect the spinal cord with higher areas (cerebellum, brain stem, and diencephalon). The pathways (dorsal column-medial lemniscal pathway, spinothalamic pathway) transmit somatosensory information to the sensory cortex via the thalamus. Spinocerebellar tracts terminate in the cerebellum; they convey information about muscle or tendon stretch.

**Descending** or **motor tracts** are composed of fibers that regulate our fast and fine (skilled) movements, balance and posture, and activate muscles controlling head, neck, and eye movements that follow objects. **Descending pathways** conduct **effluent impulses from the brain to the spinal cord** and from there via peripheral nerves to skeletal muscles. The **pyramidal** or **direct system** is composed of direct fibers that regulate fast and fine (skilled) movements. The **indirect** or **extrapyramidal system** includes the brain stem motor nuclei, and all motor pathways except pyramidal pathways. Its complex and multisynaptic pathways regulate axial muscles that maintain balance and posture, muscles controlling coarse movements, and head, neck, and eye movements that follow objects.

There are also **transverse tracts** containing commissural fibers that cross from one side of the spinal cord to the other.

**Pathways cross over to the other side** (decussate), and are paired symmetrically, i.e., there's one on each side of the spinal cord or brain.

### 12.9 Protection of the Brain and Spinal Cord

The **brain has four layers of protection**: the skull, meninges, cerebrospinal fluid, and blood brain barrier. The **spinal cord has three layers of protection only**, as the blood brain barrier is absent. In its place, the spinal cord has a fat cushion and a network of veins in the epidural space.

The **meninges** (sing. *meninx*) are membranes that cover and protect the brain and blood vessels, enclose venous sinuses, and form partitions in the skull. They are made of three distinct layers:

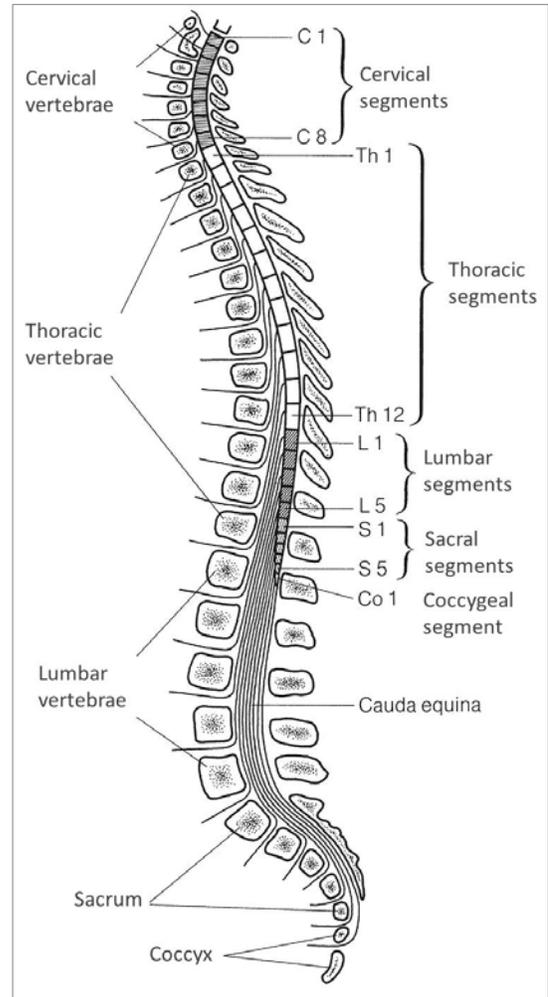
1. The outer **dura mater** (*dura* hard, tough, *mater* mother) is the strongest meninx. It has two layers, one that is attached to the bone (**periosteal layer**) and a deeper **meningeal layer** that **continues below the foramen magnum as the dura mater of the spinal cord**.

The dura forms three **septa that are designed to limit excessive movement of the brain**. The **falx cerebri** runs from the **crista galli** in front along the **longitudinal fissure** between the two cerebral hemispheres. The much smaller **falx cerebelli** runs along the vermis of the cerebellum and the **tentorium cerebelli** is a tent-like structure that separates cerebrum and cerebellum.

2. The middle layer has spider web-like extensions that lead to it being named **arachnoid mater** (*arachno*-spider). It is separated from the dura mater above by the **subdural space**. The space below the arachnoid mater is called the **subarachnoid space**. It **contains cerebrospinal fluid and blood vessels**. **Arachnoid villi** protrude into the superior sagittal sinus and permit cerebrospinal fluid reabsorption.
3. The innermost **pia mater** (*pia* soft, *mater* mother) is a delicate membrane that clings tightly to the surface of the brain.

The function of **cerebrospinal fluid (CSF)** is to allow the CNS to float in it, to protect it from mechanical stress and trauma, and to nourish the brain.

Figure 12.7 Vertebrae and spinal cord segments



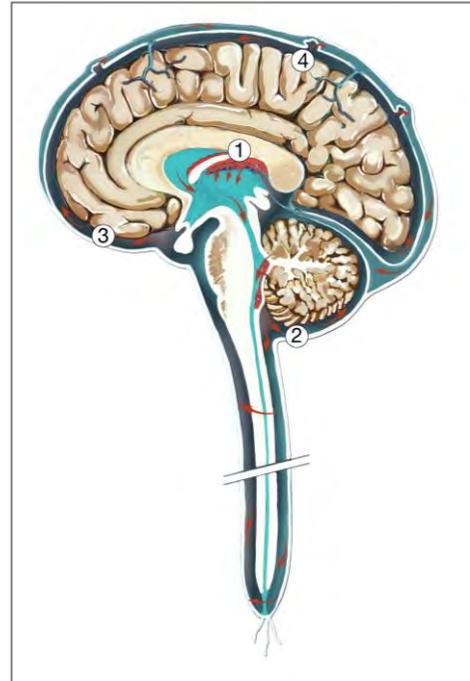
CSF is produced by **choroid plexuses [1]** that hang from the roof of each ventricle. **Ciliated ependymal cells** move the CSF from the inside of the brain through the ventricles and the central canal.

CSF leaves via the **lateral and median apertures [2]**, circulates through the **subarachnoid space [3]** until it is reabsorbed into the blood by **arachnoid villi [4]**. Because the CSF has to nourish the brain, it needs to be replenished continuously. If the production outpaces resorption via the arachnoid villi, the total volume of CSF (normally approx. 160 ml) will increase, leading to **hydrocephalus** (“water on the brain”).

Formation of the **blood-brain barrier** is an important function of the **astrocytes**. It is a **selective barrier** that helps maintain a stable environment for the brain but has to be absent in areas where the brain monitors the chemical composition of the blood. It allows any fat-soluble substances to pass, including alcohol, nicotine, and anesthetics.

The **spinal cord is protected by the vertebrae, meninges, and CSF**. There is also a **cushion of fat** and a **network of veins in the epidural space** between the vertebrae and spinal dura mater. The **denticulate ligaments** are extensions of the pia mater that secure the cord to the dura mater and protect it from moving around when the spine moves.

Figure 12.8 Circulation of cerebrospinal fluid



### 12.10 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

Structure/Meaning	Correct Answer	Answer options
1. brain	_____	spin(o)-
2. cerebrum	_____	myel(o)-
3. pain	_____	cerebell(o)-
4. myelin	_____	encephal(o)-
5. spine	_____	-algia
6. cerebellum	_____	cerebr(o)-

#### True/False

Write “T” on the line if the statement is true and “F” if the statement is false.

- The left cerebral hemisphere is usually dominant. \_\_\_\_\_
- The limbic system acts as our emotional brain. \_\_\_\_\_
- Commissural fibers form the corpus striatum. \_\_\_\_\_
- Sorting of sensory information and relaying it to the appropriate cerebral sensory area occurs in the thalamus. \_\_\_\_\_
- Declarative memory is hard to unlearn/forget. \_\_\_\_\_

6. The adult spinal cord ends between L<sub>1</sub> and L<sub>2</sub>. \_\_\_\_\_
7. The CNS is the integration and command center of the nervous system. \_\_\_\_\_
8. The two stages of memory are short-term memory and long-term memory. \_\_\_\_\_
9. REM sleep is important for learning and our mental health. \_\_\_\_\_
10. The primary motor cortex is found in the occipital lobe. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                         |  |           |
|-------------------------|--|-----------|
| 1. Frontal lobe         | a) primary sensory cortex                      | 1. _____  |
| 2. Occipital lobe       | b) axons form the major pyramidal tracts       | 2. _____  |
| 3. Parietal lobe        | c) dreaming occurs                             | 3. _____  |
| 4. Hypothalamus         | d) gateway to the cerebrum                     | 4. _____  |
| 5. Primary motor cortex | e) coordination of complex movements           | 5. _____  |
| 6. REM sleep            | f) seat of intelligence and abstract reasoning | 6. _____  |
| 7. Thalamus             | g) survival centers                            | 7. _____  |
| 8. Cerebrum             | h) visual area                                 | 8. _____  |
| 9. Brain stem           | i) executive suite                             | 9. _____  |
| 10. Cerebellum          | j) main visceral control center of the body    | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Which structure consists of the medulla oblongata, pons and midbrain?
  - Brain stem
  - Cerebrum
  - Cerebellum
  - Diencephalon
- Which of the following separates the two hemispheres of the cerebrum?
  - Central sulcus
  - Longitudinal fissure
  - Tentorium cerebelli
  - Tentorium cerebri
- Which of the following protects the brain by preventing passage of harmful substances and pathogens?
  - Dura mater
  - Arachnoid mater
  - Cerebrospinal fluid
  - Blood-brain barrier

4. Which of the following helps maintain consciousness?
  - a. Reticular activating system
  - b. Pons
  - c. Substantia nigra
  - d. Basal nuclei
  
5. Which structure is the major relay station for most sensory impulses that reach the primary somatosensory areas of the cerebral cortex from the brain stem and the spinal cord?
  - a. Thalamus
  - b. Hypothalamus
  - c. Epithalamus
  - d. Midbrain
  
6. Which of the following contains cerebrospinal fluid?
  - a. Epidural space
  - b. Subarachnoid space
  - c. Dural space
  - d. Pia mater
  
7. Which tracts of the spinal cord contain sensory information?
  - a. Ascending tracts
  - b. Descending tracts
  - c. Integration tracts
  - d. Columnar tracts
  
8. Fibers that connect gray matter between the two cerebral hemispheres are called \_\_\_\_\_.
  - a. association fibers
  - b. commissures
  - c. descending fibers
  - d. projection fibers
  
9. The cardiac reflex centers are found in the \_\_\_\_\_.
  - a. thalamus
  - b. midbrain
  - c. medulla oblongata
  - d. pons
  
10. The terminal end of the spinal cord is called the \_\_\_\_\_.
  - a. conus medullaris
  - b. filum terminale
  - c. cauda equina
  - d. lumbar enlargement

## Chapter 13 Peripheral Nervous System & Reflexes

### 13.1 Chapter Outline

The peripheral nervous system consists of all structures outside of the central nervous system, including sensory receptors and synapses with effectors. Its main parts are the cranial and spinal nerves that convey messages from receptors (sensors) to the central nervous system and signals from the central nervous system to its voluntary and involuntary effectors.

### 13.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Define the peripheral nervous system and name its major components.
- Describe the general structure of a nerve and name the different types.
- Describe regeneration of damaged nerves.
- Name the twelve cranial nerves and their main actions.
- Describe the roots of a spinal nerve and its rami.
- Name the four spinal plexuses and their major nerves with their actions.
- Define the autonomic nervous system and name its major parts.
- Compare the functions, pathways and neurotransmitters of autonomic and somatic nervous system.
- Name the different adrenergic and cholinergic fibers and receptors.
- Compare the sympathetic and parasympathetic nervous systems and their action on various organ systems.
- Describe the unique roles of the sympathetic system.
- Explain the difference between are inborn and acquired reflexes.
- Name the components of a reflex arc.
- Describe and compare stretch, Golgi tendon, flexor, and crossed-extensor reflexes.
- Define superficial reflexes.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 13.3 Combining Forms

Table 13.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 13.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
adren(o)-	adrenal gland	<i>adrenergic</i> = having the same effect as adrenaline
-algia	pain or painful condition	<i>neuralgia</i> = pain in an area innervated by a nerve
auto-	self	<i>autonomic</i> = involuntary, unconscious
crani(o)-	skull (cranium)	<i>cranial</i> = relating to the cranium or skull; towards the head
neur(i)-, neur(o)-	nerve or nervous system	<i>neuritis</i> = inflammation of a nerve or nerves
para-	near, adjacent, resembling, beyond, apart from, or abnormal	<i>paralyzed</i> = partly or wholly incapable of movement

parasympath(o)-, parasympathic(o)-	parasympathetic nervous system	<i>parasympathetic</i> = relating to or caused by the parasympathetic nervous system
-paresis	partial or incomplete paralysis	<i>paretic</i> = partly incapable of movement; affected by paresis
radicul(o)-	nerve root	<i>radiculitis</i> = inflammation of a nerve root
sympath(o)-, sympathetic(o)-	sympathetic nervous system	<i>sympathetic</i> = relating to or caused by the sympathetic nervous system
vag(o)-	vagus nerve	<i>vagotomy</i> = surgical removal of a part of the vagus nerve

### 13.4 Overview

The **peripheral nervous system (PNS)** consists of the all structures outside the central nervous system, including sensory receptors (see **Chapter 14 General & Special Senses**), motor endings (see **Chapter 9 Muscle Tissue**), nerves, and associated ganglia. It can be further divided into the **somatic nervous system** and the **autonomic nervous system**. The somatic nervous system is also called the **voluntary nervous system**, because it controls skeletal muscles that are under voluntary control.

In contrast, the autonomic nervous system controls organs such as the bladder, small intestine, and kidneys that are not under voluntary control. Hence, this system is often referred to as the **involuntary nervous system**.

The structures used to connect sensory receptors and motor endings with the central nervous system are called nerves. **Nerves** are cord-like bundles of **myelinated and unmyelinated axons [1]** enclosed by three connective tissue sheaths:

1. The **epineurium [2]** is the outermost tough fibrous sheath.
2. The **perineurium [3]** is a coarse sheath that bundles fibers into fascicles.
3. The **endoneurium [4]** is a loose connective tissue sheath that encloses single axons.

Based on where they leave the CNS, peripheral nerves are subdivided into **cranial** and **spinal nerves**. Furthermore, depending on the fibers they are made of, nerves can be subdivided into **afferent** or **sensory nerves** that carry signals from the periphery to the CNS and **efferent** or **motor nerves** that relay signals from the CNS to the effector. Yet, most nerves contain sensory as well as motor fibers, making them **mixed nerves**.

**Ganglia** are collections of neuron cell bodies outside the CNS. There are two main types of ganglia in the PNS: dorsal root ganglia and autonomic ganglia. **Dorsal root ganglia** contain bodies of pseudounipolar **sensory neurons** that connect receptors with the dorsal horn of the spinal cord (see also **Chapter 12 Central Nervous System**). **Autonomic ganglia** have motor neurons that send axons to effector organs.

#### Nerve Regeneration

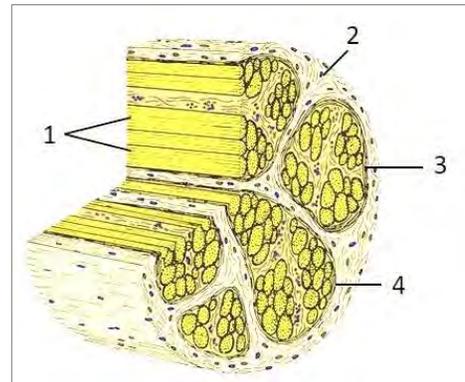
Peripheral nerves can recover from damage (regenerate) as long as the cell body hasn't been damaged. **Macrophages** clear the way by removing debris and **Schwann cells** form a regeneration tube and secrete growth factors that entice **axons** to grow back. Because everything needed has to be synthesized in the cell body and then transported along the axon, regeneration can take weeks to months to years.

In the central nervous system, however, oligodendrocytes bear growth-inhibiting proteins that prevent CNS fiber regeneration making damage to nerve cells and axons permanent.

### 13.5 Cranial nerves

There are **twelve pairs** of cranial nerves. Each nerve is identified by a Roman number (I through XII) and a name. **Most cranial nerves are mixed** in function, **only the first two pairs are purely sensory**. The **first two pairs**, the olfactory (I) and optic nerves (II), **arise from the diencephalon**, whereas the other **ten pairs arise from the brain stem**.

Figure 13.1 Nerve and tissue sheaths



The **olfactory nerve (I)** is a **purely sensory nerve for smell** (olfaction). It arises from the olfactory receptor cells of the nasal cavity. The fibers never form a solid nerve but pass as **olfactory filaments** through the cribriform plate of the ethmoid bone into the **olfactory bulb**.

The **optic nerve (II)** also is a **purely sensory nerve for sight** (vision). It arises from the retina and leaves the eyeball at the optic disk (or blind spot). The nerve leaves the orbit through the **optic canal**. The medial fibers cross over to the other side of the brain at the **optic chiasma**. The fibers run in the **optic tract** to the thalamus and from there in the **optic radiation** to the **visual cortex** in the occipital lobe.

The **oculomotor nerve (III)** is **primarily a motor nerve** with **somatic motor fibers** to four of the six extrinsic eye muscles and the levator palpebrae superioris. **Parasympathetic motor fibers** constrict the iris (sphincter pupillae) and control the shape of the lens (ciliary muscle) for lens accommodation. Its fibers come from the ventral midbrain and enter the orbit through the superior orbital fissure.

The **trochlear nerve (IV)** is **primarily a motor nerve** that enters the orbit through the superior orbital fissure on its way to the superior oblique muscle.

The **trigeminal nerve (V)** is the largest cranial nerve. Its fibers come from the pons, but they split in the **trigeminal ganglion** into three branches:

1. The **ophthalmic nerve (V<sub>1</sub>)** is a **purely sensory branch** that passes through the superior orbital fissure and the orbit to supply the cornea, the skin of the forehead, scalp, eyelids and nose, and the mucosa of the nasal cavity and the paranasal sinuses.
2. The **maxillary nerve (V<sub>2</sub>)** is a **purely sensory branch**, too. It passes through the foramen rotundum to innervate the skin of the face over the maxilla, upper lip, and maxillary teeth, and the mucosa of the nose, maxillary sinus, and palate.
3. The **mandibular nerve (V<sub>3</sub>)** is a **mixed branch** that passes through the foramen ovale to supply **sensory fibers** to the skin over the mandible and lower lip, the mandibular teeth, temporomandibular joint, and the mucosa of the mouth and anterior 2/3 of the tongue. It also has **motor fibers** to supply the muscles of mastication.

The **abducens nerve (VI)** is **primarily a motor nerve** to supply the lateral rectus muscle. Its fibers run from the inferior pons and enter the orbit via the superior orbital fissure.

The **facial nerve (VII)** is the second largest cranial nerve. Its fibers travel from the pons through the internal acoustic meatus and leave the skull through the stylomastoid foramen. It divides into **five major branches** on the lateral side of the face. It is **primarily a somatic motor nerve** and **innervates all facial muscles** except for the muscles of mastication. It carries **taste signals** from the anterior 2/3 of the tongue, the floor of the mouth and the palate. It also has **sensory fibers** for the skin over the external acoustic meatus and **parasympathetic fibers** for the salivary glands, the lacrimal gland, and the glands of the nose and palate.

The **vestibulocochlear nerve (VIII)** is **primarily a sensory nerve** that carries auditory signals from the cochlea (**cochlear nerve**) and vestibular signals from semicircular ducts, utricle, and saccule (**vestibular nerve**) through the internal acoustic meatus to the brain stem. It also carries some motor signals for adjustment of the sensitivity of receptors.

The **glossopharyngeal nerve (IX)** is a **mixed nerve** that leaves the skull via the jugular foramen and runs to the throat. Its **motor fibers** innervate part of the tongue and pharynx for swallowing and provide **parasympathetic fibers** to the parotid gland. Its sensory fibers conduct **taste and general sensory** impulses from the pharynx and the posterior 1/3 of the tongue and impulses from carotid chemoreceptors and baroreceptors.

The **vagus nerve (X)** is the only cranial nerve whose fibers extend below the neck. It carries 90% of all **parasympathetic fibers** through the jugular foramen down to the thoracic (heart, lung) and abdominal cavity (digestive organs). Its **sensory fibers** carry impulses from thoracic and abdominal viscera, baroreceptors, chemoreceptors, and taste buds of the posterior tongue and pharynx.

The **accessory nerve (XI)** is formed from fibers of spinal neurons, but it runs upward through the foramen magnum into the cranial cavity before leaving through the jugular foramen. Therefore, it is considered a cranial nerve. It is mainly a **somatic motor nerve** that innervates the sternocleidomastoid and trapezius muscles.

The **hypoglossal nerve (XII)** is also primarily a **somatic motor nerve** that innervates extrinsic and intrinsic muscles of the tongue that contribute to swallowing and speech.

**Table 13.2 Cranial Nerves**

Nerve	Number	Function
Olfactory	I	Smell
Optic	II	Sight
Oculomotor	III	Eye movement, pupil constriction, eyelid opening
Trochlear	IV	Eye movement
Trigeminal	V	Chewing muscles, facial sensation
Abducens	VI	Eye movement
Facial	VII	Facial movement (expression), taste in frontal two thirds of tongue, tear glands, salivation
Vestibulocochlear	VIII	Hearing, balance
Glossopharyngeal	IX	Taste in back one-third of tongue, swallowing, salivation
Vagus	X	Internal organs in thorax and abdomen (parasympathetic system); taste, swallowing, palate elevation, talking
Accessory	XI	Head turning, shoulder shrugging
Hypoglossal	XII	Tongue movements

### Check Your Understanding

- Which layer is found surrounding the entire spinal nerve?
  - Duraneurium
  - Endoneurium
  - Perineurium
  - Epineurium
- Which cranial nerve is responsible for facial expression?
  - Oculomotor nerve
  - Trigeminal nerve
  - Facial nerve
  - Trochlear nerve
- Which cranial nerve (CN) is important for hearing and balance?
  - CN VIII
  - CN V
  - CN IX
  - CN VII
- Which cells suppress axon regeneration in the CNS?
  - Microglia
  - Schwann cells
  - Astrocytes
  - Oligodendrocytes

1.D.2.C.3.A.4.D

### 13.6 Spinal Nerves

There are **31 pairs of spinal nerves**: **8 cervical** (C<sub>1</sub>–C<sub>8</sub>), **12 thoracic** (T<sub>1</sub>–T<sub>12</sub>), **5 lumbar** (L<sub>1</sub>–L<sub>5</sub>), **5 sacral** (S<sub>1</sub>–S<sub>5</sub>), and **1 coccygeal** (C<sub>0</sub>) **nerve**. All spinal nerves are **mixed nerves** containing sensory and motor fibers. Each spinal nerve connects to the spinal cord via **two roots** that are made of **rootlets** [1]:

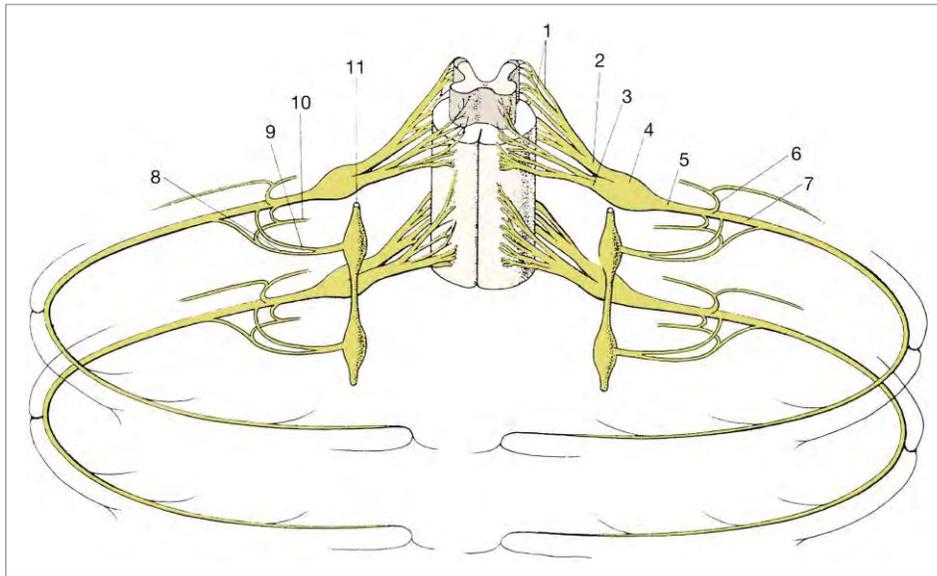
- The **dorsal root** [2] contains **sensory** (afferent) **fibers** from sensory neurons in the **dorsal root ganglion** [4].
- The **ventral root** [3] contains **motor** (efferent) **fibers** from ventral horn motor neurons that innervate skeletal (voluntary) muscles.

The two roots unite to form the **spinal nerve** [5], which leaves the vertebral canal through an **intervertebral foramen**. Immediately after the foramen, each nerve splits into **five rami** (branches):

- A short **dorsal ramus** [6] for the muscles and the skin of the posterior part of the body.
- A longer **ventral ramus** [7] to the muscles and the skin of the lateral and anterior parts of the body.
- A **meningeal ramus** [10] to the membranes (meninges) protecting the spinal cord.

- Two **rami communicantes** [8, 9] to and from autonomic ganglia [11].

Figure 13.2 Spinal nerve structure



The skin and muscles of the **back** are innervated by **dorsal rami** via several branches. The **ventral rami of the segments T<sub>2</sub>-T<sub>12</sub>** form **intercostal nerves** that supply the muscles of the ribs, anterolateral thorax, and abdominal wall.

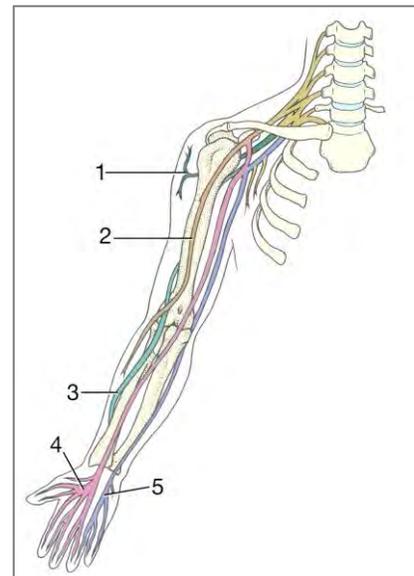
When we developed limbs during evolution, some muscles were moved to new locations, taking their spinal nerve fibers with them. Over time, the ventral rami from segments above T<sub>2</sub> and below T<sub>12</sub> formed networks called **plexuses**. There are four plexuses: the cervical, brachial, lumbar, and sacral plexus.

The **cervical plexus**, which is formed by the ventral rami of **C<sub>1</sub>-C<sub>4</sub>**, is the uppermost plexus. It innervates the skin and the muscles of the neck, ear, back of the head, and shoulder. The most important nerve coming from this plexus is the **phrenic nerve** (consists of fibers from C<sub>3</sub>-C<sub>5</sub>). It innervates the diaphragm, our most important breathing muscle.

The most complex of the plexuses, the **brachial plexus**, is formed by ventral rami from **C<sub>5</sub>-T<sub>1</sub>**. It is rather intricate with roots, trunks, divisions, and cords that give rise to nerves that innervate the skin and the muscles of the upper limb. Its major nerves are:

- **Axillary nerve [1]**: Innervates the deltoid, and teres minor muscles, and the skin and joint capsule of the shoulder.
- **Musculocutaneous nerve [2]**: Innervates the biceps brachii and brachialis muscles, and the skin of the lateral forearm.
- **Radial nerve [3]**: Innervates essentially all extensor muscles and the supinators, and the posterior skin of the limb.
- **Median nerve [4]**: Innervates the skin, most flexors and pronators in the forearm, and some intrinsic muscles of the hand.
- **Ulnar nerve [5]**: Innervates the flexor carpi ulnaris, part of the flexor digitorum profundus, most intrinsic muscles of the hand, and the skin of the medial aspect of the hand.

Figure 13.3 Major branches of the brachial plexus



The **lumbar plexus**, the superior of the two lower plexuses, arises from **L<sub>1</sub>-L<sub>4</sub>**. It supplies the skin and muscles of the thigh and abdominal wall. Its two major branches are:

- **Femoral nerve**: Innervates the quadriceps muscle and the skin of the anterior thigh and medial surface of the leg.
- **Obturator nerve**: Passes through the obturator foramen to innervate the adductor muscles.

The lowest plexus is called the **sacral plexus**; it serves the buttocks, lower limb, pelvic structures, and perineum. Its fibers come from the roots of **L<sub>4</sub>–S<sub>4</sub>**. The two major branches are the **tibial** and **common fibular nerves**. They join to form the **sciatic nerve**, which is the longest and thickest nerve of the body. The sciatic nerve innervates the hamstring muscles, the adductor magnus, and most muscles in the lower leg and foot.

**Table 13.3 Spinal Nerve Plexuses and Main Nerves**

<b>Cervical plexus [C<sub>1</sub>–C<sub>4</sub>]</b>	
Lesser occipital, greater auricular, transverse cervical, supraclavicular nerves	Skin of neck, ear, shoulder and clavicular region
Ansa cervicalis	Infrahyoid muscles
<b>Phrenic nerve</b>	Diaphragm
<b>Brachial plexus [C<sub>5</sub>–T<sub>1</sub>; (C<sub>4</sub>)–(T<sub>2</sub>)]</b>	
<b>Musculocutaneous nerve</b>	Flexor muscles of arm (biceps brachii, brachialis, coracobrachialis) Skin of lateral forearm
<b>Median nerve</b>	Flexors of anterior forearm (flexor carpi radialis, flexor digitorum superficialis, flexor pollicis longus, palmaris longus lateral part of flexor digitorum profundus, pronator teres and quadratus); intrinsic muscles of lateral palm and digital branches to fingers Skin of lateral 2/3 of hand, palm side and dorsum of fingers 2-3
<b>Ulnar nerve</b>	Flexor muscles in anterior forearm (flexor carpi ulnaris, medial part of flexor digitorum profundus); most intrinsic hand muscles Skin of anterior and posterior medial third of hand
<b>Radial nerve</b>	Posterior muscles of arm and forearm (brachioradialis, triceps brachii, anconeus, supinator, all extensor muscles and abductor pollicis longus) Skin of posterolateral surface of entire upper limb except dorsum of fingers 2-3
<b>Axillary nerve</b>	Deltoid and teres minor Skin of shoulder region over deltoid
Dorsal scapular nerve	Rhomboid major and minor, levator scapulae
Long thoracic nerve	Serratus anterior
Suprascapular nerve	Supraspinatus and infraspinatus
Medial and lateral pectoral nerves	Pectoralis major and minor
<b>Lumbar plexus [L<sub>1</sub>–L<sub>4</sub>]</b>	
<b>Femoral nerve</b>	Anterior muscles of thigh (quadriceps, sartorius), pectineus and iliacus Skin of anterior and medial thigh, medial leg and foot, hip and knee joint
<b>Obturator nerve</b>	Adductor magnus, longus and brevis, gracilis and obturator externus Skin of medial thigh, hip and knee joint
Lateral femoral cutaneous nerve	Skin of lateral thigh
Iliohypogastric nerve	Internal oblique and transversus abdominis Skin of lower abdomen and hip
Ilioinguinal nerve	Inferior abdominal muscles Skin of external genitalia and upper medial aspect of thigh
Genitofemoral	Cremaster Skin of scrotum in males, labia majora in females and anterior thigh below middle portion of inguinal region
<b>Sacral plexus [L<sub>4</sub>–S<sub>4</sub>]</b>	
<b>Sciatic nerve</b>	

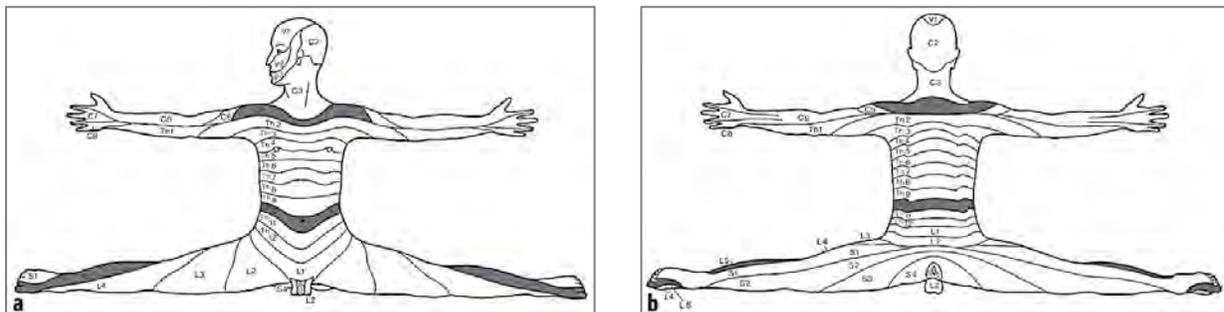
<b>Tibial nerve</b>	Hamstrings, adductor magnus (posterior part), triceps surae, tibialis posterior, popliteus, flexor digitorum longus, flexor hallucis longus and intrinsic foot muscle Skin of posterior surface of leg and sole of foot
<b>Common fibular nerve</b>	Short head of biceps femoris, fibularis longus, brevis and tertius, tibialis anterior, extensor digitorum longus and extensor hallucis longus Skin of anterior and lateral surface of leg and dorsum of foot
Superior gluteal nerve	Gluteus medius and minimus and tensor fasciae latae
Inferior gluteal nerve	Gluteus maximus
Posterior femoral cutaneous nerve	Skin of buttock, posterior thigh and popliteal region
Pudendal nerve	Skin and muscles of perineum and external anal sphincter

### Dermatome

A dermatome is the **area of skin innervated by the cutaneous branches of a single spinal nerve**. Dermatomes are important for the diagnosis of nerve root damage. All spinal nerves, except for C<sub>1</sub>, participate in dermatomes. Most dermatomes overlap, therefore, destruction of a single spinal nerve will not cause complete numbness.

**Hilton's law** states that any nerve serving a muscle that produces movement at a joint also innervates the joint and the skin over the joint.

Figure 13.4 Dermatomes, anterior [a] and posterior view [b]



### Check Your Understanding

- The ventral root of a spinal nerve contains axons of \_\_\_\_\_.
  - motor neurons
  - sensory neurons
  - association neurons
  - interneurons
- The area of skin innervated by a single spinal nerve is called a(n) \_\_\_\_\_.
  - Hilton zone
  - segment
  - integument
  - dermatome
- The muscles of the posterior arm and forearm are innervated by the \_\_\_\_\_.
  - median nerve
  - ulnar nerve
  - radial nerve
  - musculocutaneous nerve
- Inability to extend the knee could point to damage to the \_\_\_\_ plexus.
  - cervical
  - brachial
  - lumbar
  - sacral

1.A.2.D.3.C.4.C

### 13.7 Autonomic Nervous System

The autonomic nervous system (**ANS**) is the oldest part of the nervous system. The ANS consists of motor neurons that innervate smooth muscle, cardiac muscle, and glands. As this system is not under conscious control, it is also called **involuntary nervous system**. The ANS has **two divisions**: the parasympathetic division and the sympathetic division.

1. The **parasympathetic division/system** promotes maintenance activities and conserves body energy, which is why it is also called the **rest-and-relaxation division**. Its third name, **craniosacral division**, derives from the fact that its preganglionic neurons are located in the brain and the sacral spinal cord. The parasympathetic system lowers blood pressure, heart rate, and respiratory rate but increases the activity of the gastrointestinal tract. The **vagus nerve** (CN X) carries 90% of all parasympathetic fibers to organs in the abdominal cavity. Other cranial nerves carrying parasympathetic fibers are the **oculomotor** (CN III), **facial** (CN VII), and **glossopharyngeal nerve** (CN IX).

**At rest, the body is under a parasympathetic tone.** The parasympathetic system normally dominates the heart and smooth muscle of digestive and urinary tract organs. However, the sympathetic division can override these effects during times of stress.

2. The **sympathetic division/system** mobilizes the body during work, exercise, or stress. Therefore, it is also called the **fight-or-flight division**. It increases heart and respiratory rates but inhibits digestion and elimination.

The **sympathetic system controls our blood pressure, even at rest.** The vasomotor tone of the sympathetic system keeps the blood vessels in a continual state of partial constriction. Sympathetic fibers fire more rapidly to constrict blood vessels and cause blood pressure to rise vice a versa the nerves can fire less rapidly to prompt blood vessels to dilate which decreases our blood pressure.

Because of its role as the fight-or-flight system, the sympathetic system is in **exclusive and complete control of certain functions that are needed for immediate survival:**

- The adrenal medulla, sweat glands, arrector pili muscles, kidneys, and most blood vessels receive only sympathetic fibers.
- It controls thermoregulatory responses to heat and release of renin from the kidneys (increases blood pressure).
- It increases the metabolic rates of cells, raises blood glucose levels, and mobilizes fat for use as fuel.

**Most internal organs are served by both divisions; however, the two divisions cause opposite effects.** This dynamic interaction allows for precise control of visceral activity.

Occasionally, both systems work together, such as in the control of the external genitalia. The parasympathetic system causes vasodilation, which leads to erection of the penis or clitoris, whereas the sympathetic system causes ejaculation of semen in males and reflex contraction of a female's vagina.

**Table 13.4 Effects of the Sympathetic and Parasympathetic Systems on Different Organs**

Organ	Sympathetic System	Parasympathetic System
Iris	Pupil dilation	Pupil constriction
Salivary glands	Saliva production reduced	Saliva production increased
Oral and nasal mucosa	Mucus production reduced	Mucus production increased
Heart	Heart rate increased	Heart rate decreased
Lungs	Airway relaxation	Airway constriction
Stomach	Decreased motility	Increased motility; gastric juices secreted
Small & large intestine	Decreased motility	Increased motility
Liver	Breakdown of glycogen stores and release of glucose into the blood	Glycogen synthesis
Kidney	Decreased urine secretion	Increased urine secretion
Bladder	Bladder wall relaxed; sphincter closed	Bladder wall contracted; sphincter open

### Pathways of the ANS

The **efferent ANS pathways consist of two neurons:**

1. **Preganglionic neurons** inside the CNS have lightly myelinated axons. These axons are called preganglionic because they convey signals to the ganglion.

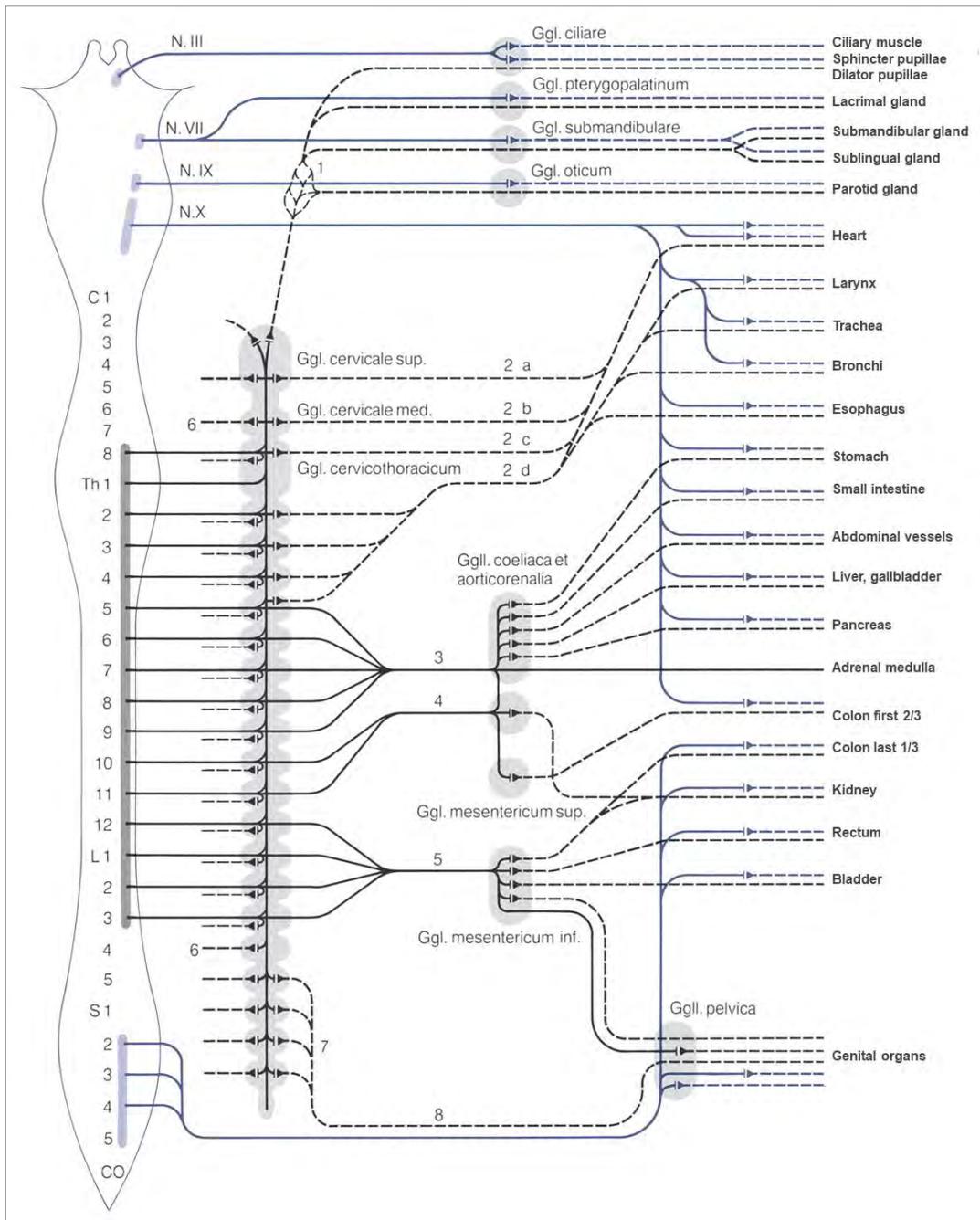
2. **Ganglionic neurons** inside the autonomic ganglia have unmyelinated axons extending to the effector. These axons are called postganglionic because they convey signals away from the ganglion.

The **preganglionic neurons of the sympathetic system form the lateral horn of the spinal cord** that stretches from T<sub>2</sub>-L<sub>2</sub>. Because of that, the sympathetic system is also called the **thoracolumbar division**.

Preganglionic fibers from the lateral horn neurons run in **white rami communicantes** to **23 paravertebral ganglia** that are connected and form the **sympathetic trunk (or chain)**. The fibers can synapse with a ganglionic neuron in this ganglion, ascend or descend inside the trunk to synapse in another ganglion, or travel in **splanchnic nerves** down into the abdomen or pelvis.

**Postganglionic fibers** from paravertebral ganglia enter the ventral rami of spinal nerves via **gray rami communicantes**. These fibers innervate sweat glands, vascular smooth muscle, and the arrector pili muscle that cause goose bumps.

Figure 13.5 Parasympathetic (blue) and sympathetic (gray) innervation of organs



Fibers that run in **splanchnic nerves** synapse in ganglia inside the abdominopelvic cavity, such as the **celiac, superior** and **inferior mesenteric**, and **hypogastric ganglion**.

Some preganglionic fibers pass directly to the **adrenal medulla** without synapsing along the way. Their stimulation leads to a release of **epinephrine** (or **adrenaline**) and **norepinephrine** from medullary cells into the blood.

The **parasympathetic system** does not have ganglia close to the spinal cord, but they usually are found in the walls of the target organs. Therefore, the parasympathetic system has **long preganglionic fibers and short postganglionic fibers**, while the preganglionic sympathetic fibers are short and the postganglionic sympathetic fibers are long.

**Reflexes of the ANS are called visceral reflexes.** Their reflex arcs have the same components as somatic reflexes (see below), but there is one main difference: The visceral reflex arc has two motor neurons whereas the somatic reflex arc has one only.

**Visceral pain signals** travel along the same pathways as somatic pain signals. Because the pathways travel together, pain stimuli from viscera can be perceived as pain in a somatic area. This phenomenon is called **referred pain**. For example, pain associated with a heart attack can radiate all the way down the left arm to the pinky.

### Neurotransmitters and Receptors

The ANS uses two neurotransmitters: **acetylcholine (ACh)** and **norepinephrine (NE)**. **Epinephrine** (adrenaline) is only released from the adrenal medulla into the blood and, therefore, is considered a hormone and not a neurotransmitter.

All **preganglionic fibers** and all **postganglionic parasympathetic fibers** release **acetylcholine**, whereas **postganglionic sympathetic fibers** can release **acetylcholine** or **norepinephrine**.

The **effect** of either neurotransmitter **can be stimulatory or inhibitory**, depending on the type of receptor they interact with.

ANS fibers that release ACh are called **cholinergic fibers**, whereas fibers that release NE are called **adrenergic fibers**. All preganglionic axons and all parasympathetic postganglionic axons are cholinergic fibers. Most sympathetic postganglionic axons are adrenergic fibers, i.e., they release NE; exceptions are sympathetic postganglionic fibers that secrete ACh at sweat glands and some blood vessels in skeletal muscles.

The same terminology applies to the receptors the neurotransmitters interact with. **Cholinergic receptors** bind ACh. Depending on their ability to bind certain drugs, they are subdivided into:

- **Nicotinic receptors** that are found on motor-end plates of skeletal muscles, all ganglionic neurons, and cells of the adrenal medulla. **Activation always leads to stimulation.**
- **Muscarinic receptors** that are found on all effector cells stimulated by postganglionic cholinergic fibers. ACh can have an inhibitory or excitatory effect depending in the receptor type of the target.

**Adrenergic receptors** also come in two types called **alpha ( $\alpha$ )** and **beta ( $\beta$ ) receptors**. Both types have subtypes, two for  $\alpha$  receptors and three for  $\beta$  receptors. **The effect of NE depends on which subtype of receptor predominates on the target organ.** For example,  $\beta_1$  receptors are predominantly found on the heart,  $\beta_2$  receptors in the lungs and the walls of blood vessels serving heart, liver and skeletal muscle, and  $\alpha_1$  receptors in the walls of blood vessels of all other organs and tissues.

**The effects of the parasympathetic system are short-lived** and restricted to a certain area, whereas the **effects of the sympathetic system are long-lasting** and body wide. This is mainly due to the fact that acetylcholine is inactivated faster than norepinephrine at synapses. The second reason is that norepinephrine and epinephrine are released into the blood in the adrenal medulla and remain there until metabolized by the liver.

**Table 13.5 Adrenergic Receptors**

Receptor	Major locations outside the CNS	Effect
$\alpha_1$	Blood vessels of skin, mucosae, abdominal organs, kidneys, and salivary glands; all other sympathetic target organs, e.g., eyes, but not the heart.	Constricts blood vessels and the sphincters of internal organs. Dilates the pupils of the eyes. <b>Sympathomimetic drugs</b> that bind to $\alpha_1$ receptors are used as nasal decongestants
$\alpha_2$	Pancreas; blood platelets; membranes of adrenergic axon terminal	Inhibits insulin secretion by pancreas (increases or keeps blood glucose level high); promote blood clotting; inhibits NE release from adrenergic terminals

$\beta_1$	Predominantly heart, but also kidneys and adipose tissue	Increases heart rate and contractility (strength) of cardiac muscle; stimulates renin release in the kidneys (increases blood pressure) <b>Cardioselective <math>\beta_1</math> blockers</b> are used to protect the heart by decreasing heart rate and contractility
$\beta_2$	Lungs and most other sympathetic target organs; blood vessels serving the heart, liver, and skeletal muscles	Dilates blood vessels and bronchi in lungs; relaxes smooth muscle cells in walls of digestive and urinary organs and uterus <b>Sympathomimetic drugs</b> that bind to $\beta_2$ receptors are used for treatment of asthma
$\beta_3$	Adipose tissue	Stimulates fat breakdown (lipolysis)

### Control of ANS Function

The **hypothalamus is the main control and integration center for ANS activity** and also coordinates and synchronizes its interaction with the endocrine system. Centers of the hypothalamus, for example, control our heart rate and blood pressure (see **Chapter 16 Cardiac Anatomy & Physiology**), our body temperature, water balance, and endocrine activity (see **Chapter 15 Endocrine System**), our emotional states (rage, pleasure) and biological drives (hunger, thirst, sex) as well as our reactions to fear and the “fight-or-flight” system.

**Higher CNS areas can influence the hypothalamus** through subconscious cerebral input via the limbic lobe, which explains an increased heart rate and blood pressure while anxious. Biofeedback, meditation, and relaxation techniques can also influence some functions of the ANS by helping us to calm down.

### Check Your Understanding

- Acetylcholine is released by \_\_\_ postganglionic neurons and is removed \_\_\_ than norepinephrine.
  - sympathetic, slower
  - sympathetic, faster
  - parasympathetic, slower
  - parasympathetic, faster
- The output of the ANS does **not** control \_\_\_\_.
  - exocrine glands
  - skeletal muscle
  - cardiac muscle
  - smooth muscle
- The sympathetic nervous system is more active when we \_\_\_\_.
  - sleep
  - exercise
  - watch TV
  - read
- Which of the following is a type of adrenergic receptor?
  - Nicotinic
  - Muscarinic
  - Alpha
  - Gamma

1.D 2.B 3.B 4.C

### 13.8 Reflexes

Both the somatic and the autonomic division of the peripheral nervous system have reflexes. There are **two basic types of reflexes**:

- Inborn or intrinsic reflexes** are involuntary motor responses to a stimulus. Inborn reflexes can be suppressed or modified. For example, to insert contact lenses we have to suppress the blink reflex that wants to close the eye.
- Learned or acquired reflexes** result from practice or repetition. For example, driving a car or a riding bike involves learned reflexes.

A **reflex arc** (neural path) has five parts:

- A **sensor or receptor** at the site of the stimulus impact.
- A **sensory neuron** that conducts the afferent impulse to the dorsal horn of the spinal cord or the brain stem.
- An **integration center** inside the CNS, which can be monosynaptic or polysynaptic.
- A **motor neuron** the sends signals to an effector organ.

5. An **effector**, a muscle or gland, that responds to the efferent impulse.

### Spinal Somatic Reflexes

The integration center for these reflexes is in the spinal cord and the effectors are in the skeletal muscles. Testing of somatic reflexes is important clinically to assess the condition of the nervous system.

The two **major receptors** are the muscle spindles and the Golgi tendon organs. **Muscle spindles** inform the CNS of the length of a specific muscle, whereas **Golgi tendon organs** inform the brain of the amount of tension in the muscle and its tendon(s).

If a muscle gets stretched suddenly, the muscle spindle gets activated, which leads to a muscle contraction. This reflex is called a **stretch reflex**. It is a type of reflex **mainly used to maintain muscle tone in large postural muscles**. **All stretch reflexes are monosynaptic** (i.e., involve one synapse only) **and ipsilateral** (i.e., sensor and effector are on the same side of the body).

In order to protect muscles that are antagonistic to the effector, they need to be inhibited from contracting by **reciprocal inhibition**. For example, in the **patellar reflex**, the quadriceps as the stretched muscle will contract, while its antagonist (the hamstrings) has to relax.

**Golgi tendon reflexes** are polysynaptic, i.e., they involve more than one synapse. They help prevent damage due to excessive force generation by producing muscle relaxation (lengthening) in response to tension. The tendon organs are activated by contraction or passive stretch of a muscle. The reflex arc leads to a relaxation of the contracted/stretched muscle and a contraction of its antagonist(s). This effect is called **reciprocal activation**.

The **muscle stretch reflex** protects the muscle from being overstretched by initiating contraction, while the **Golgi tendon reflex** protects the muscle from too much tension by leading to relaxation.

An important reflex that helps us to escape danger is the **flexor or withdrawal reflex**. It causes automatic withdrawal of a threatened body part if there is a painful stimulus. If we touch a hot plate, for instance, contraction of the major flexors on the forearm (brachialis, biceps brachii) will move our hand away from the plate.

If a flexor reflex involves a weight-bearing limb, such as the leg, the second limb has to be able to carry our weight when the first limb is being flexed. The stability of our position is thus maintained by the so-called **crossed extensor reflex**. It consists of a flexor reflex on the stimulated side and an extensor reflex on the contralateral side.

- If, for example, you are about to step on a nail with your right foot the flexor reflex will bend your right knee and the right hip to get your foot away from the nail. At the same time, the extensor reflex will cause a contraction of the quadriceps of your left leg to make sure you can stand safely on one leg.

**Superficial reflexes** are elicited by gentle cutaneous stimulation.

- A fairly often used superficial reflex is the so-called **plantar reflex**, which tests the correct function of the corticospinal tracts. The stimulus is a gentle stroking of lateral aspect of the sole of the foot. This leads to a downward flexion of the toes.
- In infants and patients with corticospinal or motor cortex damage, the same stimulus leads to dorsiflexion of hallux and fanning of toes. This reaction is called **Babinski sign** or **reflex**.
- **Abdominal reflexes** cause contraction of abdominal muscles and movement of the umbilicus in response to stroking of the skin. They vary in intensity from one person to another and are absent when corticospinal tract lesions are present.

### 13.9 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	nerve root	_____	neur(o)-
2.	nerve	_____	sympathic(o)-

- |    |                            |       |             |
|----|----------------------------|-------|-------------|
| 3. | sympathetic nervous system | _____ | para-       |
| 4. | cranium                    | _____ | radicul(o)- |
| 5. | abnormal                   | _____ | crani(o)-   |

**True/False**

Write "T" on the line if the statement is true and "F" if the statement is false.

1. Irritation of the phrenic nerve may cause diaphragm spasms called hiccups. \_\_\_\_\_
2. There are 41 pairs of spinal nerves. \_\_\_\_\_
3. Cranial nerve XI is the accessory nerve that controls tongue movement. \_\_\_\_\_
4. The musculocutaneous nerve is a major nerve of the brachial plexus. \_\_\_\_\_
5. The only cranial nerves to extend beyond the head and neck region are the vagus nerves. \_\_\_\_\_
6. The obturator nerve branches from the sacral plexus. \_\_\_\_\_
7. The second cranial nerve forms a chiasma at the base of the brain for partial crossover of neural fibers. \_\_\_\_\_
8. Dorsal and ventral rami are similar in that they both contain sensory and motor fibers. \_\_\_\_\_
9. A drooping eyelid could be caused by damage to the oculomotor nerve. \_\_\_\_\_
10. The dorsal root consists only of motor fibers bringing information to the spinal cord. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                            |   |           |
|----------------------------|---|-----------|
| 1. Oculomotor nerve        | a) obturator and femoral nerves branch from this plexus     | 1. _____  |
| 2. Abducens nerve          | b) serves the senses of hearing and equilibrium             | 2. _____  |
| 3. Vagus nerve             | c) damage causes wrist drop                                 | 3. _____  |
| 4. Lumbar plexus           | d) has cranial and spinal roots                             | 4. _____  |
| 5. Cervical plexus         | e) controls lens shape and pupil size                       | 5. _____  |
| 6. Vestibulocochlear nerve | f) loves deodorant  | 6. _____  |
| 7. Radial nerve            | g) phrenic nerve branches from this plexus                  | 7. _____  |
| 8. Accessory nerve         | h) moves eyes laterally                                     | 8. _____  |
| 9. Sciatic nerve           | i) promotes digestive activity and regulates heart activity | 9. _____  |
| 10. Olfactory nerve        | j) biggest nerve of the body                                | 10. _____ |

## Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

1. Which nerves supply eye muscle and, thus, move the eyeball?
  - a. Cranial nerve II, III and IV
  - b. Cranial nerve I, V and X
  - c. Cranial nerve III, IX and V
  - d. Cranial nerve III, IV and VI
2. Which cranial nerve is responsible for regulating visceral activity?
  - a. Oculomotor nerve
  - b. Trigeminal nerve
  - c. Vagus nerve
  - d. Facial nerve
3. A man presents with median nerve damage in his left hand. What is the most likely site of the injury?
  - a. Brachial plexus
  - b. Intercostal nerves
  - c. Lumbar plexus
  - d. Cervical plexus
4. Our “*funny bone*” is actually the \_\_\_ nerve.
  - a. brachial
  - b. median
  - c. radial
  - d. ulnar
5. The patellar “*knee jerk*” reflex is an example of a(n) \_\_\_\_\_.
  - a. stretch reflex
  - b. crossed-extensor reflex
  - c. stress reflex
  - d. extensor thrust reflex
6. Which of the following nerves does **not** arise from the brachial plexus?
  - a. Radial
  - b. Ulnar
  - c. Phrenic
  - d. Median
7. Which of the following is an effect of the parasympathetic nervous system?
  - a. increase in heart rate
  - b. increase in digestion
  - c. increase in respiration
  - d. increase in blood pressure
8. Body temperature regulation is under the control of the \_\_\_\_\_.
  - a. sympathetic nervous system
  - b. parasympathetic nervous system
  - c. voluntary nervous system
  - d. limbic system
9. The main integration center for the ANS is the \_\_\_\_\_.
  - a. medulla
  - b. midbrain
  - c. hypothalamus
  - d. thalamus

10. Increased activity of the sympathetic nervous system will cause pupil diameter to \_\_\_\_.
- a. increase
  - b. decrease
  - c. stay the same
  - d. change depending on ambient light



## Chapter 14 General & Special Senses

### 14.1 Chapter Outline

The general and special senses play an important role in collecting information about the world outside and the internal environment inside our body. Our central nervous system combines the information from many senses to come to the best possible assessment of the situation. Without this information, our brain would struggle to respond to environmental changes.

### 14.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Define sensation and perception.
- Describe sensory integration.
- Define sensory receptor and list different classifications.
- Name and describe the structure and function of accessory eye structures.
- Describe the structure of the eyeball with its major parts.
- Name the layers of the eyeball and their function.
- Name the internal chambers and fluids.
- Describe the structure of the lens.
- Explain refraction.
- Discuss the pathway of light through the eye and how it is focused for distant and near vision.
- Describe the different photoreceptors and how they work.
- Compare light and dark adaptation.
- Name the chemical senses.
- Describe the anatomy and physiology of olfaction (smell).
- Explain the anatomy and physiology of gustation (taste).
- Describe the structure and basic function of outer, middle, and inner ear.
- Outline the physiology of hearing.
- Describe the physiology of balance and equilibrium.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 14.3 Combining Forms

Table 14.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 14.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
acoust(o)-	hearing; sound	<i>acoustic</i> = relating to sound or the sense of hearing
aud-, audi(o)-, audit(o)-, aur(i)-, aur(o)-	hearing; ear	<i>auditory</i> = relating to the sense of hearing
blephar(o)-	eyelid	<i>blepharoptosis</i> = drooping of the eyelid
cochle(o)-	spiral; snail	<i>cochlear</i> = relating to the cochlea
conjunctiv(o)-	conjunctiva	<i>conjunctivitis</i> = inflammation of the conjunctiva; pink eye

corne(o)-	cornea	<i>corneal</i> = relating to the cornea
dacry(o)-	tears	<i>dacryorrhea</i> = excessive flow of tears
gusto(o)-	taste	<i>gustatory</i> = relating to the sense of taste
ir(i)-, ir(o)-, irid(o)-, irit(o)-	iris	<i>iritis</i> = inflammation of the iris
kerat(o)-	cornea	<i>keratitis</i> = inflammation of the cornea
lacrim(o)-	tears; tear duct	<i>lacrimal</i> = relating to tears or the secretion of tears
ocul(o)-, ophthalm(o)-, -opia	eye	<i>ophthalmologist</i> = specialist for the study and treatment of disorders of the eye
olfact(o)-	smell	<i>olfactory</i> = relating to the sense of smell
opt(i)-, optic(o)-, opt(o)-	vision; eye	<i>optician</i> = person qualified to make and supply eyeglasses and contact lenses for correction of vision
ot(o)-	ear; hearing	<i>otoliths</i> = tiny crystals inside the ear
phac(o)-, phak(o)-	lens	<i>phacoemulsification</i> = use of ultrasound to break up the lens in order to make it easier to remove
retin(o)-	retina	<i>retinopexy</i> = treatment to reattach the retina
scler(o)-	sclera	<i>scleritis</i> = inflammation of the sclera
tympan(o)-	tympanic cavity or membrane	<i>tympanoplasty</i> = reconstruction of the tympanic membrane
vestibul(o)-	vestibule	<i>vestibular</i> = relating to the vestibule

#### 14.4 General Senses

Survival depends upon **sensation**, i.e., the awareness of changes in the internal and external environment, and **perception**, i.e., the conscious interpretation of those stimuli.

Integration of sensory signals happens on three levels starting at the **receptor level**, i.e., the **sensor receptors**. These sensory receptors have **specificity** for stimulus energy, but the stimulus must be applied in a **receptive field** for the stimulus energy to be converted into a graded potential called a **receptor potential**.

**Adaptation** is a change in the sensitivity of the receptor in the presence of a constant stimulus. **Phasic** or **fast-adapting receptors** signal the beginning or end of a stimulus, e.g., receptors for pressure, touch, and smell. **Tonic receptors** adapt slowly or not at all, e.g., nociceptors (pain receptors).

Integration at the **circuit level** of the ascending pathways starts with the **first-order neuron** that conducts impulses from the receptor to the **second-order neurons** in the CNS. These neurons in turn transmit the signal to the thalamus or the cerebellum. **Third-order neurons** in the thalamus then conduct the impulses up to the **somatosensory cortex**.

Finally, the **neuronal circuits in the cerebral** perform integration at the **perceptual level**. Aspects of sensory perception are:

- **Perceptual detection:** The ability to detect a stimulus (requires summation of impulses).
- **Magnitude estimation:** The intensity is coded in the frequency of impulses.
- **Spatial discrimination:** Identification of the site of the stimulus.
- **Feature abstraction:** Identification of more complex aspects and several stimulus properties.
- **Quality discrimination:** The ability to identify submodalities of a sensation, such as sweet or sour taste.
- **Pattern recognition:** The recognition of familiar or significant patterns in stimuli, e.g., the sounds of footsteps coming closer.

**Sensory receptors** (also called **receptors** or **sensors**) are specialized cells or groups of cells that respond to changes in their environment (stimuli). **Activation of sensors results** in formation of graded potentials that trigger **nerve impulses** (action potentials). These electric signals travel in nerve fibers to the central nervous system, where

the transmitted information is analyzed.

Most sensory fibers carrying information to the central nervous system terminate in the diencephalon, the brain stem, or the cerebellum. Because of this, we are not consciously aware of the information they carry. However, our body uses the information to make necessary adjustments, such as increasing our blood pressure to prevent fainting when we get up from a sitting or lying position.

**Only signals that terminate in sensory areas of the parietal lobe of the cerebrum give us conscious awareness of a sensation.** We learned in Chapter 12 Central Nervous System that some sensory areas receive and process signals from the special senses, while other areas process signals from our skin, muscles, and joints (**somatosensation**) and signals from our internal organs such as the stomach and the bladder (**visceral sensation**).

**Association areas** integrate this diverse information. They allow us to give meaning to information received, store it as memory, compare it to previous experience, and decide on which action to take.

**Sensation**, i.e., the awareness of a stimulus, **and perception**, i.e., the interpretation of the meaning of the stimulus, **occur in the brain only.**

Receptors can be **classified based on the stimulus they respond to:**

- Receptors that respond to touch, pressure, vibration, stretch, and itch (**mechanoreceptors**).
- Receptors that are sensitive to changes in temperature can respond to warm or cold stimuli (**thermoreceptors**).
- Receptors in the retina of the eye that respond to light energy (**photoreceptors**).
- Receptors that respond to chemicals, such as receptors for smell and taste (**chemoreceptors**).
- Receptors that respond to pain-causing stimuli, such as extreme heat or cold, excessive pressure, or inflammatory chemicals (**nociceptors**). **Pain warns us of actual or impeding cell/tissue damage.** Because our brain needs warning, nociceptors have to be tonic receptors, i.e., they will not adapt no matter how long the stimulus lasts. Stimuli include extreme pressure and temperature, histamine,  $K^+$ , ATP, acids, and bradykinin. Pain impulses travel on fibers that release the neurotransmitters glutamate and substance P. Some pain impulses are blocked by inhibitory endogenous opioids.

A **classification of receptors by location** identifies three types:

1. **Exteroceptors** respond to stimuli arising outside the body. They are found in most special senses organs as well as the skin. The skin has various receptors for touch, pressure, pain, and temperature.
2. **Interoceptors** are also known as **visceroceptors** as they respond to stimuli arising in internal viscera and blood vessels. They are sensitive to chemical changes, tissue stretch, and temperature changes.
3. **Proprioceptors** respond to stretch in skeletal muscles, tendons, joints, ligaments, and connective tissue coverings of bones and muscles. They inform the brain of the body's movements and position.

Receptors can also be **classified by their structural complexity**. This classification subdivides them into **complex receptors**, which are found in **special senses organs**, and **simple receptors** for the **general senses**.

Simple receptors can further be subdivided into **unencapsulated** or **free dendritic endings** and **encapsulated dendritic endings**.

**Table 14.2 Simple Receptors for General Sensation**

Unencapsulated Dendritic Endings
<ul style="list-style-type: none"> <li>• Thermoreceptors               <ul style="list-style-type: none"> <li>• Cold receptors (50–104°F); in superficial dermis</li> <li>• Heat receptors (90–120°F); in deeper dermis</li> </ul> </li> <li>• Nociceptors respond to pinching, chemicals from damaged tissue, temperatures outside the range of thermoreceptors, capsaicin</li> <li>• Light touch receptors               <ul style="list-style-type: none"> <li>• Tactile (Merkel) discs</li> <li>• Hair follicle receptors</li> </ul> </li> </ul>

### Encapsulated Dendritic Endings - All are mechanoreceptors

- Meissner's (tactile) corpuscles - discriminative touch
- Pacinian (lamellated) corpuscles - deep pressure and vibration
- Ruffini endings - deep continuous pressure
- Muscle spindles - muscle stretch
- Golgi tendon organs - stretch in tendons
- Joint kinesthetic receptors - stretch in joint capsules

## 14.5 Eye and Vision

The **visual sense** is the most important of the special senses as no blind person can survive without help from the environment around them. It is a very complex sense (70% of all sensory receptors of the body are in the eye) and nearly half of the cerebral cortex is involved in the processing of visual information.

The eye (or eyeball) has **five accessory structures**:

1. The **eyebrows** overlie the supraorbital margins. Their function is to shade the eye and to prevent sweat from reaching the eye.
2. The **eyelids (palpebrae)** protect the eye anteriorly. They have connective tissue plates called **tarsal plates** that provide stability. The lower eyelid is pulled down by gravity, but the upper lid needs to be lifted by the **levator palpebrae superioris** muscle to open the eye. The secretions of three glands (**tarsal** or **Meibomian glands**, **sebaceous glands**, and **ciliary glands**) act as lubricant and prevent the eyelids from sticking together.

The **eyelashes** have nerve endings around their follicles that initiate the **blinking reflex** when activated. The **palpebral fissure** separates the eyelids. The **lacrimal caruncle** is an elevation at the medial commissure of the eye. It contains oil and sweat glands.

3. The transparent membrane covering the anterior part of the eye is called the **conjunctiva**. It has two parts: a **palpebral conjunctiva** that lines the back of the eyelid and a **bulbar conjunctiva** that covers the white of the eye. The cornea, the central part of the anterior eye, is not covered by the conjunctiva.
4. The tear-producing **lacrimal apparatus** consists of the **lacrimal** or **tear gland** and a duct system that drains the tear liquid into the nose. Every time we blink, some liquid is squeezed out of the gland and spread across the eye. It enters the **lacrimal canaliculi** via the **lacrimal puncta** and is drained into the **nasolacrimal (or tear) duct** that opens into the inferior nasal meatus.

**Tears** are a dilute saline solution containing mucus and substances to fight pathogens. However, its composition changes considerably depending on our emotional state. Laughter tears are different from sad tears. On average, we produce about 1 ml of tear fluid per day.

5. The **six extrinsic (outer) eye muscles** can be subdivided into **four rectus muscles** and **two oblique muscles**. All muscles originate from the bony orbit and insert into the sclera. They can move the eye to the left and right and up and down, as well as rotate it to the inside and outside. This allows us to move our eyeballs into the perfect position to look at objects and to follow them if they move.

The **lateral rectus abducts** the eye around its axis to the outside, the **medial rectus adducts** to the inside, and the **superior** and **inferior rectus elevate and depress** the eyeball respectively.

The oblique muscles move the eye up (**inferior oblique**) and down (**superior oblique**) and also rotate it to the inside (**superior oblique**) and the outside (**inferior oblique**).

### Eyeball

The **wall of the eyeball** has three layers: fibrous, vascular, and sensory. Its internal (intraocular) cavity is filled with fluids called humors. The lens separates this cavity into an anterior and posterior segment or cavity.

The outermost **fibrous layer** consists of two regions: the posterior sclera and the anterior cornea. The **sclera** forms the white of the eye, which protects and shapes the eyeball and anchors the extrinsic eye muscles; the **cornea** is a transparent layer that lets the light into the eye. The cornea has a very high density of pain receptors that initiate blink and tearing reflexes when irritated.

The pigmented middle layer is called **uvea** or **vascular layer**, because it contains many blood vessels. It has three regions: choroid, ciliary body, and iris.

The **choroid** forms the posterior part of the uvea. It supplies blood to all layers of the eyeball and its brown pigment absorbs light to prevent visual confusion. It morphs into the **ciliary body**, which forms a ring surrounding the **lens**. Its smooth muscle fibers (**ciliary muscle**) regulate the tension of the so-called **ciliary zonule**, which holds the lens in position.

The **ciliary processes** that secrete **aqueous humor** into the intraocular cavity are also part of the ciliary body.

The most anterior part is the **iris**, the visible colored part of the eye. Its central opening forms the **pupil**, whose task it is to regulate the amount of light that enters the eye.

The iris has two muscle layers: an inner **sphincter pupillae** that constricts the pupil when it contracts and an outer **dilator pupillae** that opens (dilates) the pupil on contraction. The size of the pupil changes depending on the ambient light but is also influenced by our emotional state - the pupils dilate when the subject matter is appealing or requires problem-solving skills or when we are frightened. Inability of the pupil to adjust its size and, thus, the amount of light entering the eyeball, has a rather negative effect on our ability to see clearly regardless of how dark or bright our surroundings are.

The innermost **sensory layer** called the **retina** is a delicate two-layered membrane with an outer **pigmented layer** that **absorbs light** and stores vitamin A, and an inner **neural layer** with **photoreceptors** that react to light energy.

The two types of photoreceptors are called **rods** and **cones**, depending on the shape of their outer photopigment-containing segment. **Rods** are more numerous at the peripheral region of the retina away from the macula lutea. They operate in **dim light** and provide an **indistinct, fuzzy, non-color peripheral vision**. **Cones** operate in **bright light** and provide a **high-acuity color vision**. They are mainly found in the **macula lutea**, a yellow (lutea = yellow) spot at the center of the retina, with an exceptionally high concentration in the **fovea centralis**, which explains why the optical axis runs through its center.

The neural layer also contains the axons of bipolar neurons that leave the eye as the **optic nerve**. The site where the nerve leaves the eyeball is called the **optic disc**, also known as the **blind spot**, because there are no photoreceptors.

The retina receives its **blood supply** from the choroid, especially the outer third, as well as **central retinal arteries and veins**. The retina is the only place in our body where we can directly examine blood vessels and get information about the health of our cardiovascular system or general conditions, such as high cholesterol levels or changes caused by diabetes mellitus.

The **lens** is a biconvex, transparent, flexible, elastic, and avascular body that helps us to focus light on the retina. It grows in layers of **lens epithelium** that form the bulk of the lens. The cells are filled with a transparent protein called crystalline.

Figure 14.1 Eyeball, cross-section

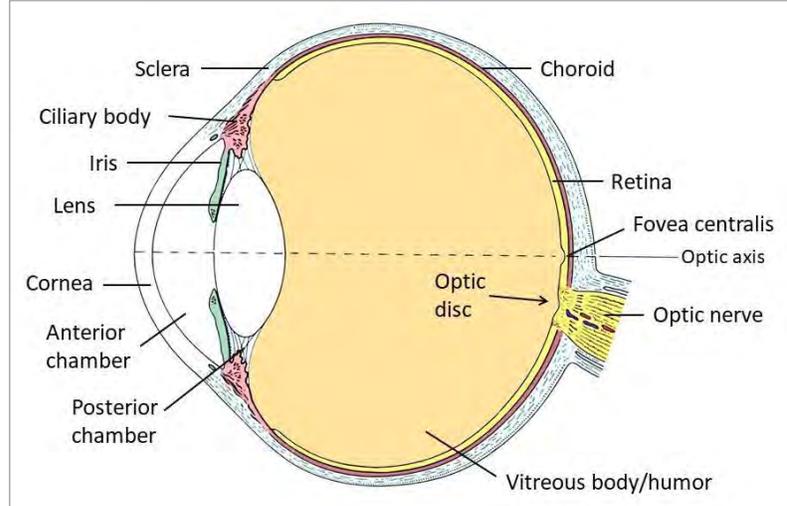
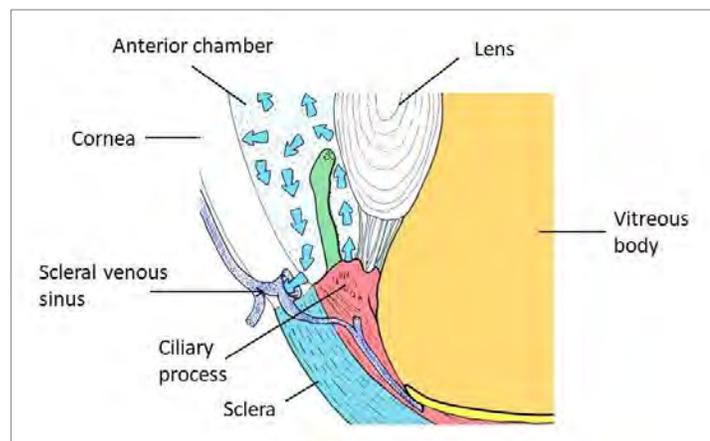


Figure 14.2 Circulation of aqueous humor



Together, the **lens** and the **ciliary zonule** subdivide the intraocular cavity into a **posterior segment** that contains the **vitreous humor**, and an **anterior segment** that is subdivided into an **anterior** and **posterior chamber** by the **iris**.

The **vitreous humor** (*vitreous* = glass-like, *humor* = liquid) is a jelly-type liquid surrounded by a thin capsule. It allows light to pass through on its way to the retina, supports the posterior surface of the lens, holds the retina in place, and contributes to the intraocular pressure.

The **anterior segment** is filled with a thin, watery liquid called **aqueous humor**. The aqueous humor is formed by the **ciliary processes** of the ciliary body. The humor is released into the **posterior chamber** behind the iris. It circulates through the pupil into the **anterior chamber** and drains out of the eye via the **scleral venous sinus** (also known as **canal of Schlemm**) at the **sclera-cornea junction**.

The aqueous humor is a plasma-like fluid that is continuously filtered from capillaries of the ciliary processes. The humor supplies nutrients and oxygen mainly to the lens and cornea but also to the retina and removes wastes.

### Check Your Understanding

- |  |   |
|--|---|
| <p>1. Receptors that respond to touch are called ____.</p> <p>a) mechanoreceptors<br/>b) thermoreceptors<br/>c) photoreceptors<br/>d) chemoreceptors</p> <p>3. The lacrimal glands produce ____.</p> <p>a) sebum<br/>b) tears<br/>c) saliva<br/>d) cerumen</p> | <p>2. The function of the eyebrows is to ____.</p> <p>a) produce tears<br/>b) initiate the blinking reflex<br/>c) improve our vision<br/>d) prevent sweat from reaching the eye</p> <p>4. The conjunctiva covers ____.</p> <p>a) the sclera and cornea<br/>b) the eyelids and the cornea<br/>c) the cornea only<br/>d) the eyelids and the sclera</p> |
|--|---|

1.A.2.D.3.B.4.D

### Physiology of Vision

Light coming in through the pupil is focused on the retina. Once the light hits the retina, its photoreceptors generate action potentials that are conducted to the brain by the optic nerve. The primary visual center together with the visual association area analyzes these signals to give them meaning.

**Light** consists of packets of energy called photons (quanta) that travel in a wavelike fashion. Our eyes only respond to visible light (400-700 nm), i.e., a small portion of the spectrum. Rods and cones respond to different wavelengths of the visible spectrum.

Bending of a light ray is called **refraction**. Light bends or is refracted at the interface of two media with different optic densities or when it passes through a convex or concave lens. Light passing through a convex lens, like the one in our eye, is bent so that the rays converge at a focal point. **Because the shape of the cornea cannot be changed, changing the shape of the lens curvature is the only way for final focusing of an image.**

The eye has **to focus the light in a focal point on the retina**. The light enters the eye through the cornea and then travels through aqueous humor, lens, and vitreous humor to the receptors in the neural layer of the retina. Along the way the light is refracted at the cornea, entering the lens, and leaving the lens. **The image created on the retina is upside-down and reversed right to left.**

There are two types of vision: **distant** and **close vision**. In **distant vision**, light rays from objects arrive nearly parallel at the eye and need little refraction beyond what occurs in the at-rest eye. **A normal (emmetropic) eye can see any objects of a certain size beyond 20 feet** (the so-called the **far point of vision**). The eye has **20/20 vision**. The ciliary muscles are relaxed and the lens is stretched flat by the tension of the ciliary zonule.

If an object is closer than 20 feet, the eye must make **adjustments for close vision** because the light rays from the object diverge and the eye has to increase its refractive power to bend the rays and to focus them on the retina. Thus, we find **three kinds of adjustments for close vision**:

1. The ciliary muscles relax, allowing the elastic lens to go from flat to round. This so-called **accommodation** increases the refractive power and helps to bend the rays and focus them on the retina. This brings the **near point of vision** closer to the eye. The near point of vision is determined by the maximum bulge the lens can achieve.

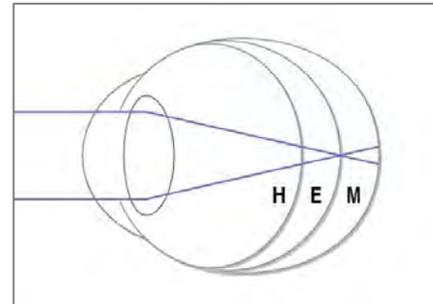
A decline in lens elasticity after age 50 leads to a loss of accommodation and the near point of vision moves further away from the lens. This is called **presbyopia** (*presby(o)*- old age, *-opia* eye, sight) and requires the use of reading glasses.

2. **Constriction of the pupil** restricts light to an area over the greatest bulge of the lens.
3. **Convergence**, i.e., the eyes rotate to the inside (medially), to focus on the close object. This leads to double vision for objects further away.

The most common functional deficits are refractive disorders (ametropias). There are three **disorders of refraction**:

- In **myopia**, the eyeball is too long and the focal point is in front of the retina when we look into the distance, and we are unable to focus the image. Because we can still focus light from close images, this disorder is also called **nearsightedness**. Concave lenses or refractive surgery, such as LASIK, can correct the problem.
- In **hyperopia**, the focal point is behind the retina because the eyeball is too short, and we are unable to focus light coming from close objects. But, we can still see distant objects, which is why we call this condition **farsightedness**. It can be corrected with the help of convex lenses that increase the overall refractive power.
- **Astigmatism** is caused by unequal curvatures in different parts of the cornea or lens. It can be corrected with cylindrical lenses, corneal implants, or laser procedures.

**Figure 14.3 Emmetropic [E], myopic [M], and hyperopic [H] refraction**



### Photoreceptors

There are two types of photoreceptors: **rods and cones**. They are named based on the shape of their **outer photopigment-containing segment**.

Rods have a cylindrical shape, while cones have a 3D shape with a circular base that tapers to a point.

The location and function of our retinal rods and cones differs. **Rods** are found mainly in the **outer region of the retina**. They can operate in **low-light conditions** and are best suited for **night** and **peripheral vision**. The **image generated in the brain is indistinct, fuzzy** and made of many **shades of gray and black**.

Rods function by breaking down a pigment. In the dark, the **visual pigment rhodopsin** (derived from vitamin A) forms and accumulates. When light is absorbed, rhodopsin breaks down, i.e., retinal and opsin separate (so-called **bleaching of the pigment**). This generates action potentials that are relayed to the brain.

**Night blindness** is a nutritional deficiency caused by a lack of rhodopsin due to a lack of vitamin A. It can be cured by vitamin A ingestion.

The **cones** are concentrated in center of the retina (called the **macula lutea**) with the highest density in the **fovea centralis**. Their pigment has a **low light sensitivity** and so they can function only in **bright light**. Cones give us **high-acuity color vision**.

The **three types of cones** are: **blue, green, and red**. They were named for the colors of light absorbed: blue cones absorb blue light and so on. Intermediate hues are perceived by activation of more than one type of cone at the same time.

**Color blindness** is due to a congenital lack of one or more of the cone types, i.e., it cannot be cured. The most common form is **red-green color blindness**, followed by **yellow-green color blindness**, and **total color blindness**. Some patients are missing one or more cone types (for example, red cones); other patients have the cones, but they contain a mutated pigment that does not work as well (for example, red pigment).

### How your cat or dog sees the world

Cats and dogs see the world mainly in shades of blue, green, and yellow, because red is missing from their color spectrum.

An object a dog can see from 20 feet away, we can see from 60 feet. Cats are even worse; what they can see from 20 feet, we can see from a distance of 100-200 feet.

However, cats are great at perceiving movement, even when the object is half a mile away. They also have a wider field of vision and better peripheral vision than us, not to mention their superior dim light vision.

Sudden changes in the brightness of the ambient light pose a challenge to our visual system. **Light adaptation** occurs when moving from darkness into bright light. Large amounts of pigments are broken down instantaneously, producing glare, rod function ceases, and the pupils constrict. But, the cones and neurons rapidly adapt, visual acuity improves over 5–10 minutes.

**Dark adaptation** occurs when moving from bright light into darkness. The cones stop functioning in low-intensity light. The pupils dilate to increase the amount of light entering the eye. Rhodopsin accumulates in the dark and retinal sensitivity increases within 20–30 minutes.

Transmission of the action potentials generated in the retina to the sensory cortex is a prerequisite for being able to see. The **optic nerve** is formed by axons of the retinal ganglion cells. Its medial fibers decussate in the **optic chiasma**, so that all the signals generated by light hitting the retina from one side end up on the same side of the brain. This step increases acuity of vision.

The signal continues in the **optic tract** to the **thalamus** and then in the **optic radiation** to the **primary visual cortex** in the **occipital lobe**. If the signal doesn't get to the primary visual cortex, we are blind. The surrounding area is called **visual association area**. Its task is to help us make sense of what we see by using past visual experiences. This is a very complex process involving the entire posterior half of the cerebral cortex.

**Depth perception** is based on both eyes viewing the same image from slightly different angles. The fusion of the slightly different images in the brain creates **three-dimensional vision**. People with one eye only have two-dimensional vision and struggle with estimating how far away objects are.

### Check Your Understanding

- The average eye has \_\_\_\_\_.
  - distant vision only
  - 20/40 vision
  - 20/20 vision
  - color vision only
- Which disorder is caused by a vitamin deficiency?
  - Color blindness
  - Myopia
  - Astigmatism
  - Night blindness
- The medical term for nearsightedness is \_\_\_\_\_.
  - astigmatism
  - myopia
  - hyperopia
  - presbyopia
- Bending of the light is called \_\_\_\_\_.
  - reflection
  - focusing
  - refraction
  - splitting

1.C.2.D.3.B.4.C

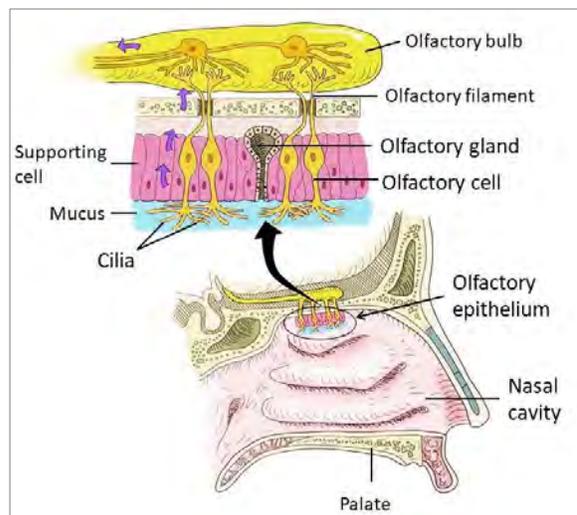
## 14.6 Chemical Senses

**Smell** (or **olfaction**) and **taste** (or **gustation**) are chemical senses. Both senses use chemoreceptors that respond to chemicals dissolved in water. Thus, only water-soluble substances can be tasted or smelled. For example, sugar is a water-soluble carbohydrate with a sweet taste. Flour, which is made of long chains of the same carbohydrates, is not water-soluble and does not taste sweet.

The **olfactory epithelium** in the roof of the nose has three types of cells: **receptor cells** that are bipolar neurons with radiating **olfactory cilia**, **supporting cells** that surround and cushion the receptor cells, and **basal cells** at the base of the epithelium.

Substances we smell (so-called **odorants**) bind to a receptor protein in the cilium membrane and trigger an action potential. The **axons** of the receptor cells form the **filaments** of the **olfactory nerve** (cranial nerve I). They cross through **olfactory foramina** in the **cribriform plate** of the ethmoid bone.

Figure 14.4 Olfactory epithelium and olfactory pathway



They synapse with cells in the **olfactory bulb** and the signal travels along the **olfactory tract** to the **olfactory cortex**, as well as to areas such as **hypothalamus**, **amygdala**, and **limbic system** so that we can make best use of the information. For example, smell information stored in our long-term memory can help us avoid dangerous or unpleasant situations as well as help us relax when we smell certain odors. **Olfactory glands** produce fluid that helps dissolve the odors and to wash them away so the olfactory cilia are ready for the next odorant.

The **receptors for taste** are mainly found on the anterior two thirds of the tongue, although there can be some in the back part of the mouth and throat. There are **three kinds of papillae that carry taste buds: fungiform, foliate, and circumvallate (or vallate) papillae**. Foliate papillae are found on the lateral side of the tongue only; they disappear after adolescence. The large vallate papillae are aligned in a V-shape in front of the V sulcus, which forms the border to the root of the tongue.

Each **taste bud** is a flask-shaped structure with receptor cells (**gustatory or taste cells**) and dynamic stem cells (**basal cells**) that replace sloughed off receptor cells. **Gustatory hairs** project through a **taste pore** and bind substances we can taste (so-called **tastants**).

There are glands at the base of the taste buds that secrete fluid to help dissolve substances so we can taste them. If you stick out your tongue, dry it with a cloth, and put sugar or salt on the dry tongue, you will not taste the sugar or salt at first. If you wait a bit, however, the fluid from the glands will dissolve the salt or sugar, and you will start tasting it.

Action potentials from the taste cells travel in fibers of the **facial nerve** (cranial nerve VII, **anterior 2/3 of tongue**), **glossopharyngeal nerve** (cranial nerve IX, **posterior 1/3 of tongue and upper pharynx**), and **vagus nerve** (cranial nerve X, **epiglottis and lower pharynx**) to the **solitary nucleus** in the medulla and from there to the **thalamus**. Their final destination is the **gustatory cortex** in the insula, but some fibers go to the **hypothalamus** and the **limbic system**.

Figure 14.5 Tongue and taste papillae

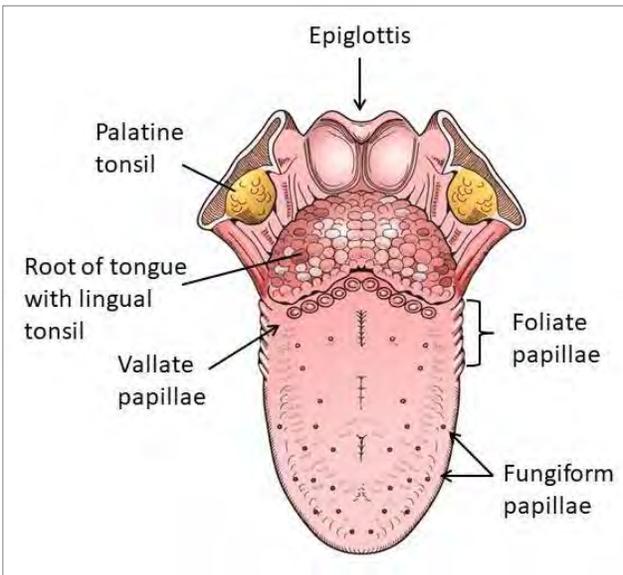
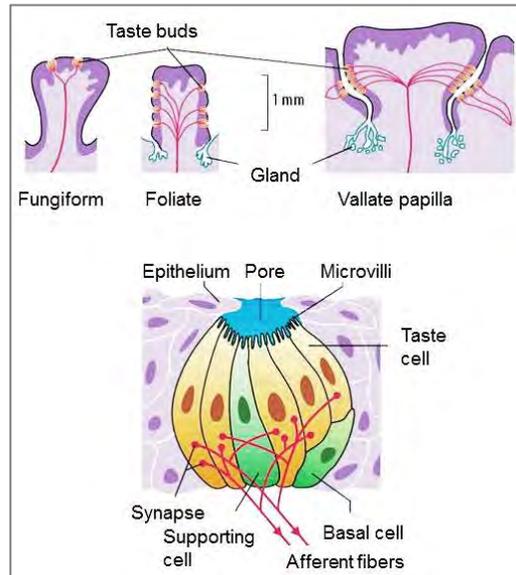


Figure 14.6 Lingual papillae and taste bud structure



Taste is a much more complex sense than smell, although 80% of taste actually is smell. We have all noticed that food tastes bland when our nose is stuffed due to a cold. It is still unknown how the brain recognizes that a certain substance irritating smell fibers is actually a tastant and not an odorant, and, subsequently, processes this signal as taste.

There are **five basic taste sensations**:

1. **Sweet**: Sugars, saccharin, alcohol, and some amino acids.
2. **Sour**: Hydrogen ions (i.e., acid, such as acetic acid in vinegar).
3. **Salty**: Metal ions (for example, sodium in table salt).
4. **Bitter**: Mainly organic compounds found in plants, for example, alkaloids such as quinine and nicotine.
5. **Umami**: A meaty taste caused by the amino acids glutamate and aspartate.

However, signals from other receptors, such as thermoreceptors, mechanoreceptor, and pain receptors in the mouth influence taste as well. For example, cold pizza tastes differently than hot pizza. Even air pressure and humidity affects taste, which is why food on airplanes tastes rather bland.

### 14.7 Hearing

The ear has three parts called the **outer** or **external ear**, **middle ear**, and **inner** or **internal ear**. The **outer** and **middle ear** is involved in **hearing** only, whereas the **inner ear** (labyrinth) is involved in both **hearing and balance** (equilibrium). However, receptors for hearing and balance respond to separate stimuli and are activated independent from each other. They travel in separate nerve fibers to different centers in the somatosensory cortex.

The outer ear consists of the **auricle** or **pinna**, which is made of elastic cartilage. It has two parts: the **rim** or **helix** and the **earlobe** or **lobule**. The **auditory canal** or **external acoustic meatus** is a short, curved tube lined with skin bearing hairs (to keep insects out) and glands that produce oil (sebaceous glands) and a waxy secrete (**ceruminous glands**). The **earwax (cerumen)** coming out of the auditory canal is a mix of wax, oils, and dead cells. The taste of the wax is said to deter insects from crawling into the auditory canal.

The **eardrum** or **tympanic membrane** forms the boundary to the middle ear. It is a thin connective tissue membrane that vibrates in response to sound, transferring the sound energy to the bones of the middle ear.

The **middle ear** is also called **tympanic cavity** because it's a small, air-filled, mucosa-lined cavity in the temporal bone. Its superior portion is called **epitympanic recess**. The tube connecting the middle ear with the nasopharynx is known by three synonymous names: **auditory tube**, **Eustachian tube** or **pharyngotympanic tube**. Its task is to help equalize the pressure in the middle ear with the air pressure outside.

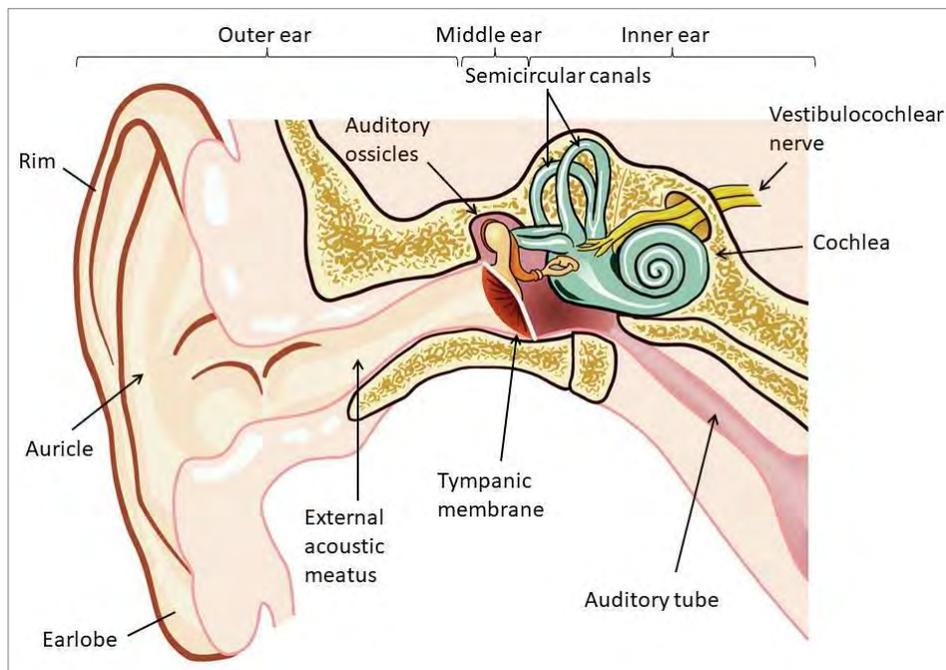
The bony wall on the medial side of the tympanic cavity has two openings that are covered by membranes: the **oval (vestibular) window** and the **round (cochlear) window**.

Three tiny bones, the **middle ear** or **auditory ossicles**, connect the **eardrum** with the **oval window**. They are connected by synovial joints and held in place by ligaments.

The first middle ear bone is called **malleus** or **hammer**, because it seems to hammer on the second bone, the **incus** or **anvil**. The last bone, the **stapes**, looks like a **stirrup**. Its base fits perfectly into the oval window.

Two muscles, the **tensor tympani** and **stapedius**, make sure the tension on the **eardrum** is adjusted to the sound pressure.

Figure 14.7 Ear, cross-section



The **inner ear** is a rather complex structure and therefore called a **labyrinth**. Its basis is a tortuous channel in the temporal bone called the **bony labyrinth**.

The bony labyrinth has three parts that are filled with a fluid called **perilymph**. Inside the labyrinth is a series of **membranous sacs** that are filled with **endolymph**.

The central egg-shaped cavity of the inner ear is called the **vestibule**. It contains two membranous sacs, the **sacculus**, which is continuous with the **cochlear duct**, and the **utricle**, which is continuous with the **semicircular ducts**.

The sacculus and utricle house sensory regions called **maculae** with receptors that respond to gravity and to changes in the position of the head.

The three bony **semicircular canals** contain membranous **semicircular ducts** that communicate with the utricle of the vestibule. At the base of each duct is an **ampulla** that houses a sensory region called **crista ampullaris**. Its receptors respond to angular or rotational movement of the head.

The snail-shaped **cochlea** has a conical, bony chamber that coils around a central pillar called the **modiolus**. The cavity inside the cochlea contains membranous sacs that are divided into three chambers. The **scala vestibuli** starts at the **oval window** and runs all the way up to the apex of the cochlear cavity, which is called the **helicotrema**. Here it turns into the **scala tympani** and runs down to the **round window**.

In between those two perilymph-filled ducts is a third duct called **scala media** or **cochlear duct**, which is filled with endolymph.

The cochlear duct has a roof, the **vestibular membrane**, and a floor made of the bony **spiral lamina** and the **basilar membrane**, which supports the **organ of Corti** (or **spiral organ**).

The organ has **hair cells with stereocilia** that protrude into the endolymph or the gel-like stiff **tectorial membrane**.

### Physiology of Hearing

**Sound waves** travel through the **auditory canal** and their pressure leads to **vibration of the tympanic membrane**. These vibrations are passed along the chain of **middle ear ossicles**. Due to the way these tiny bones are set up and connected, the ossicles amplify the sound heard ten times and transmit it into the **perilymph** of the **scala vestibuli**.

The signal is turned into a **pressure wave** that travels along the **scala vestibuli** until it comes to a point of the **basilar membrane** that resonates with the pressure and **starts vibrating**. This vibration causes **deflection of the stereocilia** of the hair cells and **generation of action potentials**.

This type of sound conduction is called **air conduction** and most of our hearing happens this way. However, sound can also be transmitted to the bones of the skull in a type of transmission called **bone conduction**. Bones are denser than air and, thus, conduct lower frequencies better. Because of that, we perceive our own voices to be lower and fuller than others do and when we hear a recording of our own voice it usually sounds higher than we are used to. Hearing aids may take advantage of the body's natural ability to transfer sounds via bone conduction.

We can only hear sounds with frequencies between 20 and 20,000Hz. **High frequencies** are picked up by short fibers near the **oval window**, whereas **low frequencies** lead to resonance of long fibers near the **apex**. Waves below 20 Hz travel all the way through the helicotrema and **scala tympani** down to the round window.

In order to measure the loudness of sound, the **decibel scale** was developed. Normal conversation takes place at 35-40 dB, busy traffic in a city generates 60-70 dB, and power boats and chainsaws come in at 100 dB. Firearms and

Fig. 14.8 Middle ear and inner ear

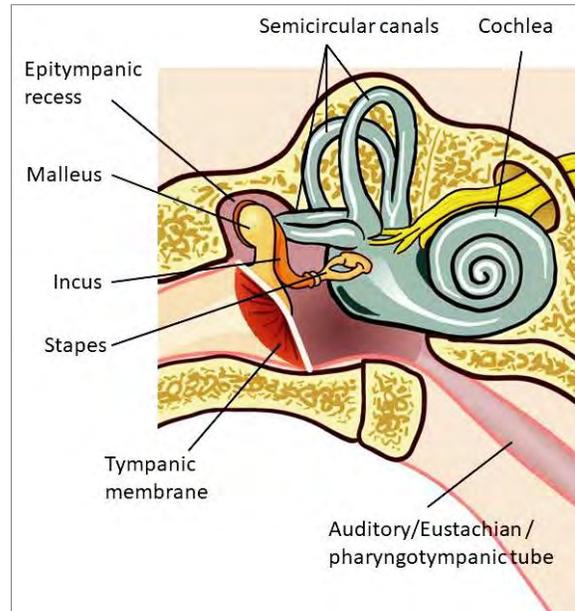
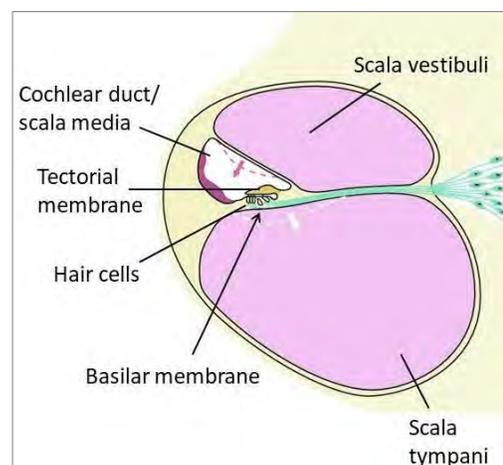


Figure 14.9 Cochlea, cross-section enlarged



personal music devices can go up to 160 dB, which is very painful and can cause damage to the tympanic membrane and the inner ear. However, it is long-term exposure to moderately high sound levels (60-80 dB) that causes sensorineural deafness in most cases.

Axons coming from the receptors of the spiral organ form the **cochlear branch** of the **vestibulocochlear nerve** (cranial nerve VIII). The signals run via the **cochlear nuclei** in the medulla and the **thalamus** to the **auditory cortex**.

### Check Your Understanding

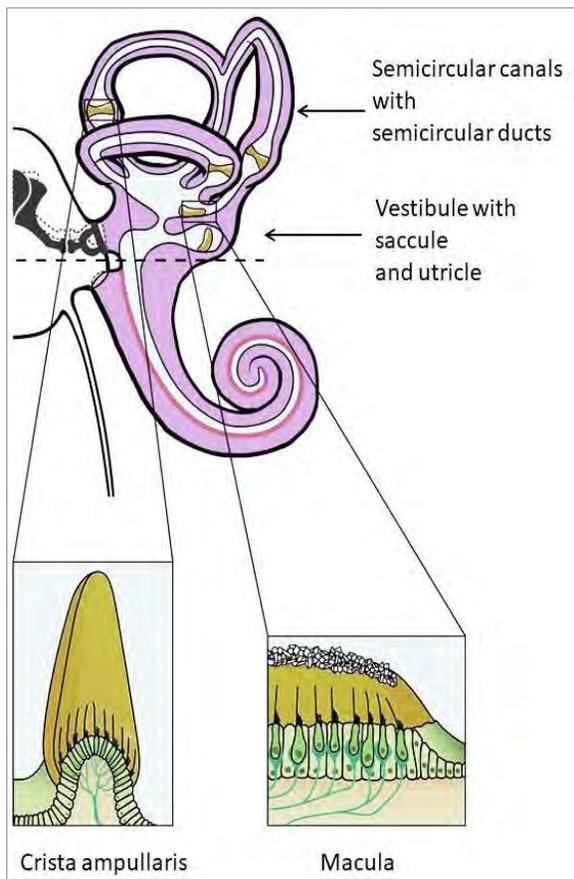
- The receptors for taste are mainly found \_\_\_\_\_.
  - on the cheeks
  - in the throat
  - on the tongue
  - in the nose
- The middle ear is also called \_\_\_\_\_.
  - labyrinth
  - Eustachian tube
  - tympanic cavity
  - tympanic membrane
- The inner ear has receptors for \_\_\_\_\_.
  - hearing only
  - balance only
  - hearing and vision
  - hearing and balance
- The Eustachian tube connects the nose and the \_\_\_\_\_.
  - inner ear
  - outer ear
  - cochlear duct
  - middle ear

1.C.2.C.3.D.4.D

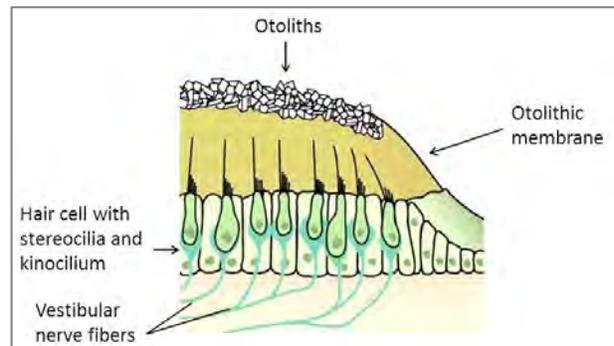
## 14.8 Balance and Equilibrium

The **receptors for balance and equilibrium** are found in the **vestibule** and the **semicircular ducts**. Together, they form the **vestibular apparatus**.

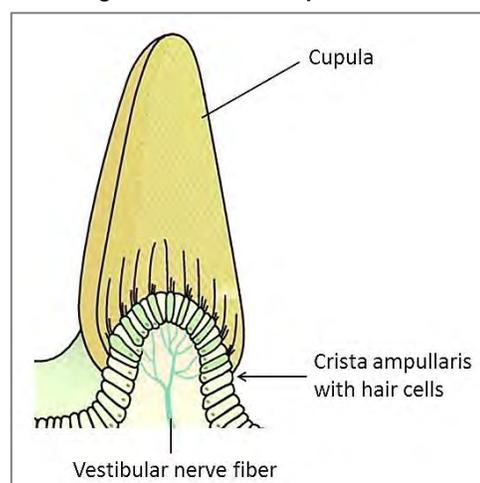
**Figure 14.10 Inner ear with receptors for static and dynamic equilibrium**



**Figure 14.11 Macula**



**Figure 14.12 Crista ampullaris**



The **sensory areas in the vestibule**, known as the **maculae**, contain receptors for **static equilibrium**. They monitor the position of the head in space and **respond to linear acceleration**, such as nodding the head in approval, but not rotation.

The **maculae** have **hair cells** with **stereocilia** and one **kinocilium** that are embedded in a gel-like **otolithic membrane**. On top of the membrane are tiny  $\text{CaCO}_3$  stones called **ear crystals** (or **otoliths**; *oto-* ear, *lith-* stone).

The maculae rely on gravity. Any change in the position of the head will lead a change in the gravitational pull, causing movement of the membrane and deflection of the stereocilia and the kinocilium. This movement of the cilia generates action potentials that inform the brain of the change.

The sensory receptors of the **semicircular ducts** are sensors for **dynamic equilibrium** because they generate action potentials only when we move our head around. Each **ampulla** at the base of a semicircular duct has one so-called **crista ampullaris**, which has hair cells that extend into a gel-like mass called the **cupula**.

Rotational movement of the head causes deflection of the hair cells, which causes formation of action potentials that inform the brain of the rotational movement.

The signals from both types of equilibrium receptors travel in the **vestibular branch** of the **vestibulocochlear nerve** to the brain.

**Balance and equilibrium is a complex sense** that relies upon signals from the vestibular apparatus, our eyes (visual signals), and our joints and muscles (somatic signals). Sometimes, these signals may contain contradicting information. For example, when we sit in a car and look out of the window, our somatic signals indicate that we are not moving, whereas the visual signals tell our brain that we are moving compared to the world outside the window. If the brain becomes confused by apparent contradiction, **motion sickness** develops.

## 14.9 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	sound	_____	olfact(o)-
2.	eyelid	_____	scler(o)-
3.	cornea	_____	irid(o)-
4.	smell	_____	gusto(o)-
5.	sclera	_____	phac(o)-
6.	tears	_____	blephar(o)-
7.	taste	_____	ot(o)-
8.	lens	_____	acoust(o)-
9.	iris	_____	dacry(o)-
10.	ear	_____	kerat(o)-

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Both the cornea and the lens are avascular. \_\_\_\_\_
- The macula lutea is the location where the optic nerve leaves the eyeball. \_\_\_\_\_

3. The bending of light rays is called reflection. \_\_\_\_\_
4. Light passes through the entire thickness of the neural layer of the retina to excite the photoreceptors. \_\_\_\_\_
5. The function of the lens of the eye is to allow precise focusing of light on the retina. \_\_\_\_\_
6. Thermoreceptors are sensitive to changes in temperature. \_\_\_\_\_
7. The cornea is covered by the conjunctiva. \_\_\_\_\_
8. The wall of the eyeball has five layers. \_\_\_\_\_
9. The anterior segment of the eye is filled with aqueous humor. \_\_\_\_\_
10. Proprioceptors collect information from internal organs. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                    |   |           |
|--------------------|---|-----------|
| 1. Retina          | a) bending of light                           | 1. _____  |
| 2. Aqueous humor   | b) night vision                               | 2. _____  |
| 3. Fovea centralis | c) area without photoreceptors                | 3. _____  |
| 4. Refraction      | d) exteroceptor                               | 4. _____  |
| 5. Optic disc      | e) sensory layer of the eye                   | 5. _____  |
| 6. Blind spot      | f) need bright light                          | 6. _____  |
| 7. Rods            | g) pain sensor                                | 7. _____  |
| 8. Cones           | h) circulates in the anterior part of the eye | 8. _____  |
| 9. Nociceptor      | i) birth place of the optic nerve             | 9. _____  |
| 10. Touch receptor | j) area of greatest visual acuity             | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

1. The combining form “opt(o)-” relates to \_\_\_\_\_.
  - a. smell
  - b. hearing
  - c. vision
  - d. taste
2. Which type of sensory receptor responds to stimuli resulting from physical or chemical damage to tissue?
  - a. Mechanoreceptors
  - b. Proprioceptors
  - c. Nociceptors
  - d. Chemoreceptors

3. Proprioception means awareness of \_\_\_\_\_.
  - a. noise
  - b. temperature
  - c. pressure
  - d. position
  
4. Which cells provide for the sense of smell?
  - a. Olfactory hair cells
  - b. Glial cells
  - c. Bowman's glands
  - d. Gustatory cells
  
5. Which is a thin layer that protects the anterior surface of the eyeball?
  - a. Palpebral fissure
  - b. Conjunctiva
  - c. Tarsal plate
  - d. Choroid
  
6. The main function of which structure is to regulate the amount of light entering the eyeball through the pupil?
  - a. Retina
  - b. Cornea
  - c. Iris
  - d. Choroid
  
7. Which of the receptors below is primarily used during bright light situations?
  - a. Macula lutea
  - b. Rods
  - c. Cones
  - d. Optic nerve
  
8. The innermost layer of the wall of the eyeball with the receptors for light is called the \_\_\_\_\_.
  - a. retina
  - b. choroid
  - c. cornea
  - d. sclera
  
9. Which of the below structures acts to convert sound waves to vibrations?
  - a. Cochlea
  - b. Tympanic membrane
  - c. Organ of Corti
  - d. Middle ear ossicles
  
10. Which of the below structures senses dynamic equilibrium?
  - a. Semicircular ducts
  - b. Maculae of vestibule
  - c. Organ of Corti
  - d. Vestibulocochlear nerve
  
11. Otoliths are part of which receptors?
  - a. Spiral organs
  - b. Maculae
  - c. Cristae ampullares
  - d. Mitral cells

12. Which of the following is ***not*** a basic taste sensation?
- Sweet
  - Sour
  - Spicy
  - Salty
13. The \_\_\_ forms the border between outer ear and middle ear.
- pinna
  - Eustachian tube
  - tympanic membrane
  - oval window
14. Bone conduction makes our voice sound \_\_\_ for us than others.
- lower and fuller
  - faster and louder
  - higher but quieter
  - more relaxing
15. Which of the following is ***not*** a type of cone?
- Green
  - Blue
  - Yellow
  - Red

## Chapter 15 Endocrine System

### 15.1 Chapter Outline

The endocrine system acts together with the nervous system to coordinate and integrate the activity of body cells. It influences metabolic activities by means of hormones released in the blood or into the local environment. Its responses occur more slowly but tend to last longer than those of the nervous system.

### 15.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Define hormone, paracrine and autocrine.
- Explain the difference between endocrine and exocrine glands and name the major endocrine glands
- Describe the different kinds of interactions of water-soluble and lipid-soluble hormones with their target cells.
- Name the three kinds of interactions of hormones acting on the same target cell.
- Discuss the different mechanisms of control of hormone release.
- Explain the endocrine functions of the hypothalamus.
- Describe the structure and function of the pituitary gland and name the two hormones released by the posterior pituitary and their function.
- Name the six anterior pituitary hormones and their chief effects.
- Describe the location and structure of the thyroid gland and major effects of thyroid hormone.
- Explain the release stimulus and function of calcitonin.
- Describe the location of the parathyroid glands and the release stimulus and major effects of parathyroid hormone.
- Name the adrenocortical hormones and their chief physiological effects.
- Explain the origin and effect of melatonin.
- Name the two major hormones produced by the endocrine part of the pancreas and their chief physiological effects.
- Discuss the sex hormones and their major effects.
- Name other hormone-producing structures and their hormones.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 15.3 Combining Forms

Table 15.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 15.1 Overview of Major Combining Forms**

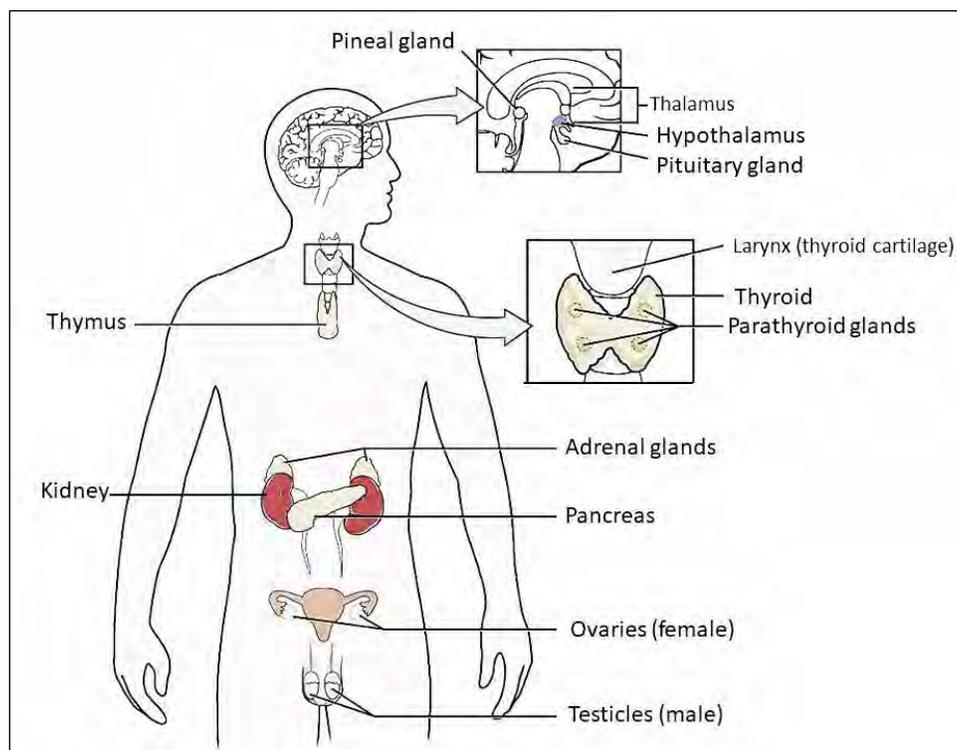
Combining Form	Meaning	Example(s)
adeno(o)-	gland	<i>adenopathy</i> = any disorder of a gland
andr(o)-	male	<i>androgen</i> = a male sex hormone produced by the adrenal cortex
cortic(o)-	cortex	<i>corticosteroid</i> = steroid hormone produced by the adrenal cortex
crin(o)-, -crine	secrete	<i>endocrine</i> = relating to hormone secretion
estr(o)-	female	<i>estrogens</i> = major female sex hormones
gluc(o)-, glyc(o)	sugar, glucose	<i>glucosuria</i> = sugar in the urine

gonad(o)-	sex gland (gonad)	<i>gonadopathy</i> = any disease of the gonads
pancreat(o)-	pancreas	<i>pancreatitis</i> = inflammation of the pancreas
parathyroid(o)-	parathyroid gland	<i>hypoparathyroidism</i> = insufficient or absent secretion from the parathyroid glands
pineal(o)-	pineal gland	<i>pinealectomy</i> = surgical removal of the pineal gland
pituitar(o)-, pituit(o)-	pituitary gland	<i>hyperpituitarism</i> = excessive secretion of the hormones of the anterior pituitary
thym(o)-	thymus	<i>thymoma</i> = benign tumor of the thymus
thyr(o)-, thyroid(o)-	thyroid gland	<i>hyperthyroidism</i> = overactive thyroid gland

## 15.4 Basic Principles

A **gland** consists of one or more cells that make and secrete a fluid. Because hormone-secreting glands release hormones inside the body, they are called **endocrine** (*endo-* inside, *-crine* secreting) **glands**. The endocrine system consists of glands and tissues that use chemical messengers as communication signals. Messengers used for long distance communication via the blood or lymph are called **hormones**. If messengers act on other cells within the same tissues, they are called **paracrines** (tissue hormones); if they exert their effects on the cells that secreted them, they are called **autocrines**.

Figure 15.1 Major endocrine glands



Most glands of the endocrine system are endocrine glands only, such as the pituitary, thyroid, parathyroid, adrenal, and pineal gland. Other glands are **mixed endocrine-exocrine organs**. For example, the **pancreas** not only secretes most of the enzymes needed to digest food (**exocrine part**) but also hormones (**endocrine part**) that regulate our blood sugar level.

For some organs, secreting hormones is only a minor part of their function. The **heart**, for instance, releases a hormone (**atrial natriuretic hormone**) that will lower high blood pressure, but the main function of the heart is, of course, to pump blood through the circulation. Other tissues and organs that produce hormones include adipose cells, cells in the walls of the small intestine, the thymus, stomach, and kidneys.

Not every hormone can act on every cell and not all cells respond to every hormone. **Only cells that have** specific

structures called **receptors**, to which the hormone can bind, will react to a hormone. These **hormone-sensitive cells** are called **target cells**.

### Hormones

**Hormones help keep our body in homeostasis.** Homeostasis (*home(o)*- constant, *-stasis* maintenance) refers to the maintenance of a stable environment, despite continuous outside changes. This involves constant monitoring and regulation. For example, blood sugar levels can neither be too high (hyperglycemia) nor too low (hypoglycemia) because either condition could be life threatening. Hormones can influence the number of receptor on target tissues through:

- **Up-regulation:** Target cells form more receptors in response to the hormone.
- **Down-regulation:** Target cells lose receptors in response to the hormone

**Target cell activation** depends on three factors: 1) blood levels of the hormone, 2) number of receptors on or in the target cell, and 3) affinity of binding between receptor and hormone. If any of these factors is impaired, target cell activation and, thus, hormone activity may be diminished or missing completely.

There are **three ways two or more hormones can interact on target cells**:

1. **Permissiveness:** One hormone cannot exert its effects without another hormone being present.
2. **Synergism:** More than one hormone produces the same effects on a target cell.
3. **Antagonism:** One or more hormones oppose the action of another hormone.

**Tropic hormones** or **tropins** are hormones that act on other endocrine organs/tissues only. For examples, thyroid-stimulating hormone (TSH) is released by the anterior pituitary and acts on the thyroid gland (see below).

Depending on their **chemical structure**, hormones are subdivided into **amino acid-based hormones** and **steroids** that are synthesized from cholesterol.

More important, from a physiologic point of view, is a **classification based on the mechanism of hormone action**.

- **Water-soluble hormones** cannot enter target cells, but **need receptors in the plasma membrane and a second-messenger system inside the cell**. This group consists of **all amino acid-based hormones except thyroid hormone**. The **hormone acts as a first messenger**. It binds to a G protein in the plasma membrane, which then activates an **intracellular second messenger** system.
- **Lipid-soluble hormones** can cross the plasma membrane into the cell and, thus, act on **intracellular receptors** that directly activate genes in the nucleus. This group consists of **steroids and thyroid hormone**. The receptors are found either in the cytoplasm for steroids hormones or the cell nucleus for thyroid hormone. The **receptor-hormone complex** binds to a specific region of DNA, which prompts DNA transcription to produce mRNA, which in turn directs protein synthesis. Accordingly, all effects of lipid-soluble hormones can be attributed to the production of specific proteins.

**Hormones circulate in the blood either free** (water-soluble hormones) or **bound to transport proteins** (lipid-soluble hormones). The **concentration of a circulating hormone** reflects its rate of release from the endocrine gland or the transport protein and the speed of inactivation and removal from the body.

Hormones are **removed from the blood or tissues** by:

- Enzymatic degradation
- Metabolism in the liver
- Excretion through the kidneys

The **half-life** of a hormone is the time required for a hormone's blood level to decrease by half. As a rule, water-soluble hormones have short half-lives and lipid-soluble hormones have long half-lives.

**Table 15.2 Correlation of Protein Binding and Plasma Half-life of Hormones**

Hormone	Protein binding (%)	Plasma half-life
Thyroxine	99.97	6 days
Triiodothyronine	99.7	1 day
Cortisol	94	100 min

Testosterone	89	85 min
Aldosterone	15	25 min
Insulin	little	8 min

Hormones are synthesized and released in response to three types of stimuli:

- 1. Humoral stimuli:** Changing blood level of a monitored variable directly stimulates release of a hormone.
- 2. Neural stimuli:** Nerve fibers stimulate hormone release.
- 3. Hormonal stimuli:** Hormones stimulate other endocrine organs to release their hormones. Hormones that stimulate other endocrine organs are called **tropic hormones** or **tropins**.

The release of some hormones follows a **circadian rhythm**. For example, **melatonin** levels are highest at around 9-10 pm when it's time to get sleeps. Cortisol levels, on the other hand, are highest early in the day and keep decreasing until they reach a low point between midnight and 2-3 am.

There are also **annual cycles and seasonal patterns** for some hormones. The pituitary gland releases more growth hormone in late winter and early spring, stimulating the growth of bones and tissues in children. More babies are being born in late summer and early fall due to increased levels of sex hormones in both men and women in midwinter.

**Blood levels of hormones are controlled by negative feedback systems.** For instance, in humoral stimulation an increase in the blood level of the monitored variable will decrease hormone release, whereas a falling blood level will lead to an increased hormone release.

The **nervous system modifies** the stimulation of endocrine glands and their negative feedback mechanisms. For example, under stress the menstrual cycle of women changes due to a change in activity of the hypothalamus.

**Table 15.3 Major Hormones and their Functions**

Hormone(s)	Endocrine Gland	Functions
aldosterone	adrenal cortex	regulates salt and water balance
androgens	adrenal cortex	influences sex drive & sex characteristics in both males and females
adrenocorticotrophic hormone (ACTH)	anterior pituitary	stimulates cortisol secretion
antidiuretic hormone (ADH)	posterior pituitary	retains water in the body
calcitonin	thyroid gland	decreases blood calcium level
cortisol	adrenal cortex	regulates metabolism of nutrients, has anti-inflammatory effects, and depresses immune responses
epinephrine (Epi) and norepinephrine (NE)	adrenal medulla	fight-or-flight: increases stress response
estrogens	ovaries	major female sex hormones
follicle-stimulating hormone (FSH)	anterior pituitary	females: follicle maturation and secretion of estrogens in the ovaries males: production of sperm in the testes
glucagon	pancreas	increases blood glucose
growth hormone (GH)	anterior pituitary	promotes growth of bone and muscle
insulin	pancreas	lowers blood glucose
luteinizing hormone (LH)	anterior pituitary	females: causes release of egg each month from ovary males: stimulates testosterone secretion
melatonin	pineal gland	sets the body's biological, 24-hour clock
oxytocin	posterior pituitary	uterine contractions during birth; release of milk from mammary glands

parathyroid hormone (PTH)	parathyroid glands	increases blood calcium level
progesterone	Ovaries	prepares uterus for pregnancy
prolactin (PRL)	anterior pituitary	production of milk in the mammary glands
testosterone	testes	maintains male sex characteristics; regulates production of sperm
thymosin	thymus	stimulates maturation of T cells for the immune system
thyroid-stimulating hormone (TSH)	anterior pituitary	stimulates secretion of thyroid hormones by the thyroid gland
thyroid hormone thyroxine (T4) and triiodothyronine (T3)	thyroid gland	regulates metabolism

### 15.5 Hypothalamus and Pituitary

The **hypothalamus** is **part of the diencephalon** (together with the thalamus and epithalamus). The hypothalamus is a center for emotional response and the control center for functions such as blood pressure, body temperature, and water balance. In addition, it controls the release of hormones from the anterior pituitary and produces two hormones that are stored in and released from the posterior pituitary.

The hypothalamus produces **steering hormones** that direct the anterior pituitary to either release a hormone or to stop releasing the hormone. Thus, these steering hormones are called **releasing (RH)** or **inhibiting hormones (IH)**. Examples are the growth hormone–releasing hormone (GHRH) and growth hormone–inhibiting hormone (GHIH) that regulate the release of growth hormone.

Tropic hormones released from the anterior pituitary exert a negative feedback on the hypothalamus. The hormone(s) produced by the final target gland exert a negative feedback on both anterior pituitary and hypothalamus. The feedback loop called the **hypothalamus-pituitary-target organ axis** demonstrates how closely connected the hypothalamus and anterior pituitary are.

The **pituitary**, also called **hypophysis**, is a pea-sized gland that hangs off of the base of the brain. The primary function of the pituitary is to secrete hormones that control the activity of other endocrine glands. However, the pituitary itself is controlled via regulating hormones of the hypothalamus. The pituitary has two parts or lobes:

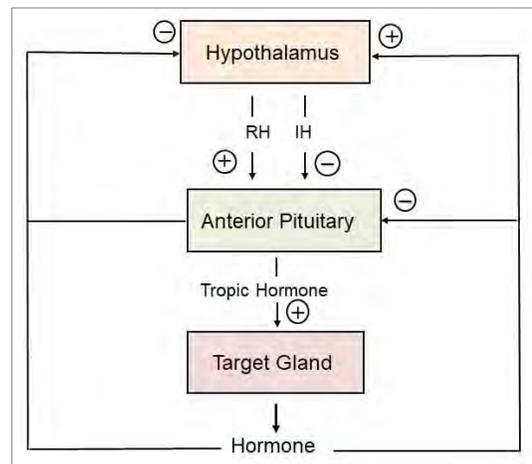
1. The **anterior pituitary** (or **adenohypophysis**) secretes hormones in response to stimuli that it receives from the hypothalamus. These hormones either control other endocrine glands (such as thyroid stimulating hormone) or act directly on specific tissues or organs (such as growth hormone).
2. The **posterior pituitary** (or **neurohypophysis**) does not produce but **only stores and releases oxytocin** and **antidiuretic hormone (ADH)**. Both hormones are produced in nuclei in the hypothalamus (that's why they are called **neurohormones** or neuropeptides) and are transported in axon fibers inside the **hypothalamic-hypophyseal tract** down to the posterior lobe for storage and release.

**Oxytocin** stimulates uterine contractions during childbirth, triggers milk ejection (“letdown” reflex) in breast-feeding women, and plays a role in milk ejection and orgasm in men and women.

**Antidiuretic hormone (ADH)** is the hormone in **charge of the water balance of the body**. It is released in response to changes in the solute concentration (i.e., the osmolarity) of the blood (see **Chapter 24 Fluid, Electrolyte, and Acid-Base Balance**).

- If the **osmolarity goes up, ADH is released** and our body produces less urine to save water.
- If the **osmolarity goes down, ADH is not released** and the kidneys produce more urine, which leads to our body losing more water.

**Figure 15.2 Hypothalamus-anterior pituitary-target organ axis**



- **Alcohol inhibits the release of ADH**, which leads to more frequent urination and dehydration of the body.

The **anterior pituitary** produces and releases six protein hormones **under the control of the hypothalamus**, which releases **steering hormones** that travel in the **hypophyseal portal system** to the anterior lobe (see above). Only two anterior pituitary hormones act on non-endocrine organs (growth hormone, prolactin), whereas the other four hormones are tropic hormones that regulate the action of other endocrine glands.

- **Growth hormone (GH)** is produced by cells called somatotrophs. Growth hormone **stimulates most body cells**, but its main targets in adults are **bone and skeletal muscle tissue**. It **promotes protein synthesis and encourages the use of fat for fuel**, which is why people say growth hormone builds lean muscle mass.
- **Prolactin (PRL)** is secreted by cells called lactotrophs. It is only released towards the end of pregnancy and stimulates milk production. Suckling stimulates the release of a releasing hormone (PRH) from the hypothalamus, which promotes continued milk production. Outside of pregnancy and breast feeding, PRL release is controlled by prolactin-inhibiting hormone (PIH). PRH is also known as **dopamine** when found as a neurotransmitter in the central nervous system.
- **Thyroid-stimulating hormone (TSH)**, also called **thyrotropin**, is a typical tropic hormone. It is produced by thyrotrophs and **stimulates development and secretory activity of the thyroid gland**. TSH release is stimulated by thyrotropin-releasing hormone (TRH) and inhibited by rising blood levels of thyroid hormones that exert a negative feedback on the pituitary and hypothalamus.
- **Adrenocorticotropic hormone (ACTH)** is another tropic hormone; it is also called **corticotropin**. ACTH is secreted by corticotrophs and stimulates the adrenal cortex to release its hormones. ACTH release is triggered by hypothalamic **corticotropin-releasing hormone (CRH)** in a daily rhythm with the highest levels early in the morning (see below under cortisol). Internal and external factors, such as fever, hypoglycemia, and stressors, can increase or decrease the release of CRH and, thus, the release of ACTH.
- **Follicle-stimulating hormone (FSH)** and **luteinizing hormone (LH)** are collectively known as **gonadotropins** because they exert their effect on the primary sex organs or gonads. Their production and release by gonadotrophs starts at the beginning of puberty under the influence of **gonadotropin-releasing hormone (GnRH)**. Blood levels of the **gonadal or sex hormones** suppress the release of GnRH as well as FSH and LH via a negative feedback loop (for more see **Chapter 16 Reproductive System & Pregnancy**).

### Check Your Understanding

- The acronym ACTH stands for \_\_\_\_\_.
  - antidiuretic hormone
  - corticotropin-releasing hormone
  - anterior pituitary hormone
  - adrenocorticotropic hormone
- Which hormone regulates milk production in the breast?
  - Prolactin
  - Oxytocin
  - FSH
  - LH
- The hypothalamus is most closely associated with regulation of the \_\_\_\_\_.
  - pineal gland
  - kidney
  - thyroid
  - pituitary
- Growth hormone \_\_\_\_\_.
  - is produced by the thyroid gland
  - is secreted by the thymus
  - prevents urine production
  - promotes growth in long bones and skeletal muscles

1.D.2.A.3.D.4.D

## 15.6 Thyroid Gland

The **thyroid** (gland) is a butterfly-shaped organ located on the front of the neck below the voice box. It consists of two **lateral lobes** and a median part called the **isthmus**. The thyroid is composed of **follicles** that contain **thyroglobulin**. The follicles are surrounded by **parafollicular cells** that produce the hormone **calcitonin** and, hence, are also called **C cells**.

**Thyroid hormone (TH)** is a collective term for two iodine containing hormones: thyroxine and triiodothyronine. **Thyroxine** is made of two **tyrosine** molecules and four **iodine** atoms, which is why it is also called **tetraiodothyronine** (*tetra-* four) and its symbol is **T<sub>4</sub>**. **Triiodothyronine (T<sub>3</sub>)** is almost identical but contains only three iodine atoms (*tri-* three).

Thyroid hormone is the **major metabolic hormone of the body**. Increased hormone release increases the metabolic rate of almost all body cells and thus the heat production of the body (**calorigenic effect**). Additionally, TH also is important for the normal development of skeletal and nervous tissues and the reproductive system.

The thyroid releases both  $T_3$  and  $T_4$  and, because they are not water-soluble, they are transported in the blood linked to **thyroxin-binding globulin (TBG)**. Just like all hormones that are bound to transport proteins, TH has to be released from its transport protein to diffuse into the cell and bind to a receptor. Consequently, its activity does not depend on the overall amount of hormone in the blood but the “free” amount of hormone that can enter the cell.

**$T_3$  is ten times more active than  $T_4$** , which is why peripheral tissues convert  $T_4$  into  $T_3$ . Rising TH levels provide negative feedback inhibition on the release of TSH. This negative feedback can be overcome during pregnancy or exposure to cold by thyrotropin-releasing hormone (TRH) from the hypothalamus.

In addition to producing  $T_3$  and  $T_4$ , the thyroid produces a third hormone called **calcitonin**. In contrast to the metabolic hormones' function, calcitonin helps to regulate our blood calcium levels and **is released in response to high blood levels of  $Ca^{2+}$** . It stimulates  $Ca^{2+}$  uptake and incorporation into the bone matrix (via increased osteoblast activity) and inhibits osteoclast activity and the release of  $Ca^{2+}$  from the bone matrix.

Calcitonin release is regulated by a humoral negative feedback mechanism based on the  $Ca^{2+}$  concentration in the blood. Calcitonin is not an essential hormone in humans, i.e., a lack of calcitonin does not lead to a pathologic condition.

### 15.7 Parathyroid Glands

The parathyroid glands are 4-8 tiny glands usually embedded in the back of the thyroid gland. Their main cells, the **chief cells**, produce **parathyroid hormone (PTH)**, which is also called **parathormone**.

Parathyroid hormone is much more important than calcitonin for the homeostasis of  $Ca^{2+}$  blood levels. Its function is to raise low levels of calcium in our blood back to normal. When the  $Ca^{2+}$  level decreases, PTH is released into the blood. It **stimulates osteoclasts** to digest bone matrix so that  $Ca^{2+}$  can be released into the blood stream. PTH also **enhances the reabsorption of  $Ca^{2+}$**  and secretion of phosphate by the **kidneys**, **promotes activation of vitamin D** by the kidneys, and **increases absorption of  $Ca^{2+}$  by intestinal mucosa**. Parathormone release is inhibited by normal or high  $Ca^{2+}$  blood levels.

### 15.8 Adrenal Glands

The adrenal glands, also known as **suprarenal glands**, are triangular-shaped organs that sit above the kidneys. There are two adrenal glands, one on top of each kidney.

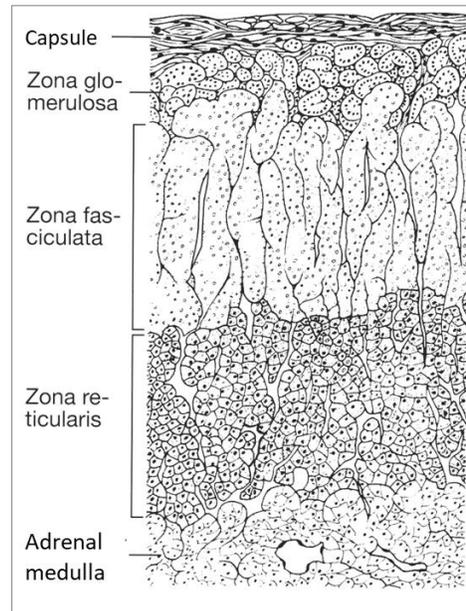
Each gland has an outer part, or **adrenal cortex**, consisting of glandular tissue that produces steroid hormones called **corticosteroids**, and a center part called the **adrenal medulla**, which contains nervous tissues and is part of the autonomic nervous system (ANS).

The cortex has three layers: an outermost layer called **zona glomerulosa** that produces **mineralocorticoids**, a middle layer called **zona fasciculata** that produces **glucocorticoids**, and an innermost layer called **zona reticularis** that produces **sex hormones**.

**Mineralocorticoids** are important for the regulation of the **electrolyte balance** of our body, especially of sodium and potassium.  $Na^+$  is the major cation outside cells and its level affects blood volume, blood pressure, and the overall volume of the extracellular fluid (ECF).  $K^+$  is the most important cation inside cells and its concentration has a direct influence on the resting membrane potential (RMP) of muscle cells and neurons.

**Aldosterone**, the most important mineralocorticoid, **directly stimulates  $Na^+$  reabsorption** and indirectly water retention by the kidneys when the blood pressure is low as part of the **renin-angiotensin-aldosterone mechanism**. The major stimulus for aldosterone release is low blood pressure. Adrenocorticotrophic hormone (ACTH) only has a minor effect on aldosterone release.

15.3 Adrenal gland, microscopic structure



Increased K<sup>+</sup> plasma levels also lead to a release of aldosterone, which increases the active secretion of K<sup>+</sup> into the urine (see also **Chapter 24 Fluid, Electrolyte, and Acid-Base Balance**).

**Glucocorticoids** received their name from their primary metabolic effect – they **raise the blood glucose level** by stimulating the formation of glucose from fats and proteins through **gluconeogenesis**. In higher doses, they also **depress cartilage and bone formation, inhibit inflammation, and depress the immune system**, which is why they are used to prevent graft rejection after organ transplant and for the treatment of chronic inflammatory diseases. The major glucocorticoid in the body is **cortisol**; the glucocorticoid most commonly used for therapeutic purposes is **cortisone**.

Glucocorticoids are **released in response to ACTH release** from the anterior pituitary, but also depending on the pattern of physical activity and physical, mental and emotional stress.

The adrenal **sex hormones**, which are sometimes also called **gonadocorticoids**, released from the zona reticularis are mostly **androgens**, i.e., male sex hormones. They are enzymatically converted into testosterone (men) or estrogens (women) in target tissues. They play a role in the onset of puberty, development of secondary sex characteristics, and sex drive in both males and females.

The **adrenal medulla is part of the autonomic nervous system (ANS)**. Its cells secrete **epinephrine (80%) and norepinephrine (20%)** in response to a neural stimulus via sympathetic nerve fibers. Both hormones cause blood glucose levels to rise, blood vessels to constrict, the heart to beat faster, and blood to be diverted to the brain, heart, and skeletal muscles as part of the **“flight-or-fight response”**. **Epinephrine** (also known as **adrenaline**) specifically stimulates metabolic activities, bronchial dilation, and blood flow to skeletal muscles and the heart. **Norepinephrine** influences peripheral vasoconstriction and blood pressure (see **Chapter 13 Peripheral Nervous System & Reflexes**).

Use the **“4S”** mnemonic to remember the function of the adrenal gland hormones in order from outermost layer of the cortex to the medulla:

- SALT** (Aldosterone)
- SUGAR** (Cortisol)
- SEX** (Androgens)
- STRESS!** (Epinephrine)

## 15.9 Pancreas

The pancreas is a feather-shaped gland located in the middle part of the abdomen behind the stomach. It is **the biggest mixed endocrine-exocrine gland of the body**. Almost all of its secretory cells (99%) are exocrine (acinar) cells that produce digestive enzymes for all major nutrients (see **Chapter 22 Digestive System**). In between these exocrine cells are microscopic island-like clusters of endocrine cells called **pancreatic islets** (islet = island) or **islets of Langerhans**. Two major cell types in these islets are the **alpha (α) and beta (β) cells**. The pancreas secretes two hormones for the regulation of **blood glucose levels** into the bloodstream: **glucagon** and **insulin**.

**Blood glucose** is also known as **blood sugar**. It is the basic form of energy used in our body. **Glycogen** (*glyc(o)-sugar*) is a storage form of glucose. It is formed when we have more than enough glucose to make energy; our liver allows us to store any excess glucose as glycogen. Glycogen storage can be thought of as putting extra money in the bank for when we might need it.

**Insulin** is secreted by **beta cells** when our glucose levels are high. Insulin helps our body cells to use this sugar to make energy. High glucose levels are a threat to our health in the short- and long-term. **Hyposecretion** or **hypoadactivity of insulin** leads to development of **diabetes mellitus (DM)**. Excessive insulin secretion (**hyperinsulinism**) leads to low blood sugar (**hypoglycemia**), which can lead to disorientation, unconsciousness, and death because neurons need glucose to stay alive.

**Glucagon** is the **antagonist to insulin**. It is **released in response to abnormally low blood glucose levels** by **alpha cells**. Its job is to prevent the glucose level in the blood from dropping too low as our brain cells need a constant supply of glucose to survive. Therefore, it promotes the breakdown of glycogen (glycogenolysis) and formation of new glucose (gluconeogenesis) in the liver, fat breakdown (lipolysis) in adipose tissue, and encourages the use of non-carbohydrates (i.e., amino acids, fatty acids) by tissues other than the nervous tissue.

**Table 15.4 Comparison of Insulin and Glucagon**

Insulin	Glucagon
<b>Release</b> from pancreatic beta cells is stimulated by <ul style="list-style-type: none"> <li>Elevated blood levels of glucose and amino acids</li> <li>Rising amino acid levels and parasympathetic stimulation</li> </ul>	<b>Release</b> from pancreatic alpha cells is stimulated by <ul style="list-style-type: none"> <li>Declining blood glucose</li> <li>Rising amino acid levels</li> </ul>
<b>Promotes</b> <ul style="list-style-type: none"> <li>Facilitated diffusion of glucose into muscle and adipose cells</li> <li>Glucose oxidation</li> <li>Glycogen and triglyceride formation</li> <li>Active transport of amino acids into tissue cells</li> <li>Protein synthesis</li> </ul>	<b>Promotes</b> <ul style="list-style-type: none"> <li>Breakdown of glycogen (glycogenolysis) and formation of glucose (gluconeogenesis) in the liver</li> <li>Breakdown of storage fat (lipolysis) in adipose tissue</li> <li>Modulation of glucose effects after a high-protein, low-carbohydrate meal</li> <li>Glucose-sparing, i.e., cells other than nerve cells burn fat</li> </ul>

### Check Your Understanding

- Aldosterone \_\_\_\_\_.
  - controls salt levels
  - regulates the body's metabolism
  - controls the pituitary
  - controls blood sugar levels
- Which hormone regulates metabolism?
  - Glucagon
  - Insulin
  - Thyroid hormone
  - Cortisol
- The pancreas releases \_\_\_\_\_.
  - estrogen and progesterone
  - insulin and glucagon
  - aldosterone and cortisol
  - glucose and glycogen
- Which hormone is released by the adrenal medulla?
  - Aldosterone
  - Epinephrine
  - Cortisol
  - Oxytocin

1.A.2.C.3.B.4.B

### 15.10 Other Hormone-Producing Organs/Tissues

The **pineal gland** in the **epithalamus** contains cells (pinealocytes) that produce one hormone with a more or less known function: **melatonin**. Melatonin is of importance for our **circadian rhythm** (day/night cycle) and may also affect the timing of sexual maturation and puberty as well as physiological processes that show rhythmic variations, such as body temperature, sleep, and appetite (see **Chapter 12 Central Nervous System**).

The **gonads are the primary sex organs** for both men and women and produce most of the body's sex hormones. In women, the **ovaries** produce two types of hormones: **estrogens** and **progesterone**. **Estrogens** regulate the menstrual cycle and are critically important in the development and maintenance of all female characteristics. **Progesterone** helps the body prepare for pregnancy (see **Chapter 16 Reproductive System & Pregnancy**).

During pregnancy, the **placenta** produces vast amounts of both sex hormones plus additional hormones, such as **human chorionic gonadotropin (HCG)**, to keep the fetus alive and growing and to prepare the mother's body for childbirth and breast feeding.

The **testicles** are the equivalent to ovaries in men. They mainly produce the major male sex hormone **testosterone**.

The **heart** releases **atrial natriuretic peptide (ANP)** in response to an increased blood volume and blood pressure. ANP has an **antagonistic action to aldosterone**. It reduces the reabsorption of  $\text{Na}^+$  in the kidney and, indirectly, reduces blood pressure and volume (see **Chapter 18 Blood Vessels and Circulation**).

The **kidneys** produce two hormones:

- Erythropoietin** controls the formation of red blood cells in the bone marrow (see **Chapter 19 Blood, Hemostasis, and Blood Groups**).
- Renin** initiates a mechanism that leads to the secretion of aldosterone and an increase in blood volume and pressure. Because it converts angiotensinogen to angiotensin I, it is also considered to be an enzyme (see **Chapter 18 Blood Vessels and Circulation**).

The **thymus** produces hormones (**thymulin, thymopoietin, thymosin**) that are involved in the **normal development of the immune system**. People born without a thymus will not develop a fully functional immune system and die early (see **Chapter 20 Lymphatic System & Immunity**).

The **skin** produces a hormone/vitamin called **cholecalciferol**, which is a **precursor of vitamin D**. It needs to be metabolized in the liver and finally the kidney before it reaches its active state.

**Adipose tissue** releases a hormone called **leptin**. Leptin is involved in appetite control and seems to be a major signal for the onset of puberty.

The **gastrointestinal system** has **enteroendocrine cells** that secrete hormones to regulate the digestive and absorptive functions of the GI tract. **Gastrin** stimulates the release of HCL from exocrine stomach cells, **secretin** stimulates the liver and pancreas, and **cholecystokinin** stimulates the pancreas and gallbladder (see **Chapter 22 Digestive System**).

### 15.11 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	gland	_____	andr(o)-
2.	thymus	_____	estr(o)-
3.	thyroid gland	_____	gluc(o)-
4.	male	_____	thym(o)-
5.	female	_____	thyr(o)-
6.	sugar	_____	cortic(o)-
7.	cortex	_____	adeno(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- The hormone that raises blood sugar levels is insulin. \_\_\_\_\_
- Iodine is an essential element required for the synthesis of thyroxine. \_\_\_\_\_
- ACTH stimulates the adrenal cortex to release corticosteroid hormones. \_\_\_\_\_
- The beta cells are the pancreatic islet cells that produce glucagon. \_\_\_\_\_
- Aldosterone is the most potent glucocorticoid produced in the adrenal glands. \_\_\_\_\_
- ACTH, FSH, and LH are secreted by the adenohypophysis. \_\_\_\_\_
- Calcitonin and parathormone are antagonistic hormones. \_\_\_\_\_
- Leptin is secreted by adipose tissue cells. \_\_\_\_\_
- Not all endocrine organs secrete hormones only. \_\_\_\_\_
- The posterior pituitary secretes two hormones, ADH and Oxytocin. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                         |   |           |
|-------------------------|---|-----------|
| 1. Prolactin            | a) lowers blood calcium levels                              | 1. _____  |
| 2. Epinephrine          | b) promotes water retention by the kidneys                  | 2. _____  |
| 3. Glucagon             | c) produces hormones that regulate glucose levels           | 3. _____  |
| 4. Calcitonin           | d) stimulates milk production                               | 4. _____  |
| 5. Antidiuretic hormone | e) produces a hormone that controls blood levels of calcium | 5. _____  |
| 6. Oxytocin             | f) adrenal gland  | 6. _____  |
| 7. Parathyroid          | g) produces hormones that stimulate other endocrine glands  | 7. _____  |
| 8. Pancreas             | h) released from the adrenal medulla                        | 8. _____  |
| 9. Hypophysis           | i) stimulates milk ejection from the breast                 | 9. _____  |
| 10. "4S"                | j) raises blood glucose levels                              | 10. _____ |

**Multiple Choice**

Choose the one alternative that best completes the statement or answers the question.

- When a hormone is present in excessive levels, the number of target-cell receptors may decrease. This is called \_\_\_\_\_.
  - receptor recognition
  - inhibition
  - up regulation
  - down regulation
- Which of the following statements is incorrect?
  - Hormones are the body's chemical messengers.
  - Hormones travel in the bloodstream or other body fluids.
  - Hormones can target a near organ or can travel to a distant target organ.
  - Glands can only be endocrine or exocrine glands.
- What is a major difference in the action of a water-soluble hormone versus a lipid-soluble hormone?
  - How they diffuse through blood.
  - How the mRNA is transcribed.
  - The use of a second messenger.
  - Only one type needs a hormone receptor.
- One hormone opposing the action of another hormone is called \_\_\_\_ effect.
  - synergistic
  - permissive
  - antagonistic
  - humoral
- The pineal gland produces \_\_\_\_\_.
  - cortisol
  - melatonin
  - adrenaline
  - insulin

6. Thyroxine is also known as \_\_\_\_.
  - a. thyroid stimulating hormone
  - b. tetraiodothyronine
  - c. parathyroid hormone
  - d. prolactin
  
7. The part of the pancreas that produces hormones is also called \_\_\_\_.
  - a. exocrine pancreas
  - b. pancreatic cortex
  - c. pancreatic medulla
  - d. pancreatic islets
  
8. Which hormone lowers calcium levels in the blood?
  - a. Calcitonin
  - b. Parathyroid hormone
  - c. Glucagon
  - d. Antidiuretic hormone
  
9. The anterior pituitary stimulates other endocrine organs by secreting a group of hormones called \_\_\_\_ hormones.
  - a. releasing
  - b. tropic
  - c. relay
  - d. target
  
10. Much of the endocrine system regulates itself through a process called \_\_\_\_.
  - a. negative feedback
  - b. positive feedback
  - c. reciprocal inhibition
  - d. receptor inhibition

## Chapter 16 Reproductive System and Pregnancy

### 16.1 Chapter Outline

The reproductive systems of males and females consist of a number of organs that work together for the purpose of sexual reproduction. Both sexes have one set of primary sex organs (or gonads) each - testicles in men and ovaries in women. These organs produce sex cells and steroid sex hormones. Ducts, glands and external genitalia are secondary reproductive organs.

### 16.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the location, structure, and function of the male reproductive organs and their role in the reproductive process.
- Discuss the sources and functions of semen.
- Outline the steps of spermatogenesis.
- Discuss hormonal regulation of testicular function and the physiological effects of testosterone on the male reproductive anatomy.
- Describe the location, structure, and function of the female reproductive organs and their role in the reproductive process.
- Explain the process of oogenesis and compare it to spermatogenesis.
- Describe the ovarian cycle phases, and relate them to the events of oogenesis.
- Describe the regulation of the ovarian and uterine cycles.
- Discuss the physiological effects of estrogens and progesterone.
- Describe fertilization and the events from zygote to implantation.
- Name the duration of the embryonic and fetal periods and the major events of development.
- Describe the effects of pregnancy on the mother.
- Explain how labor is initiated and describe the three stages of labor.
- Define contraception and discuss common methods.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 16.3 Combining Forms

Table 16.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 16.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
andr(o)-	male	<i>androgens</i> = male sex hormones
cervic(o)-	cervix	<i>endocervicitis</i> = inflammation of the mucous membrane lining the cervix
colp(o)-	vagina	<i>colporrhaphy</i> = suturing of a tear in the vagina
didym(o)-	testicle	<i>epididymitis</i> = inflammation of the epididymis
estr(o)-	female	<i>estrogens</i> = major female sex hormones
gynec(o)-	woman; female	<i>gynecology</i> = medical specialty that focuses on the health of women, especially their reproduc-

		tive organs
hyster(o)-	uterus	<i>hysterectomy</i> = surgical removal of the uterus
mamm(o)-, mast(o)-	breast	<i>mastalgia</i> = pain in the breast
men(o)-	menstruation	<i>polymenorrhea</i> = excessive menstrual flow
metra-, metr(i)-, metr(o)-	uterus	<i>myometrium</i> = muscle layer of the uterus
oophor(o)-	ovary	<i>oophorectomy</i> = surgical removal of one or both ovaries
orch(o)-, orchi(o)-, orchid(o)-	testicle	<i>orchitis</i> = inflammation of one or both testicles
ov(i)-, ov(o)-	egg (ovum)	<i>oviduct</i> = ovarian tube
ovul(o)-	ovulation	<i>anovulatory</i> = without ovulation of an egg
prostat(o)-	prostate	<i>prostatic</i> = relating to the prostate
salping(o)-	Fallopian/ovarian tubes	<i>salpingectomy</i> = surgical removal of a fallopian tube
semin(i)-	semen, seed or sperm	<i>seminal</i> = relating to the semen
test(i)-	testicle	<i>testicular</i> = relating to the testicles
vagin(o)-	vagina	<i>vaginismus</i> = involuntary contractions of the vagina that can lead to painful intercourse
vulv(o)-	vulva	<i>vulvovaginitis</i> = inflammation of vulva and vagina

## 16.4 Introduction

The **male and female genitalia are the reproductive organs of the human body**. **Internal genitalia** are the structures of the reproductive system inside the body (for example, the prostate in men and the uterus in women); **external genitalia** are the structures outside the body (for example, the penis in men and the vulva in women). The primary function of the reproductive system is to produce sex cells, sperm in men and eggs (ova) in women, and to offer a place for the sex cells to create a fertilized egg and for this egg to grow until birth. **Sex hormones** play an essential role in the development and function of the secondary reproductive organs in both sexes and in sexual reproduction.

Both men and women have one set of **primary sex organs** or **gonads** each, **testes** or **testicles** in men and **ovaries** in women. The gonads produce **sex cells** or **gametes** and steroid **sex hormones**. Ducts, glands, and external genitalia are **secondary reproductive organs**.

**Gametogenesis** (*gamet(o)-* germ cell, *-genesis* formation) or the **formation of sex cells** (gametes) is a complex process in both genders. Unlike **body cells** that are **diploid**, i.e., they have two sets of 23 chromosomes giving them 46 chromosomes overall, **sex cells have to be haploid**, i.e., they have one set of 23 chromosomes only. During fertilization (see below), two gametes combine their chromosomes (23 from each cell) to form a new cell with a normal set of 46 chromosomes. Gametogenesis involves two different types of cell division: **mitotic division** that yields genetically identical daughter cells, and **meiosis** that leads to cells with a haploid chromosome set.

**Puberty** is the process of transforming the bodies of young boys and girls into the bodies of sexually mature men and women. Puberty starts earlier in girls; on average, girls begin puberty around age 10-11 and boys at around 11-12 years of age.

**Table 16.2 Puberty in Girls and Boys**

	Average age	Range
<b>Girls</b>		
First pubic hair	10.4	8.0 – 12.8
Begin of breast development (thelarche)	10.9	8.5 – 13.3

First menstrual flow (menarche)	13.4	11.2 – 15.6
Complete pubic hair	14.0	11.4 – 16.6
Complete breast development	14.0	11.6 – 16.4

**Boys**

Onset of maturation of genital organs	11.2	8.2 – 14.2
First pubic hair	12.2	9.2 – 15.2
Complete pubic hair	14.9	12.9 – 16.9
Mature genitals	14.7	12.5 – 16.9
Complete testis development	15.3	12.9 – 17.7

**16.5 Male Reproductive System**

The male reproductive system consists of two **testicles** or **testes** (*singular testis*) as the primary sex organs, a system of **ducts** that convey **sperm**, and **accessory glands** that empty secretions into the ducts during ejaculation.

The **testicles** are located outside the abdominopelvic cavity in a pouch called the **scrotum**. They are mixed **exocrine-endocrine glands** as they produce **sperm** but also **male hormones**, such as **testosterone**.

The testicles are surrounded by two tunics: the **tunica vaginalis**, which is derived from the peritoneum, and the **tunica albuginea**, a tough fibrous capsule.

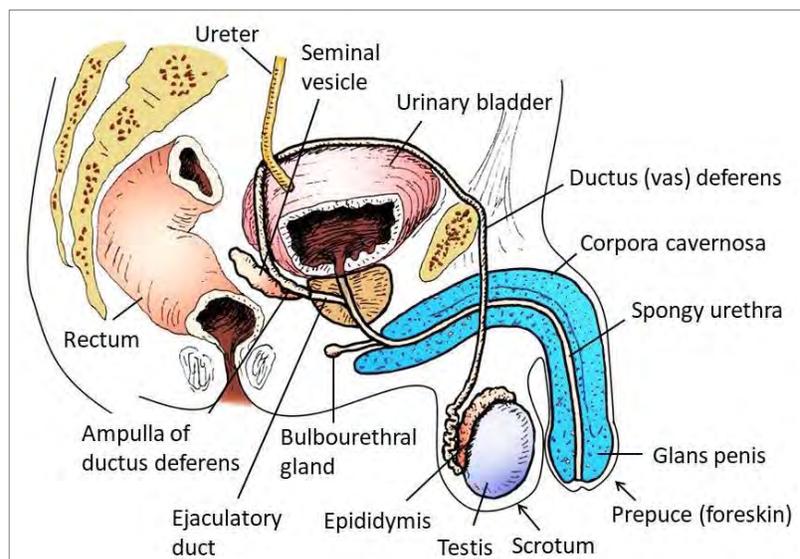
The interior of the testicles is subdivided by **septa** into 250-300 **lobules**, each containing 1-4 **seminiferous tubules** (*semin(i)-sperm, -ferous* containing) that are the site of sperm production. The sperm matures during its travel through the seminiferous tubules, straight tubules (**tubulus rectus**), a tubular network called **rete testis**, and **efferent tubules** that are already part of the epididymis. The androgen-producing cells located outside the tubules are called **interstitial** or **Leydig cells**.

The **scrotum** is a sack of skin, smooth muscle fibers, and superficial fascia. Its task is to **keep the testes at a temperature about 6°F (3 °C) lower** than the core body temperature as this is necessary for sperm production. There are two sets of muscles for maintaining regulating temperature:

1. The **dartos** muscle is a smooth muscle that wrinkles the scrotal skin when the scrotum gets colder.
2. The **cremaster** muscle consists of bands of skeletal muscle fibers that elevate the testes closer to the body when it gets colder. When the temperature rises, the cremaster fibers relax and the testicles can move away from the body to cool down.

The **epididymis** (*epi-* upon, above, *-didymis* testicle) is the first part of the duct system. Its task is to nourish the maturing sperm that enter in a non-motile state, pass slowly through, and become motile. During ejaculation, the epididymis contracts, expelling sperm into the ductus deferens.

The **spermatic cord** contains the **ductus/vas deferens**, the **testicular arteries** that are branches of the abdominal aorta, the venous **pampiniform plexus** that flows into the **testicular vein**, **nerve fibers** from the autonomic and somatic nervous systems as well as **lymphatics**. Together, they are surrounded by two connective tissue sheaths for protection, the **outer and inner spermatic fasciae**.

**Figure 16.1 Male reproductive system, overview**

The **vas** or **ductus deferens** travels upward inside the spermatic cord and passes through the **inguinal canal** into the abdominopelvic cavity. There, it continues across the roof of the bladder and down along the posterior wall of the bladder. At the base of the bladder, the duct expands to form the **ampulla** and then joins the duct of the seminal vesicle (*vesic(o)-* bladder, *-le* small, little) to form the **ejaculatory duct**. The task of the ductus deferens is to **propel sperm** from the epididymis to the urethra **during ejaculation**. Cutting and ligating of the ductus/vas deferens as a means of birth control is called **vasectomy** (see below).

The **penis** is the **male copulatory organ**. Its task is to deposit semen as close as possible to the external os (*os* = mouth, opening) of the cervical canal. It consists of a **root** and a **shaft** that ends in the **glans penis**. The cuff of loose skin covering the glans is called **prepuce** or **foreskin**. The surgical removal of this skin for medical or religious reasons is called **circumcision**.

The two **crura** form the proximal end of the penis. They are surrounded by the **ischiocavernosus muscle** and **anchor the penis to the pubic arch**.

Inside the penis are the **spongy urethra** and three cylindrical bodies of erectile tissue: two paired dorsal bodies (body = *corpus*, bodies = *corpora*) called **corpora cavernosa**, and one spongy body (**corpus spongiosum**) that surrounds the urethra and expands to form the glans at the tip and the bulb at the end.

During erection, these erectile tissues fill with blood, causing the penis to enlarge and become rigid. However, the corpus spongiosum will become less rigid than the corpora cavernosa to keep the urethra from collapsing, which would prevent the sperm from traveling through during ejaculation.

The **male urethra** conveys both urine and semen at different times. It has three regions:

1. The **prostatic urethra** (1 inch) within the prostate gland.
2. The **membranous urethra** (.8 inch) passes through the **urogenital diaphragm** in the pelvic floor.
3. The **spongy** or **penile urethra** (6 inches) passes through the penis and opens via the **external urethral orifice** on the tip of the penis.

There are **three accessory glands**: the seminal vesicles, prostate, and bulbourethral or Cowper's glands.

1. The **seminal vesicles** on the posteroinferior aspect of the bladder produce a **viscous, alkaline fluid** that **makes up approximately 70% or more of the ejaculated semen**. The secretion contains fructose, coagulating enzyme (vesiculase), and prostaglandins. The **duct of the seminal vesicle** joins the ductus deferens to form the **ejaculatory duct** inside the prostate. The ejaculatory duct received its name from the fact that sperm only enters during ejaculation.
2. The chestnut-shaped **prostate** encircles the first part of the urethra inferior to the bladder (**prostatic urethra**). It secretes a **milky, slightly acidic fluid** that plays a role in the activation of sperm. The secretion contains citrate, enzymes, and **prostate-specific antigen (PSA)**, which can be used as a tumor marker for patients with

Figure 16.2 Penis, cross-section

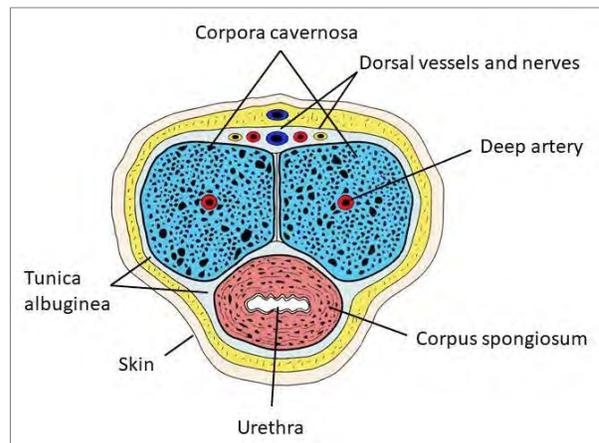
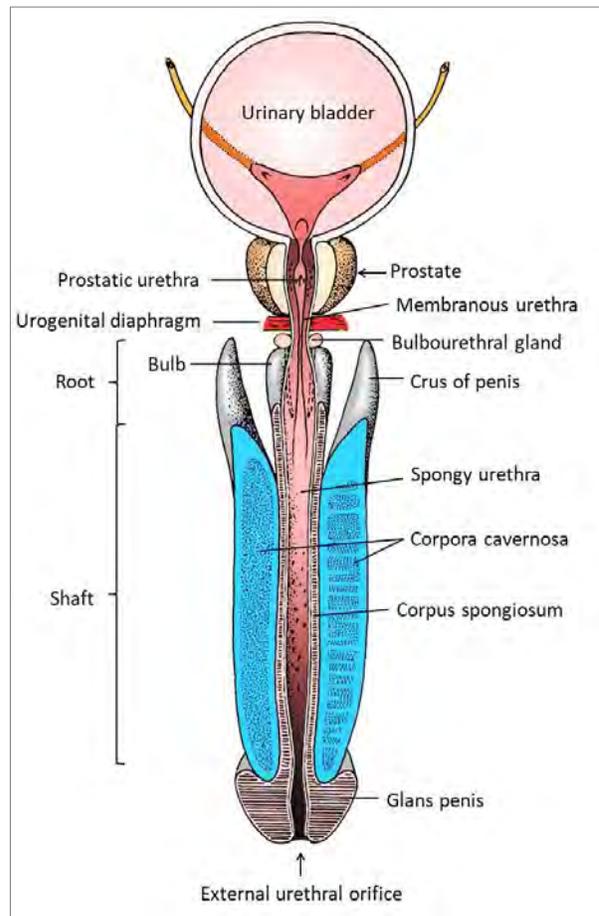


Figure 16.3 Bladder, prostate, and penis, longitudinal section



prostate cancer.

- The **bulbourethral** or **Cowper's glands** at the base of the penis are pea-sized glands. They produce a **thick, clear mucus** during excitation and prior to ejaculation. Its task is to **neutralize traces of acidic urine** in the urethra and to act as a **lubricant for intercourse**.

### Spermatogenesis

Spermatogenesis (*spermat(o)-* sperm, *-genesis* formation) is a sequence of events that produces sperm in the seminiferous tubules of the testicles. Sperm formation does not start before puberty but thereafter continues throughout a man's life. Spermatogenesis is an amazing process that transforms spermatogenic cells into freely movable sperms. The **stem cell is diploid**, i.e., has two sets of 23 chromosomes each, but the **sperm**, just like the female sex cells, is **haploid**, i.e., it has one set of chromosomes only.

In the first step, **spermatogonia** undergo **mitosis** and form **spermatocytes**. The second step uses **meiosis** to form **spermatids**, which mature in a process called **spermiogenesis** to become fully functional sperm.

A **mature sperm** has three regions:

- The **head** contains the **paternal DNA** and has a helmet-like **acrosome**.
- The **midpiece** houses many mitochondria that produce the energy (ATP) needed to propel the sperm along.
- The **sperm is the only human cell** with a flagellum (**tail**) and, thus, can **move around freely**.

Sperm formation depends very much on large supporting cells called **sustentacular** or **Sertoli cells**. They provide nutrients and release the **androgen-binding protein (ABP)**, which makes spermatogenic cells receptive to testosterone. The Sertoli cells also form the so-called **blood-testis barrier** that protects the developing sperm from the immune system. If this barrier is breached (for example, in injuries to the testicle) the immune system will produce antibodies against the sperm. This can be a rare reason for male infertility.

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### Male Sex Hormones

The regulation of the male reproductive system involves the **hypothalamic-pituitary-testis axis**. The **hypothalamus** releases **gonadotropin-releasing hormone (GnHR)**, which stimulates the **anterior pituitary** to release two **gonadotropins**:

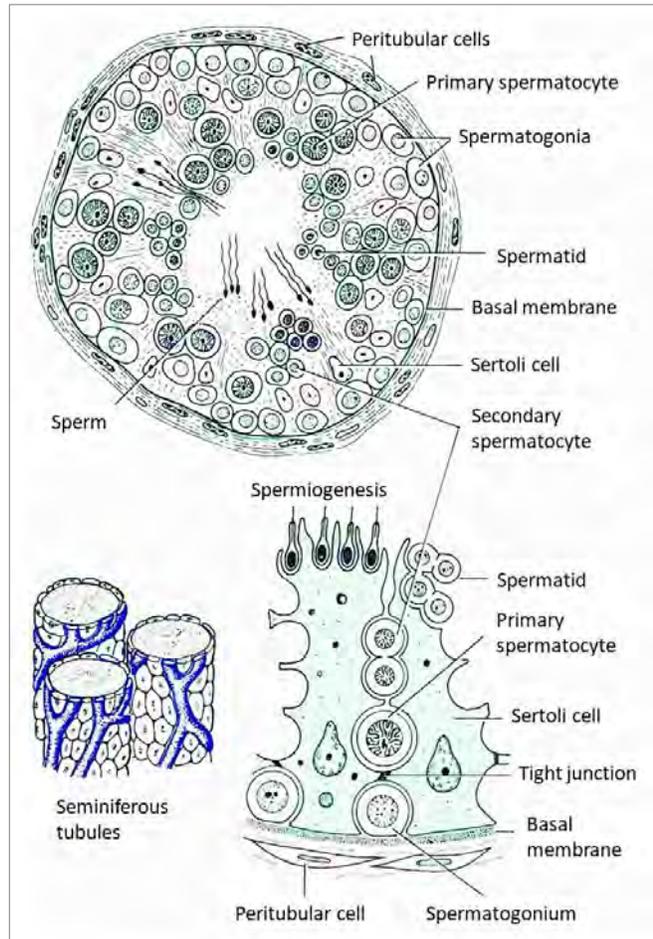
- Follicle-stimulating hormone (FSH)** causes **sustentacular** or **Sertoli cells** to release **androgen-binding protein (ABP)**, which makes spermatogenic cells receptive to testosterone.
- Luteinizing hormone (LH)** stimulates **interstitial** or **Leydig cells** to release **testosterone**, which is the final trigger for spermatogenesis.

**Feedback inhibition** on the hypothalamus and pituitary results **from rising testosterone levels** as well as the hormone **inhibin**, which is released when the sperm count is high.

**Testosterone** is the major male sex hormone (androgen). It is produced by endocrine cells of the testicle called **interstitial** or **Leydig cells**. Testosterone is responsible for the development of **secondary sex characteristics**:

- Appearance of pubic, axillary, and facial hair.

Figure 16.4 Spermatogenesis



- Enhanced growth of the chest and deepening of the voice.
- The skin thickens and becomes oily.
- Bones grow and increase in density.
- Skeletal muscles increase in size and mass.

In addition to that, testosterone has multiple effects throughout the body, including the sex drive (libido) in males

### Male Sexual Response

The male sexual response **manifests itself as an erection** - an enlargement and stiffening of the penis from engorgement of erectile tissue with blood. This is initiated by touch and mechanical stimulation of the penis, as well as erotic sights, sounds, and smells; although, it can also be induced or inhibited by emotions or higher mental activity.

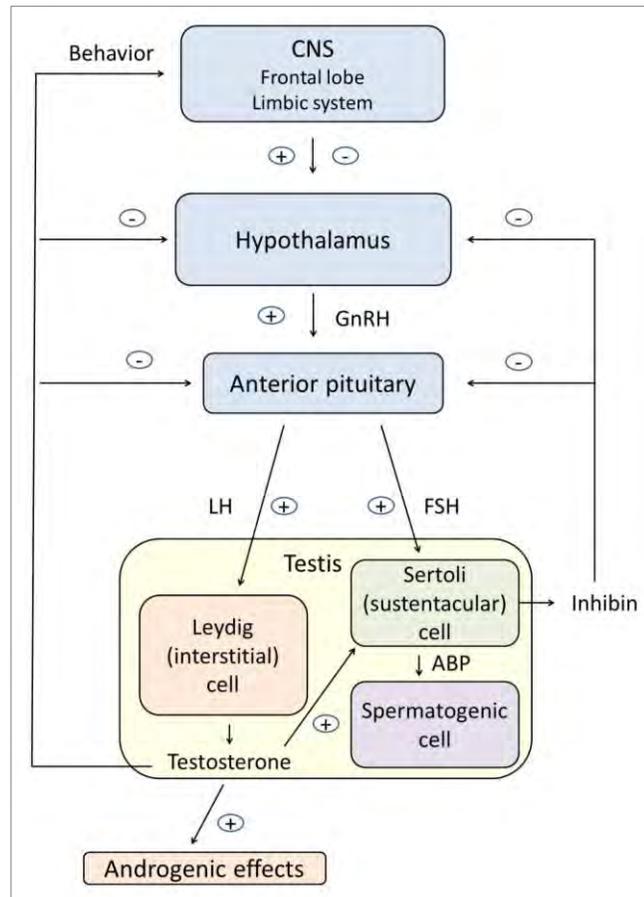
During arousal, **nitric oxide (NO)** causes vasodilation and the erectile tissue to fill with blood. **Expansion of the corpora cavernosa** compresses drainage veins and achieves and maintains **erection**. The softer **corpus spongiosum keeps the urethra open** allowing the semen to pass through during ejaculation. **Erectile dysfunction** (impotence) is the inability to attain or keep up an erection.

**Ejaculation** is the propulsion of semen from the male duct system. **Erection** is caused by a **parasympathetic reflex** and **ejaculation** is initiated by a **sympathetic reflex**. Ducts and accessory glands contract, the bladder sphincter muscle constricts, preventing the expulsion of urine, and the bulbospongiosus muscles undergo a rapid series of contractions.

Unlike women, who are potentially multiorgasmic, **men have a refractory period immediately after ejaculation**. The time before the next erection can happen (the resolution phase) varies considerably and depends on a number of physical, mental, and emotional factors

The ejaculated **semen** consists of sperm (15-25%) and secretions from the accessory glands. It contains nutrients (e.g., fructose), protects and activates sperm, and facilitates sperm movement. Prostaglandins decrease the viscosity of mucus in the cervix, allowing the sperm to enter the cervical canal and stimulate reverse peristalsis in the uterus, which will help push the sperm up toward the openings of the fallopian tubes. The semen's alkalinity neutralizes acid in the male urethra and female vagina. On average, **2–5 ml of semen is ejaculated**, containing **20–150 million sperm/ml**.

Figure 16.5 Hypothalamus-anterior pituitary-testis axis



### Check Your Understanding

1. The ductus (vas) deferens travels upward inside the \_\_\_\_\_.
  - a) epididymis
  - b) pampiniform plexus
  - c) spermatic cord
  - d) ejaculatory duct
2. Testosterone \_\_\_\_\_.
  - a) is responsible for breast growth
  - b) is the major male sex hormone
  - c) is produced in the prostate
  - d) is part of the blood-testis barrier

3. The scrotum \_\_\_\_.
- is a sack of skin inside the abdominopelvic cavity
  - has a smooth muscle layer called cremaster muscle
  - keeps the testes at a temperature lower than the core body temperature
  - is a mixed exocrine-endocrine gland
4. Which of the following statements is not correct?
- The ductus deferens is also called ejaculatory duct
  - Sperm enter the epididymis in a non-motile state, pass slowly through, and become motile
  - The task of the ductus deferens is to propel sperm during ejaculation
  - The cuff of loose skin covering the glans is called prepuce or foreskin

1.C.2.B.3.C.4.A

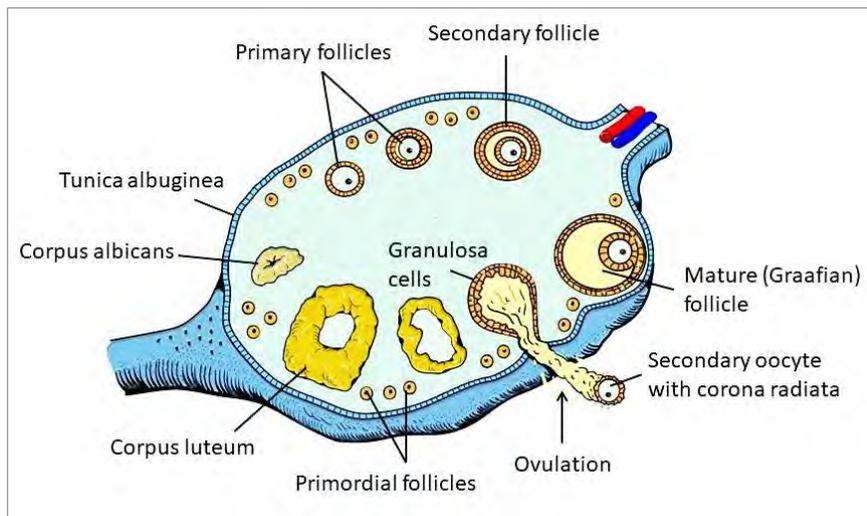
### 16.6 Female Reproductive System

Just like men, women have **one set of primary sex organs**, the ovaries. Ducts, glands, and external genitalia are **secondary reproductive organs**. The **ovaries** produce female gametes (ova; *singular* ovum) and secrete the female sex hormones estrogens and progesterone. **Accessory ducts** include uterine or fallopian tubes, uterus, and vagina.

The **ovaries** are held in place by the ovarian, suspensory, and broad ligaments, and the **mesovarium** (*mes(o)*- middle, *ovar(o)*- ovary, *-ium* noun ending). They receive blood supply from the **ovarian arteries** and the ovarian branch of the **uterine artery**.

Each ovary is surrounded by a white, fibrous capsule (tunica albuginea). The outer region of an ovary is called the **cortex**, the inner region is called the **medulla**. The cortex contains **follicles**, i.e., immature eggs (**oocytes**) surrounded by inner **follicle cells** (one cell layer thick) and outer **granulosa cells**, when more than one layer is present.

Figure 16.6 Ovary, cross-section



Follicles develop in five stages, starting with a **primordial follicle**, which is followed by a **primary follicle**, a **secondary follicle**, a **late secondary follicle**, and finally a **vesicular** or **Graafian follicle**. **Ovulation** is the ejection of an oocyte from the ripening follicle. The ruptured follicle develops into a **corpus luteum**.

The **uterine tubes** are also called **Fallopian tubes** or **oviducts** (*ovi*- egg). The part of the tubes close to the ovary (the **ampulla**), has an expanded end called the **infundibulum** with **ciliated fimbriae**.

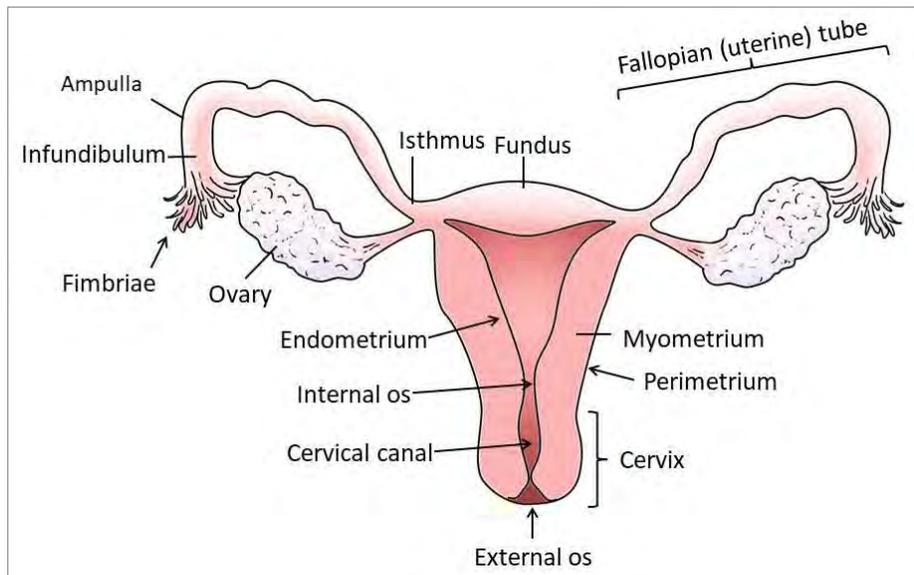
The fimbriae can move to create a current that moves the ejected egg into the uterine tube. The oocyte is carried along by peristalsis and ciliary action. **Nonciliated cells** nourish the oocyte on its way to the uterus and the sperm on its way to meet the oocyte. The constricted region where tube joins the uterus is called **isthmus**.

The **uterus** or **womb** has four parts called the **body** (major portion), **fundus** (rounded, superior region), **isthmus** (narrow, inferior region), and **cervix**, a narrow neck that projects into the **vagina**. The uterus is supported by the **lateral cervical** (cardinal), **uterosacral**, and **round ligaments** as well as the **mesometrium** (*mes(o)*- middle, *metr(o)*- uterus).

The **cervical canal** connects the uterine cavity with the vagina. It has an **internal os** (os = opening, mouth) and an **external os** on the vaginal side. **Cervical glands** secrete mucus that blocks the canal and, thus, prevents entry of pathogens and sperm. Around mid-cycle, the mucus becomes liquid to allow sperm to enter the uterus.

There are two pouches around the uterus; the **vesicouterine** (*vesic(o)-* bladder, *uter(o)-* uterus) **pouch** is situated in the front between the bladder and the uterus, and the **rectouterine** (*rect(o)-* rectum, *uter(o)-* uterus) or **Douglas pouch** is situated in the back between the uterus and the rectum.

Figure 16.7 Female reproductive system, overview



The **uterus wall consists of three layers**:

1. The **perimetrium** (*peri-* around, *-metrium* uterus) is the outermost layer. It is formed by the lining of the peritoneal cavity (peritoneum).
2. The middle layer, called the **myometrium** (*my(o)-* muscle, *-metrium* uterus), is a thick layer of interlacing **smooth muscle cells**.
3. The innermost **endometrium** (*endo-* inside, *-metrium* uterus) is the **mucosal lining of the uterine cavity**. It has two layers:

The **functional layer** (stratum functionalis) **changes in response to ovarian hormones** and is **shed during menstruation** (see below).

The **basal layer** (stratum basalis) does not react to hormones and does not change during the menstrual cycle. A new functional layer develops from the basal layer after menstruation.

The uterus is supplied by **uterine arteries** that arise from the **internal iliac arteries**. They give off **arcuate arteries** to the **myometrium** and **radial arteries** to the **endometrium**. The radial arteries branch into **spiral arteries** for the **functional layer** and **straight arteries** for the **basal layer**.

The **vagina** serves as **birth organ and organ of copulation**. It extends between the bladder in the front and the rectum in the back. Its upper end that surrounds the cervix is called **fornix**; its lower opening is called the **vaginal orifice**. The urethra is embedded into the anterior wall of the vagina. The vagina is lined by a mucus membrane. The folds of excessive mucous membrane that allow the vagina to become bigger during delivery are called **rugae**. Near the vaginal orifice, the mucosa forms a (usually) incomplete partition called the **hymen** (or maidenhead). An intact hymen has been considered proof of the virginity of women in some cultures and religions for more than 2000 years. However, presence or absence of the hymen is no proof of virginity.

The **external female genitalia** are also called **vulva** or **pudendum**. They consist of:

- The **mons pubis** is fatty area overlying the pubic symphysis for mechanical protection during intercourse.
- The **labia majora** are hair-covered, fatty skin folds.
- The **labia minora** are skin folds lying within the labia majora. The recess between them is called **vestibule**.

- The **greater vestibular** or **Bartholin glands** release mucus into the vestibule for lubrication during intercourse. They are the equivalent to the bulbourethral glands in men.
- The **clitoris** consists of erectile tissue hooded by a **prepuce** or **foreskin**. The exposed portion is called the **glans clitoris**.
- The **perineum** is a diamond-shaped region between the pubic arch and the coccyx that is bordered by the ischial tuberosities laterally.

The **breast** or **mammary glands** (*mamma* = breast) are modified sweat glands, consisting of 15–25 **lobes**. Each lobe contains smaller **lobules** that contain the milk-producing **alveoli**.

The milk flows through **lactiferous** (*lacti-* milk, *-ferous* containing) **ducts** to **lactiferous sinuses** that open to the outside at the **nipple**. The pigmented skin surrounding the nipple is called the **areola**.

### Oogenesis

Unlike the formation of sperm in men, which starts during puberty, **oogenesis** (*o(o)-* egg, *-genesis* formation) **already begins in the fetal period**. Girls are born with approximately 500,000 so-called **primary oocytes** (*o(o)-* egg, *-cyte* cell) that develop in **primordial follicles**, begin meiosis I but stall and remain in a resting state until after puberty.

Most of the primary oocytes die over the next few years, and by the time puberty is over, only about 40,000 to 50,000 are left. Each month **after puberty**, a few are **activated** by hormones (see below); however, only one (maybe two) of them is selected to resume meiosis I, which results in two haploid cells, a **secondary oocyte** and a polar body, which contains mainly DNA. The **secondary oocyte** arrests during meiosis II and is **ovulated**. If it is **penetrated by a sperm**, it **completes meiosis II**, yielding a **functional gamete (ovum)** and another polar body. Because of the formation of polar bodies, the sequence yields one giant cell (the largest cell in the human body) filled with cytoplasm.

**Fraternal twins** are possible if more than one egg develops and both eggs become fertilized by sperm. **Identical twins** develop from one fertilized egg (see below).

### Female Sex Hormones

Women produce two types of **sex hormones**, estrogens and progesterone. Just like in men, hormone production starts during puberty. However, **women must grow hormone-producing cells in their ovaries every month from cells surrounding primary follicles**. This explains the fact that women stop producing hormones once they run out of primary follicles later in life (menopause).

**Estrogens** are the **major female sex hormones**.

Figure 16.8 Female breast, cross-section

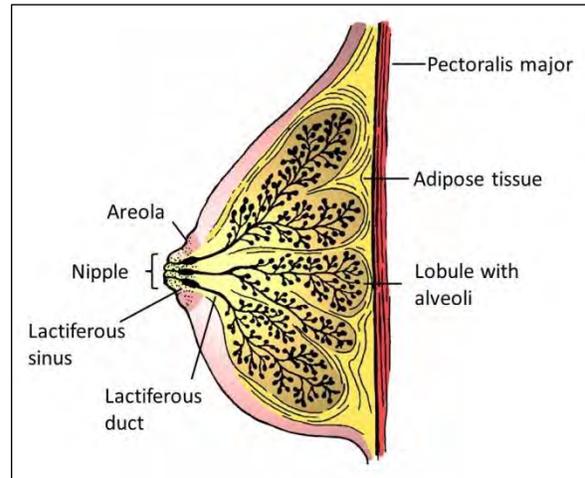
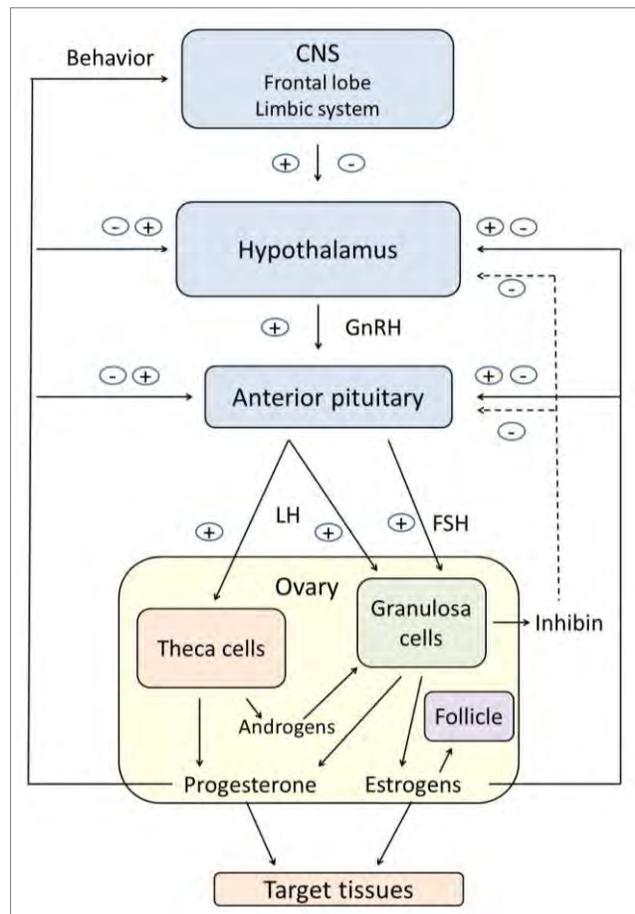


Figure 16.9 Hypothalamus-anterior pituitary-ovary axis



There are three major estrogens called **estrone** (E1), **estradiol** (E2), and **estriol** (E3), with estradiol being the most predominant. Estrogens:

- Promote **oogenesis** and **follicle growth**.
- Induce the **development of secondary sex characteristics**: growth of the breasts, increased deposit of subcutaneous fat (especially around hips, thighs, and breasts), and the widening and lightening of the pelvis.
- Support the **growth spurt** at puberty.
- Exert **anabolic effects on the female reproductive tract**.
- Have a number of **metabolic effects**, including maintenance low total blood cholesterol and high HDL levels, facilitation of calcium uptake and bone density.

**Progesterone**, the second female sex hormone, is far less active. It works with estrogens to **establish and regulate the uterine cycle**. In the second part of the cycle, it gets the endometrium ready for implantation of a fertilized ovum. During **pregnancy**, progesterone inhibits uterine motility and helps prepare the breasts for lactation.

### Ovarian and Menstrual Cycles

The **ovarian cycle** is a monthly series of events **associated with the maturation of an egg**. The average **28 day cycle** has two phases: a **follicular phase** (day 1-14) and a **luteal phase** (day 15-28). **Ovulation** occurs at **mid-cycle**.

If the length of the cycle changes, the luteal phase will still be 14 days long, i.e., a 31 day ovarian cycle has a follicular phase of 17 days and ovulation happens on day 17.

During the first phase, the **follicular phase**, **primordial follicles are activated** and enlarge to become **primary follicles**. One of them becomes dominant and matures into a **secondary follicle** that has layers of **granulosa cells** surrounding the oocyte. In the next step, the **late secondary follicle**, fluid begins to accumulate. Then an **antrum** forms and expands to isolate the oocyte with its **corona radiata** on a stalk. The follicle bulges like a vesicle from the external surface of the ovary, giving rise to the name **vesicular** or **Graafian follicle**.

During **ovulation**, the ovary wall ruptures and **expels the secondary oocyte** together with its **corona radiata**. The egg will be caught by the fimbriae of the fallopian tube and moved inside the tube.

During the second phase, the **luteal phase**, the ruptured follicle collapses and granulosa cells and internal thecal cells form the so-called yellow body (**corpus luteum**; *corpus* = body, *luteum* = yellow), which secretes **estrogens** and **progesterone**.

- If **no pregnancy** occurs, the **corpus luteum degenerates** into a **corpus albicans** (white body; *corpus* = body, *albicans* = white) and hormones production ceases.
- If **pregnancy occurs**, the **corpus luteum produces hormones** until the **placenta** takes over at about three months.

Establishing an **adult ovarian cycle** takes about four years from the onset of puberty (see table 16.2 above). **During childhood**, ovaries grow and secrete **small amounts of estrogens** that **inhibit** the hypothalamic **release of gonadotropin-releasing hormone (GnRH)**. **At puberty**, **leptin** from adipose tissue decreases the estrogen inhibition, **GnRH** is released, causing the **anterior pituitary** to release **follicle-stimulating hormone (FSH)** and **luteinizing hormone (LH)** that act on the **ovaries**. FSH stimulates the growth of primary follicles, and LH causes cells surrounding the growing follicles to produce and secrete estrogens.

An **adult ovarian cycle** starts on **day 1** with the **release of GnRH from the hypothalamus**, which triggers a release of FSH and LH from the anterior pituitary. The gonadotropins stimulate the growth of several follicles and estrogen release from the ovaries. Estrogen release, in a negative feedback, inhibits the further release of FSH and LH, although it also stimulates the production and storage of both gonadotropins. In a positive feedback, estrogen further enhances estrogen output from the ovaries.

At around **day 14** of the ovarian cycle (**mid-cycle**), a sudden **surge in LH levels** causes completion of meiosis I of the primary oocyte and **triggers ovulation**. The LH transforms the ruptured follicle into the **corpus luteum**, which produces three hormones: inhibin, progesterone, and estrogens.

The second phase of the cycle after ovulation is called **luteal phase**, because the hormones secreted by the corpus luteum have a pronounced influence on the ovary and the endometrium of the uterus.

**Towards the end of the cycle** (days 26–28), the corpus luteum degenerates because its cells are programmed to die after 10 days, and hormone levels begin to drop sharply. This leads to changes in the endometrium of the uterus and menstrual flow.

**Menstruation** or **menses** is the normal discharge of blood and shed endometrial tissue at the beginning of each cycle. Other terms for this event are **period** and **menstrual flow**. The first menstruation is called **menarche** (*men(o)-menses, -arche* beginning). It usually occurs between the ages of 11 and 16 (see table 16.2 above).

**Table 16.3 Ovarian and Menstrual (Uterine) Cycle**

Ovarian cycle	Menstrual (uterine) cycle
<p><b>Follicular phase (days 1–14)</b></p> <ul style="list-style-type: none"> <li>Follicle grows under influence of follicle-stimulating hormone (FSH)</li> <li>Luteinizing hormone (LH) causes cells surrounding the follicle to produce and secrete estrogens</li> </ul>	<p><b>Menstrual phase (days 1–5)</b></p> <ul style="list-style-type: none"> <li>Functional layer of endometrium is shed leading to menstrual flow</li> </ul> <p><b>Proliferative (preovulatory) phase (days 6–14)</b></p> <ul style="list-style-type: none"> <li>Increasing estrogen levels prompt generation of new functional layer</li> </ul>
<p><b>Mid-cycle (day 14)</b></p> <ul style="list-style-type: none"> <li>Ovary wall ruptures and expels the mature egg (<b>ovulation</b>)</li> <li><b>Mid-cycle pain</b> (<i>Mittelschmerz</i>) = twinge of pain sometimes felt during ovulation</li> <li>1–2% of ovulations release more than one secondary oocyte, which, if fertilized, results in fraternal twins</li> </ul>	
<p><b>Luteal phase (days 15–28)</b></p> <ul style="list-style-type: none"> <li>Ruptured follicle collapses; cells form <b>corpus luteum</b></li> <li>Corpus luteum secretes progesterone and estrogen</li> <li>If <b>pregnancy</b> occurs, corpus luteum produces hormones until the placenta takes over at about 3 months</li> <li>If <b>no pregnancy</b>, the corpus luteum degenerates into a corpus albicans</li> <li>GnRH causes the anterior pituitary to secrete FSH and LH, which start another follicular phase</li> </ul>	<p><b>Secretory (postovulatory) phase (days 15–28)</b></p> <ul style="list-style-type: none"> <li>High progesterone levels prompt further development of endometrium</li> <li>Endometrial glands secrete glycogen</li> <li>Formation of the cervical mucus plug</li> <li>If <b>no pregnancy</b>, arteries kink and cut off blood supply to cells of functional layer; cells die</li> <li>Reopening of arteries causes transition to menstrual phase</li> </ul>

**Menopause** (*men(o)-menses, -pause* stopping) is the cessation of menses once all follicles in the ovaries have been used or have died. By definition, menopause has occurred when menses have ceased for an entire year. The transition period leading up to menopause is called **climacterium**. However, the term menopause is often used to describe this period of change, as well. The **perimenopausal period** covers the last few years before and the first couple of years after menopause.

The **menstrual** or **uterine cycle** describes **changes in the endometrium** in response to the **changing levels of ovarian hormones**. The average menstrual cycle has 28 days but can be longer or shorter depending on the ovarian cycle. It has three phases:

- 1. Menstrual phase: Days 1–5** of the menstrual cycle during which the functional layer (stratum functionalis) is shed and the menstrual flow (menstruation) occurs. Ovarian hormones are at their lowest levels.
- 2. Proliferative phase: Days 6–14** of the menstrual cycle are also called the **preovulatory phase** because the ovary has not yet ovulated the egg. High estrogen levels lead to the generation of a new functional layer and increased synthesis of progesterone receptors in the endometrium.
- 3. Secretory phase: Days 15–28** of the menstrual cycle are also called the **postovulatory phase** because they occur after ovulation. High progesterone levels cause further development of the endometrium, secretion of glycogen to nourish a fertilized egg, and formation of a **cervical mucus plug**.

If **fertilization does not happen**, the **corpus luteum degenerates** and forms a **corpus albicans**. **Progesterone levels fall**, causing **hormone-sensitive spiral arteries** to **kink and spasm**, which causes **endometrial cells** to **die**.

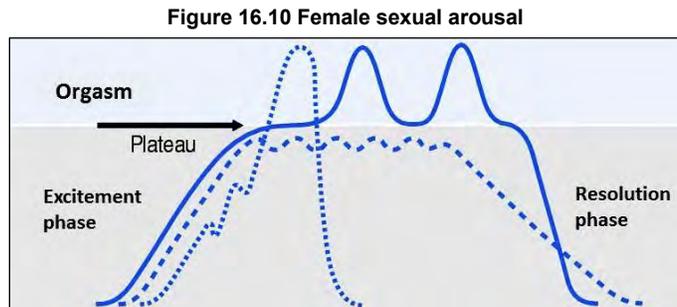
The **arteries** then **relax** and open wide, the resulting rush of blood fragments the weakened capillary beds, and the **functional layer sloughs as menstrual bleeding**.

### Female Sexual Response

The female sexual response is initiated by touch and psychological stimuli. The **clitoris**, **vaginal mucosa**, and **breasts engorge** with blood, and the secretions of the **greater vestibular glands lubricate the vestibule** to ease penetration.

The **orgasm** is accompanied by muscle tension, increase in pulse rate and blood pressure, and rhythmic contractions of the uterus. Women do not have a refractory period following the orgasm and can experience multiple orgasms in a single sexual experience.

Unlike in men, where the orgasm leads to the semen being ejaculated, the **female orgasm is not essential for conception** itself, as ovulation is independent from sexual activity and only regulated by hormones.



### Check Your Understanding

- Which of the following statements about the menstrual cycle is correct?
  - The preovulatory phase is also called menstrual phase
  - Menstruation takes place on days 15-28
  - The endometrium changes in response to the changing levels of ovarian hormones
  - The menstrual cycle always has 28 days
- Which of the following statements is *not* correct?
  - The second phase is called luteal phase
  - Ovulation occurs at mid-cycle
  - The corpus luteum develops only if pregnancy occurs
  - If the length of the cycle changes, the luteal phase will still be 14 days long
- The middle layer of the uterus is called \_\_\_\_\_.
  - endometrium
  - perimetrium
  - mesometrium
  - myometrium
- Progesterone \_\_\_\_\_.
  - promotes oogenesis and follicle growth
  - supports the growth spurt at puberty
  - increases bone density
  - prepares the endometrium for implantation of a fertilized ovum

1.C.2.C.3.D.4.D

## 16.7 Pregnancy

**Pregnancy** or **gestation** is the time from fertilization until the infant is born. The developing offspring is called a **conceptus**. In a **multiple pregnancy**, more than one offspring develop at the same time; **fraternal** and **identical twins** are the most common multiple pregnancies.

The **gestation period** is the time from the first day of the last menstrual period (LMP) until birth (approximately 280 days). Measured from conception (usually day 14 of the last menstrual cycle), the gestation period is about 38 weeks. The **embryonic period** covers the time from fertilization through week eight and the baby is known as an **embryo**. During this period, the formation of all body organs and systems (**organogenesis**) takes place. The **fetal period** covers the time from the beginning of week nine until birth and the baby is now called a **fetus**.

Under **clinical aspects**, pregnancy is divided into three **trimesters of unequal length**:

- The **first trimester extends from conception until the end of week 12**. At the end of the first trimester all body organs and systems have been formed, and the placenta is developed enough to keep the baby alive.
- The **second trimester extends from the beginning of week 13 until the end of week 28**. By the end of the second trimester, more than 90% of babies can survive outside of the uterus if born prematurely.
- The **third trimester extends from the beginning of week 29 through week 40 (or delivery)**.

**Conception** of a child is a complicated process involving multiple steps. The **ovulated oocyte is viable for 12 to 24 hours; sperm is viable for 24 to 48 hours after ejaculation.** For **fertilization to occur, coitus must occur** no more than **2 days before ovulation or no later than 24 hours after ovulation.**

**The odds are against fertilization** happening, as most of the sperm fail to make it through the cervical canal into the uterus. The vast majority of sperm cells either leaks out of the vagina or is destroyed by the acidic environment of the vagina. Of the sperm cells that reach the uterus, just a few hundred to a few thousand reach the ovarian tubes. Remember, the average ejaculate contains 20–150 million sperm/mL.

The sperm still must travel all the way to the end of the tubes to meet the oocyte for fertilization. However, the oocyte is protected by cells (*corona radiata* = radiating crown) and a tough outer wall. It can take the enzymes from the acrosomes of hundreds of sperm cells to weaken that wall enough for one sperm to slip through into the cell.

Once a sperm is inside the cell, it loses its tail and midpiece, and the head moves towards the nucleus of the oocyte. **Fertilization** is the process of a sperm's chromosomes combining with the chromosome of the egg (oocyte). The fertilized egg is called a **zygote**. It immediately **begins to undergo** divisions called **cleavages**. The **first cleavage is completed after 24 hours** and creates two identical daughter cells called blastomeres. If the cells separate and both cells implant and grow, they create **identical twins**.

Once the embryo consists of more than 16 cells, it is called a **morula**. The next stage, the **blastocyst** (*blast(o)*- immature cell, bud), **reaches the uterus 3-4 days after fertilization.** It already consists of more than 100 cells. Its **trophoblast cells** (*troph(o)*- nourishment -*blast* immature cell, bud) will participate in the formation of the placenta (**placentation**), while the so-called **inner cell mass** will form the **embryo** and the **embryonic membranes**.

The **blastocyst floats for 2-3 days inside the uterine cavity** before implanting into the endometrium. **Implantation** is completed by the twelfth day after ovulation. After successful implantation, the blastocyst is transformed into a **gastrula**. In the next step, the germ layers and embryonic membranes develop. The embryo has **three germ layers** from which all tissues and organs derive:

1. The outer **ectoderm** (*ecto*- outside, -*derm* skin) forms the nervous system and the epidermis of the skin.
2. The inner **endoderm** (*endo*- inside, -*derm* skin) forms the epithelial linings of the digestive, respiratory, and urogenital systems, and their associated glands.
3. The middle **mesoderm** (*meso*- middle, -*derm* skin) forms all other tissues, such as muscles and internal organs.

The **chorion** is the outermost of the **embryonic membranes**. It helps to form the placenta and encloses the embryonic body and all other membranes. The **amnion** forms the transparent sac containing the embryo. It is filled with **amniotic fluid** that provides a buoyant environment, which protects the embryo from physical trauma. The **yolk sac** forms part of the gut of the embryo and produces the earliest blood cells and blood vessels. It is also the origin of germ cells that migrate into the embryo to seed the **gonads** (testicles and ovaries). The **allantois** forms the base for the **umbilical cord**. It also becomes part of the urinary bladder of the baby.

The **placenta** (also known as **afterbirth**) received its name from the fact that it looks like a flat cake (placenta means flat, slab-like in Greek). It connects the developing fetus to the uterus and creates an interface for the exchange of nutrients, gases (oxygen, carbon dioxide), and waste products between the blood of the fetus and the mother. The placenta also produces hormones that keep the fetus alive and stop the ovaries from producing new eggs while still pregnant. It has a fetal part (**chorion**) and a maternal part (**decidua**). The **umbilical cord** contains blood vessels that transport blood from the fetus to the placenta (**umbilical arteries**) or from the placenta to the fetus (**umbilical vein**).

### Pregnancy Hormones

**Human chorionic gonadotropin** (hCG) is first secreted by **trophoblast cells** and later by the **chorion**. It stimulates the corpus luteum to continue secretion of progesterone and estrogen until about three months, when the placenta is ready to secrete enough hormones to keep the pregnancy going. Pregnancy tests look for hCG in the urine or the blood.

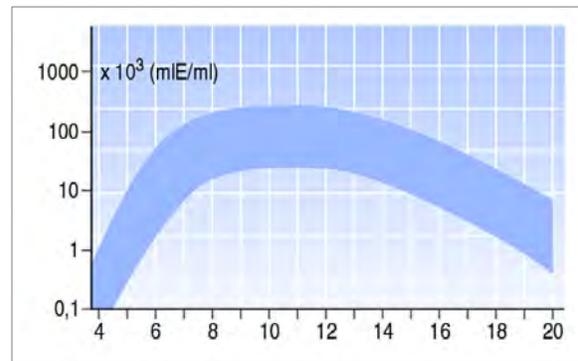
As the **placenta** grows, it **produces a number of hormones** to help the baby grow and the mother's body to adjust to the pregnancy and delivery.

- **Estrogens** and **progesterone** are vital for the development of the uterus and the fetus.
- **Inhibin** stops the anterior pituitary from releasing FSH to make sure no additional follicle can develop during the pregnancy.
- **Relaxin** causes pelvic ligaments and the pubic symphysis to soften and relax. This allows the pelvis to increase

in size during delivery. On the other hand, it makes the pelvis less stable and explains the wide walk of pregnant women.

- **Human placenta lactogen** (hPL) supports estrogens and progesterone in getting the breast gland ready for lactation. It also promotes fetal growth and causes the maternal metabolism to burn fatty acids in tissues other than nervous tissue. This so-called glucose-sparing effect saves glucose for the nervous system of the mother and the baby.
- **Human chorionic thyrotropin** (hCT) increases the metabolic rate of the mother. Due to the heat created by the increased metabolic activity of the cells, pregnant women often feel warm and sweat more even when the environment is cold.

**Figure 16.11 Human chorionic gonadotropin levels through week 20**



**Women go through a number of changes and adaptations during pregnancy** that are designed to help their body adjust to the pregnancy and to create the best possible environment for the baby to grow. The **average weight gain** during pregnancy is 25-30 pounds. It is mainly due to the growth of the fetus as well as the maternal reproductive organs and breasts and the increased blood volume of the mother. The **uterus enlarges enormously** from its normal size (2" x 6") to accommodate the growing fetus. This growth and the weight of the uterus and its content shift the woman's center of gravity and causes accentuated lordosis of the lumbar curvature.

**Morning sickness** in the first few months of pregnancy is caused by elevated levels of sex hormones to which the body must get used to. **Heartburn** is caused by displacement of the esophagus; **constipation** is a result of the decreased motility of the digestive tract. The **blood volume increases** to accommodate the needs of the fetus, leading to a **rise in blood pressure** and an **increased heart rate**. The **kidneys produce more urine**, because there is additional fetal metabolic waste to excrete. Many pregnant women suffer from difficult breathing (**dyspnea**) and their breathing rate is faster than normal.

### Delivery

Delivery or **parturition** is the process of giving birth. Most births happen within 15 days of the expected **due date**, which is **280 days from the first day of the last period before pregnancy**.

There are **three stages of labor**:

1. The **dilation stage** extends from the onset of labor to the time when the cervix is fully dilated (about 10 cm; 4 inches) by the baby's head.
2. The **expulsion stage** extends from full dilation until the time the infant is delivered. **Crowning** occurs when the baby's head distends the vulva. When the baby is in the **vertex** or **head-first position**, the skull acts as a wedge to dilate the cervix, vagina, and vulva. Once the head has been delivered, the rest of the baby follows much more easily. After birth, the umbilical cord is clamped and cut.
3. During the **placental stage**, uterine contractions cause detachment of the placenta from the uterine wall. This allows for delivery of the placenta and the membranes (afterbirth).

The **average full-term baby weighs about 7.5 pounds**. Only 5% are lighter than 5.5 pounds or heavier than 10 pounds. The **average length** of full-term babies is **20 inches** (18–22 inches). In the first month, a healthy full-term baby gains about 4-8 ounces of weight per week and grows 1.5-2 inches.

**Lactation** is the production of milk by the mammary glands. Milk production is stimulated by the hormone **prolactin** from the anterior pituitary. Prolactin secretion, itself, is regulated by the **prolactin-releasing hormone** (PRH), which is produced by the hypothalamus under the influence of placental estrogens, progesterone, and lactogen.

The first high-protein, low-fat milk secreted by the breast glands is called **colostrum**. True breast milk is secreted within two to three days.

Stimulation of the nipples during breast feeding causes the release of **oxytocin** from the posterior pituitary and of PRH from the hypothalamus. PRH leads to a release of prolactin and increased milk production; oxytocin causes the so-called **letdown reflex**, resulting in the release of milk from the glands of both breasts.

There are many benefits to breast milk, such as better absorption and more efficient metabolism of many components; antibodies and other chemicals that protect the infant; a natural laxative effect that helps to prevent physiological jaundice; and encouragement of the natural intestinal fauna. Formula has proven to be as beneficial for the babies' growth and development. However, recent studies indicate that babies fed non-cow milk (such as soy or almond milk) may lack calcium and other nutrients leading to shorter growth than babies who receive breast milk or formula.

### Genetic Sex

**Women** have **two sex chromosomes (XX)** in each body cell; their gametes (**oocytes**) have **one X chromosomes** each. Men have **one X chromosome and one Y chromosome** in each body cell; sperm cells contain either one X chromosome or one Y chromosome. **The genetic sex of the offspring is determined by the sex chromosome carried by the sperm.**

- If an egg is fertilized by an X sperm, the zygote has two X chromosomes and the baby is genetically female.
- If an egg is fertilized by a Y sperm, the zygote has one X chromosome and one Y chromosome and the baby is genetically male.

The **SRY** (sex-determining region on the Y chromosome) **gene** on the Y chromosome initiates testes development and maleness. Without it, an XY individual will develop female sex characteristics.

The embryo goes through a **sexually indifferent stage** at first. The **development of the external genitalia depends on which sex hormones, male or female, are present.** Male sex hormones lead to the development of a penis from the genital tubercle; female sex hormones lead to the development of a clitoris. Male sex hormones cause the urethral fold to form the male urethra; estrogens lead to the formation of the labia minora. The labioscrotal folds develop either into the labia majora (estrogens) or the scrotum (androgens).

The **gonads** begin their development in the area close to the kidney during the seventh week in males and the eighth week in females. About two months before birth, **testosterone stimulates the migration of the testes** out of the abdominopelvic cavity and toward the **scrotum**, where they arrive around the time of birth. Testicles that fail to descend (**maldescensus testis**) have a very high rate of testicular cancer. The **ovaries** also descend but are anchored by the broad ligament and, therefore, stay inside the pelvic cavity.

**Table 16.4 Terms Associated with Pregnancy and Birth**

Term	Meaning	Example(s)
gravida	pregnant woman	<i>nulligravida</i> = a woman who has never been pregnant <i>primigravida</i> = a woman who is pregnant for the first time or has been pregnant once before <i>multigravida</i> = a women who is pregnant for the second time or has been pregnant at least twice
para	a woman who has given birth at least once	<i>nullipara</i> = a woman who has never born a child <i>primipara</i> = a woman who has given birth once <i>multipara</i> = a woman who has given birth twice or more
parous	having given birth one or more times	<i>nulliparous</i> or <i>nonparous</i> = never having borne a child <i>primiparous</i> = giving or having given birth for the first time <i>multiparous</i> = having given birth more than once
natal	relating to birth (from the baby's point of view)	<i>prenatal</i> or <i>antenatal</i> = (occurring) before birth <i>postnatal</i> = (occurring) after birth <i>perinatal</i> = relating to the period from about five months (week 20) before birth to one month after birth <i>neonatal</i> = relating to the first four week (28 days) after birth
ante partum, pre partum	occurring before delivery (from the mother's point of view)	<i>ante partum bleeding</i> = bleeding after the 24 <sup>th</sup> week of gestation but before delivery
peri partum	occurring during the last month of pregnancy and the first five months after delivery (from the mother's point of view)	<i>peri partum cardiomyopathy</i> = uncommon form of heart failure that occurs during the last month of pregnancy or up to five months after delivery

postpartum, puerperal	occurring after delivery (from the mother's point of view)	<i>postpartum period</i> or <i>puerperium</i> = the first six weeks after delivery
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## Birth Control

Birth control or **contraception** is a term for methods used to prevent pregnancy.

- **Hormonal birth control** includes the use of birth control pills, hormone injections or skin patches, hormone implants under the skin, and vaginal rings. Some IUDs (see below) also release small amounts of hormone.
- **Intrauterine devices (IUDs)** are inserted into the uterine cavity. They prevent implantation of a fertilized egg by causing a local inflammation (**copper IUD**) or the release of levonorgestrel (**hormone IUD**).
- **Barrier methods** are physical contraceptives that prevent the sperm from getting into the uterus. They include condoms, diaphragms, sponges, and cervical caps.
- **Emergency contraceptives** (so-called **Plan B** or **morning-after pill**) are used to prevent pregnancy after unprotected sex or failure of barrier methods, e.g., condom rupture. The pill contains 1.5 mg levonorgestrel.
- **Permanent birth control** or **sterilization** can be used by women (**tubal ligation**) or men (**vasectomy**).

## 16.8 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	male	_____	salping(o)-
2.	vagina	_____	oophor(o)-
3.	testicle	_____	mast(o)-
4.	ovarian tubes	_____	andr(o)-
5.	breast	_____	colp(o)-
6.	ovary	_____	metra-
7.	uterus	_____	orchi(o)-

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- The glans penis is a part of the male duct system. \_\_\_\_\_
- Semen passes from the vas deferens to the ejaculatory duct to the urethra. \_\_\_\_\_
- Spermatogenesis delivers sperm with 23 chromosomes only. \_\_\_\_\_
- Testosterone is produced throughout a man's life. \_\_\_\_\_
- The secretions of the accessory glands make up 70% or more of the semen. \_\_\_\_\_
- Viable sperm cannot be produced at below body temperature. \_\_\_\_\_
- The penis is the primary sex organ in men. \_\_\_\_\_

8. The hormone that causes secondary sex characteristics in males is progesterone. \_\_\_\_\_
9. Sperm formation starts before puberty. \_\_\_\_\_
10. The male urethra transports both urine and semen at different times. \_\_\_\_\_
11. During the secretory phase of the uterine cycle progesterone levels are the highest. \_\_\_\_\_
12. The bladder is located in front of the uterus. \_\_\_\_\_
13. The mammary gland is structurally the same in men and women. \_\_\_\_\_
14. The formation of female gametes begins at puberty and continues throughout life. \_\_\_\_\_
15. The corpus luteum secretes progesterone and estrogens. \_\_\_\_\_
16. The diamond-shaped area between the coccyx, pubic arch, and ischial tuberosities in the female is the vulva. \_\_\_\_\_
17. Without pregnancy, the corpus albicans degenerates into a corpus luteum. \_\_\_\_\_
18. Female accessory ducts include uterine or fallopian tubes, uterus, and vagina. \_\_\_\_\_
19. The placenta is also known as afterbirth. \_\_\_\_\_
20. Women have two X chromosomes, men one X and one Y chromosome. \_\_\_\_\_

**Matching**

*Choose the item in column 2 that best matches each item in column 1.*

- |                       |  |           |
|-----------------------|--|-----------|
| 1. Epididymis         | a) produces a thick, yellowish secretion                 | 1. _____  |
| 2. Testis             | b) foreskin  | 2. _____  |
| 3. Corpora cavernosa  | c) ejaculation   | 3. _____  |
| 4. Prostate           | d) sperm maturation                                      | 4. _____  |
| 5. Tunica albuginea   | e) release androgen binding protein                      | 5. _____  |
| 6. Prepuce            | f) only human cell with a tail                           | 6. _____  |
| 7. Vasectomy          | g) white fibrous capsule of testis                       | 7. _____  |
| 8. Sympathetic system | h) testosterone  | 8. _____  |
| 9. Sertoli cells      | i) cutting and ligation of vas deference                 | 9. _____  |
| 10. Sperm             | j) cause the appearance of secondary sex characteristics | 10. _____ |
| 11. Myometrium        | k) week 29 through week 40                               | 11. _____ |
| 12. Estrogens         | l) production of milk                                    | 12. _____ |

- |                      |   |           |
|----------------------|---|-----------|
| 13. Gestation        | m) after ovulation                                  | 13. _____ |
| 14. Third trimester  | n) first eight weeks of pregnancy                   | 14. _____ |
| 15. Ovulation        | o) day 1-5 of uterine cycle                         | 15. _____ |
| 16. Embryonic period | p) time from fertilization until the infant is born | 16. _____ |
| 17. Secretory phase  | q) fertilized egg                                   | 17. _____ |
| 18. Zygote           | r) erectile tissue in the penis                     | 18. _____ |
| 19. Menstrual phase  | s) caused by LH surge                               | 19. _____ |
| 20. Lactation        | t) muscular layer of the uterus                     | 20. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Which structure is the site of sperm production?
  - Vas deferens
  - Seminiferous tubules
  - Albuginea
  - Epididymis
- Which cells secrete testosterone?
  - Sertoli cells
  - Spermatogenic cells
  - Leydig cells
  - Chief cells
- The function of the epididymis is \_\_\_\_\_.
  - sperm maturation
  - sperm production
  - spermatid storage
  - provide nutrition to sperm
- Which of the following lies posterior to the bladder and anterior to the rectum and secretes an alkaline fluid?
  - Prostate
  - Cowper's glands
  - Seminal glands
  - Epididymis
- The \_\_\_\_ are male accessory glands.
  - Cowper glands
  - vas deferens
  - ejaculatory glands
  - Bartholin glands
- Erection of the penis \_\_\_\_\_.
  - is caused by a parasympathetic reflex
  - has a refractory period
  - is caused by a sympathetic reflex
  - is initiated by GnRH

7. In the hypothalamus-pituitary-testis axis \_\_\_\_\_.
  - a. sperm is produced by positive feedback
  - b. inhibin suppresses testosterone release
  - c. FSH is needed for ABP production
  - d. GnRH is released by the anterior pituitary
  
8. What is produced by the ovaries?
  - a. Primary oocytes, insulin and estrogen
  - b. Secondary oocytes, progesterone and testosterone
  - c. Tertiary oocytes, insulin and estrogen
  - d. Secondary oocytes, estrogen and progesterone
  
9. Which is the usual site of fertilization of the egg?
  - a. Ureters
  - b. Uterine tubes
  - c. Ovaries
  - d. Vagina
  
10. Which is the portion of the uterus that opens into the vagina?
  - a. Urethra
  - b. Cervix
  - c. Vulva
  - d. Inguinal canal
  
11. \_\_\_\_\_ secreted by the \_\_\_\_\_ controls the ovarian and uterine cycles.
  - a. FSH, anterior pituitary
  - b. LH, anterior pituitary
  - c. GnRH, hypothalamus
  - d. Estrogens, ovaries
  
12. Which hormone triggers ovulation?
  - a. GnRH
  - b. LH
  - c. FSH
  - d. Estrogen
  
13. The fusion of the secondary oocyte and the sperm results in which developmental stage?
  - a. Female pronucleus
  - b. Male pronucleus
  - c. Zygote
  - d. Morula
  
14. In the developing fetus all body systems are present by \_\_\_\_\_.
  - a. 8 weeks
  - b. 12 weeks
  - c. 20 weeks
  - d. 40 weeks
  
15. Which of the following is ***not*** a sex hormone?
  - a. estrogen
  - b. aldosterone
  - c. testosterone
  - d. progesterone

16. After successful implantation has occurred, the corpus luteum is maintained by a hormone called \_\_\_\_.
- FSH
  - hCG
  - hCT
  - hPL
17. Which of the following is in the correct chronological order?
- Zygote, morula, blastocyst
  - Zygote, blastocyst, morula
  - Blastocyst, morula, zygote
  - Morula, zygote, blastocyst
18. Which of the following statements is ***not*** correct?
- The third trimester extends from the beginning of week 29 through week 40.
  - The embryonic period covers the time from fertilization through week eight.
  - Implantation is completed by the second day after ovulation.
  - The fertilized egg is called a zygote.
19. Which of the following statements is correct?
- The gestation period covers the time from fertilization through week eight.
  - The first trimester extends from conception until birth.
  - From the beginning of week nine until birth, the baby is called a fetus.
  - The gestation period is about 38 lunar months.
20. The average menstrual cycle has \_\_\_\_ days.
- 28
  - 2-7
  - 12-24
  - 280

## Chapter 17 Cardiac Anatomy & Physiology

### 17.1 Chapter Outline

The cardiovascular system consists of the heart and the blood vessels. The heart generates the force to pump the blood into the circulation and the blood vessels distribute the blood to tissues and organs.

### 17.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the size, shape, location, and orientation of the heart in the thorax.
- Name the coverings of the heart.
- Explain the structure and function of each of the three layers of the heart wall.
- Describe the structure and functions of the four heart chambers.
- Trace the pathway of blood through the heart.
- Name the major branches and describe the distribution of the coronary arteries.
- Explain the heart valves and describe their location, function, and mechanism of operation.
- Describe the structural and functional properties of cardiac muscle, and explain how it differs from skeletal muscle.
- Explain the events of cardiac muscle cell action potential.
- Name the components of the conduction system of the heart, and trace the conduction pathway.
- Draw a diagram of a normal electrocardiogram tracing, name the individual waves and intervals, and indicate what each represents.
- Explain normal heart sounds and how heart murmurs differ.
- Describe the timing and events of the cardiac cycle.
- Define cardiac output and how changes to heart rate and stroke volume affect cardiac output.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 17.3 Combining Forms

Table 17.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 17.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
angi(o)-	vessel	<i>angiostenosis</i> = narrowing of a blood vessel
aort(o)-	aorta	<i>aortic</i> = relating to the aorta
arteri(o)-	artery	<i>arteriosclerosis</i> = hardening of an artery
atri(o)-	atrium	<i>atrioventricular</i> = relating to an atrium and a ventricle
cardi(o)-, card(o)-	heart	<i>cardiomegaly</i> = enlargement of the heart
coron(o)-	crown (corona)	<i>coronary arteries</i> = arteries that supply the heart muscle with blood
valv(o)-, valvul(o)-	valve	<i>valvuloplasty</i> = surgical repair or replacement of a heart valve
vas(o)-, vascul(o)-	vessel	<i>vasodilator</i> = drug that dilates blood vessels

ven(o)-, veni-	vein	<i>venous</i> = relating to a vein or veins
ventricul(o)-	ventricle	<i>ventricular</i> = relating to a ventricle

## 17.4 Cardiac Anatomy

The **cardiovascular system** consists of the **heart** (*cardio-* = heart) and the **blood vessels** (*vascular* = vessel) that form the circulatory system. The heart's job is to pump blood into the blood vessels that carry it to all organs and tissues, and back again to the heart. Blood vessels that carry blood away from the heart are called **arteries**; blood vessels returning blood to the heart are called **veins**.

Functionally speaking, the heart consists of two side-by-side pumps: the **right heart** is the pump for the **pulmonary circulation** and the **left heart** is the pump for the **systemic circulation**.

The **heart** is approximately **the size of a fist** and is **located** in the space between the lungs (the **mediastinum**) close to the anterior wall of the thoracic cage between the second rib and fifth intercostal space (above the sixth rib).

Although we feel the heart beat on the left side of our chest, only **two-thirds of the heart** is located to the **left of the midsternal line**, anterior to the vertebral column, and **posterior to the sternum**. The other one-third is actually to the right of the middle of the sternum.

The heart is **cone-shaped** with the tip of the cone (the **apex**) **pointing downwards toward the left hip**. The average heart **weighs about 9-10 ounces** and **beats 125,000-150,000 times per day**. This adds up to about **45-50 million beats per year** and about **4-6 billion beats over our lifetime**. During that time, the heart will pump an estimated **75 million gallons of blood**, enough to fill 120 Olympic-sized swimming pools.

The heart is enclosed in a **double-walled sac called the pericardium** (*peri-* around, *cardi(o)-* heart). The pericardium is a typical **serosa**, i.e., it has a **parietal layer** that covers the wall of the cavity and a **visceral layer** that covers the organ (= heart) inside the cavity.

Because the pericardium has to protect and anchor the heart, it has a tough outer layer, the **fibrous pericardium**. Its inner surface is lined by the **parietal pericardium**, while the **visceral pericardium** covers the external surface of the heart. The visceral pericardium is fused with the underlying heart muscle and, therefore, forms the outermost layer of the heart wall called the **epicardium**. The (virtual) space between those two serous membranes, the **pericardial cavity**, is filled with a tiny amount of fluid that acts as a lubricant to reduce friction.

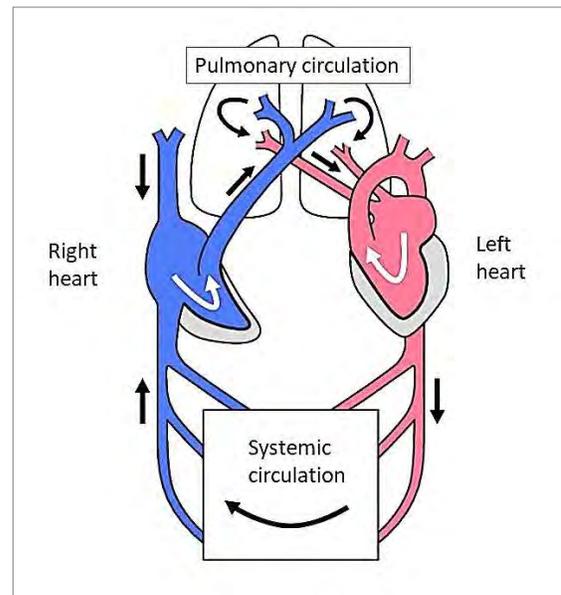
The wall of the heart has three layers: the epicardium, myocardium, and endocardium.

1. The outer layer, or **epicardium** (*epi-* above, upon, *cardi(o)-* heart), is also the visceral layer of the serous pericardium (see above). It consists of a single layer of cells.
2. The middle layer consists of spiral bundles of cardiac muscle cells; therefore, it is called **myocardium** (*myo-* muscle, *cardi(o)-* heart). The **fibrous skeleton of the heart** inside the myocardium is made of a crisscrossing, interlacing layer of connective tissue. It anchors cardiac muscle fibers, supports great vessels and valves, and limits the spread of action potentials to specific pathways.
3. The innermost layer is formed by an epithelium covering the inside of the heart wall. It is called **endocardium** (*endo-* inside, within, *cardi(o)-* heart). The endocardium continues as the innermost layer of all of the blood vessel; it is then called endothelium.

### Atria and Ventricles

The heart has **four separate chambers: two atria and two ventricles**. The atria are separated by the thin **interatrial septum** (*inter-* between, *atri(o)-* atrium), the ventricles are separated by the much thicker and muscular **interventricular septum** (*inter-* between, *ventricul(o)-* ventricle).

Figure 17.1 Pulmonary and systemic circulation

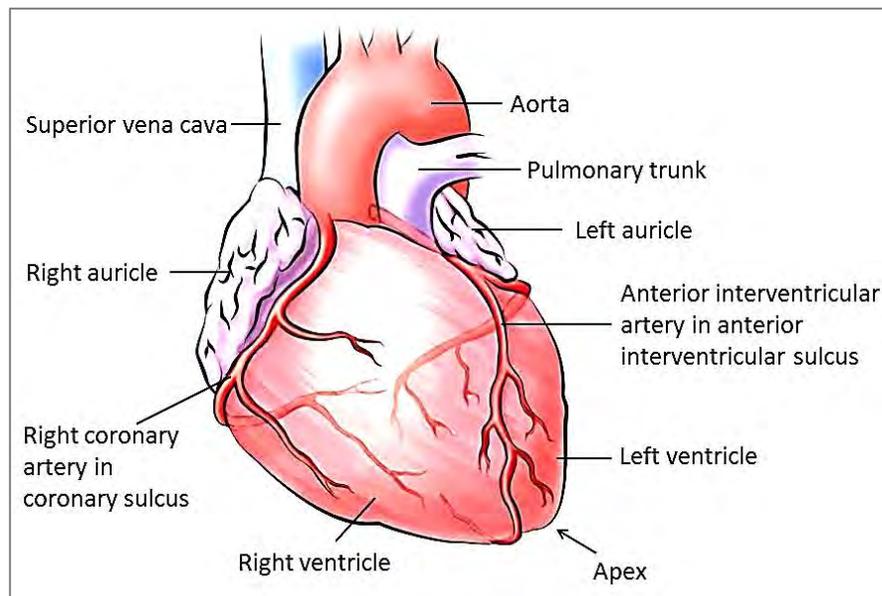


The border between atria and ventricles can be seen even on the outside of the heart as the so-called **atrioventricular groove** that encircles the junction of the atria and ventricles. The atria are located above the groove; the ventricles are located below. Because the major arteries supplying the heart muscle with oxygen run in the groove, it is also called **coronary sulcus**.

The atria, themselves, cannot be seen from the outside as they are covered by two structures that resemble dog ears and, accordingly, are called **auricles** (*auricle* = little ear). The auricles' function is to increase the volume of the atria so they can hold more blood.

The border between the ventricles can also be seen on the outside. There are two shallow grooves (sulci): one on the anterior aspect of the heart (**anterior interventricular sulcus**) and one on the posterior aspect (**posterior interventricular sulcus**). When we look at the heart from the front (anterior view), the right ventricle is to the right of the anterior interventricular sulcus; the left ventricle, to the left.

Figure 17.2 Heart, anterior view



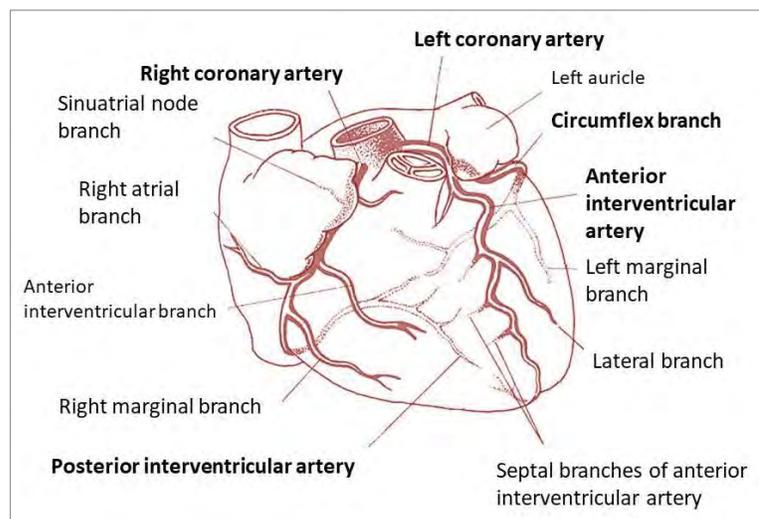
The **atria are the receiving chambers** of the heart. They have thin muscular walls that are ridged by **pectinate muscles**. The **right atrium** receives blood from the **inferior and superior vena cava** and the **coronary sinus**; the **left atrium** receives blood from the **right and left pulmonary veins**.

The **ventricles are discharging**, i.e., **pumping chambers** with thick muscular walls that are ridged by **trabeculae carneae**. Both ventricles also have cone-shaped **papillary muscles** that project into the ventricular cavities. These muscles are anchors for the strings that hold some of the heart valves in place (see below).

The blood is pumped from the right ventricle into the **pulmonary trunk** and from the left ventricle into the **aorta**. Both vessels are considered arteries because they lead the blood away from the heart. The pulmonary trunk is the beginning of the pulmonary circuit; the aorta is the first vessel of the systemic circuit.

The **pulmonary circuit** is a short, low-pressure circulation, while the **systemic circuit** is a much long circulation with higher pressure. The anatomy of the ventricles reflects these differences: **the wall of the left ventricle is much thicker than the wall of the right ven-**

Figure 17.3 Coronary arteries



**tricle and the interventricular septum is part of the left ventricular wall.**

Regardless of these pressure differences, **equal volumes of blood have to be pumped through the pulmonary and systemic circuits at any given time**; any disequilibrium is pathologic.

The third circulation, the **coronary circulation**, is much shorter but nevertheless at least as important as the systemic and pulmonary circuits as it supplies the heart muscle itself with blood and drains it into the right atrium. The **coronary arteries** form what looks like an upside-down crown (Latin *corona*), which gave the circulation its name. The major coronary arteries are the **right and left coronary arteries** (in the atrioventricular groove), **marginal artery**, **circumflex artery**, and **anterior and posterior interventricular arteries**. Arterial supply of the myocardium varies considerably and contains many anastomoses (junctions) among branches. Collateral routes provide additional routes for blood delivery.

**Major veins** of the heart are the **small cardiac vein**, **anterior cardiac vein**, **great cardiac veins**, and the **coronary sinus**.

### Heart Valves

The only way to make sure that blood moves in a unidirectional flow and always in the right direction through the heart and the circuits is by using **heart valves** to direct the flow. There are four valves overall: two atrioventricular valves and two semilunar valves.

The **atrioventricular valves** or **AV valves** are located at the junction of the atria and the ventricles. Their task is to allow blood flow from the atria into the ventricles and to **stop blood from flowing back into the atria**. Each valve consists of sail-shaped structures called **cusps** and strings that hold them in place (the **chordae tendineae**).

The valve between the right atrium and right ventricle is called **right AV valve** or **tricuspid valve** because it has three cusps. The corresponding valve on the left side has three names: **left AV valve** because of its location, **bicuspid valve** because it has only two cusps, and **mitral valve** because it resembles the hat worn by a catholic bishop (mitre).

The valves guarding the exit out of the ventricles have to **prevent backflow of blood when the ventricles relax**. Each valve consists of three cup-shaped or half-moon shaped parts and is called a **semilunar valve** or **SL valve** (*semi-* half, *lunar* moon). The valve between the right ventricle and the pulmonary trunk is called **pulmonary valve**; the valve between the left ventricle and the aorta is called the **aortic valve**.

Blood flowing back to the heart first collects in the right atrium. From here it flows through the right AV valve (tricuspid valve) into the right ventricle and then through the pulmonary valve into the pulmonary trunk.

Blood flowing back from the lungs first enters the left atrium before flowing through the left AV valve (mitral valve) into the left ventricle. It is then pumped through the aortic valve into the aorta.

Figure 17.4 Pig heart, coronal section

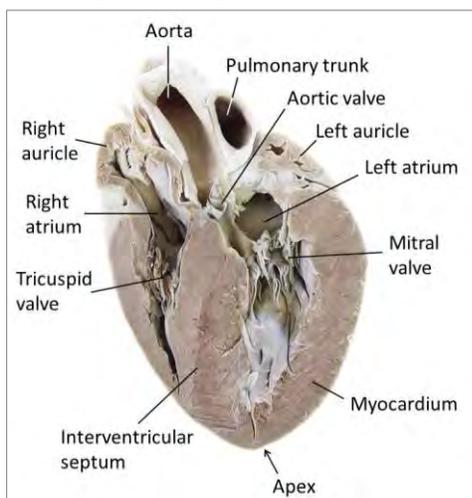
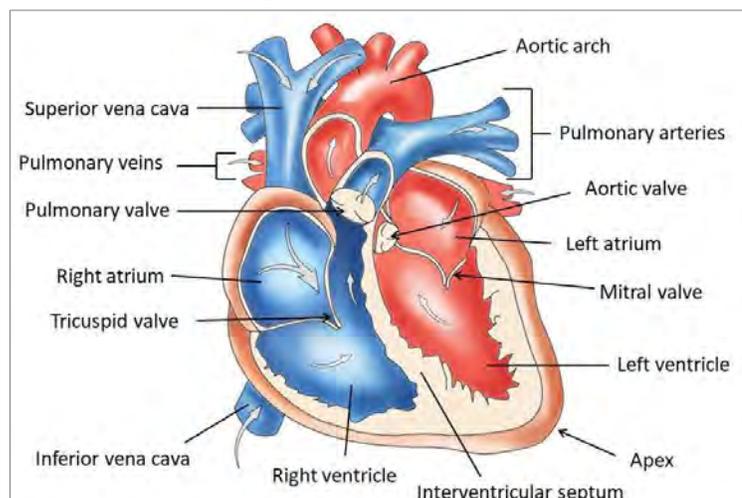


Figure 17.5 Heart, blood flow and valves



### Cardiac Muscle Cells

Cardiac muscle cells have features from both voluntary skeletal muscle cells and involuntary smooth muscle cells.

They have **regular striations** like skeletal muscle cells. But, they are **short** like smooth muscle cells and, just like smooth muscle cells, they are **connected by gap junctions** that allow for ions to pass freely from cell to cell. These junctions are the basis for the heart muscle to be a **functional syncytium**, i.e., all cardiac muscle cells act as if they were one big cell.

What makes cardiac muscle cells unique is that they are **branched**, which creates a three-dimensional network. Cardiac muscle cells are anchored to each other by **desmosomes**. These cell rivets prevent cells from separating during contraction and form the so-called **intercalated discs**.

Cardiac muscle cells have **many more mitochondria** (25-35% of cell volume) than skeletal muscle fibers, and **only one connective tissue layer (endomysium)** instead of three in skeletal muscle.

### Check Your Understanding

- The heart is \_\_\_\_\_.
  - the size of a fist
  - shaped like a ball
  - located behind the left lung
  - surrounded by the myocardium
- Vessels that carry blood back to the heart are called \_\_\_\_\_.
  - coronaries
  - arteries
  - capillaries
  - veins
- The muscle layer of the heart is called \_\_\_\_\_.
  - epicardium
  - pericardium
  - myocardium
  - endocardium
- The \_\_\_\_ valve regulates blood flow from the right ventricle into the pulmonary trunk.
  - mitral
  - aortic
  - tricuspid
  - pulmonary

1.A.2.C.3.D.4.D

## 17.5 Cardiac Physiology

### Cardiac Muscle Contraction

Skeletal muscle contraction is regulated by two ion channels: one for  $\text{Na}^+$  inflow and one for  $\text{K}^+$  outflow. **Cardiac muscle cells have a third channel for  $\text{Ca}^{2+}$  inflow.** Just like in skeletal muscle, **calcium binds to troponin**, which regulates access to the active site of the actin subunit of the thin filaments.

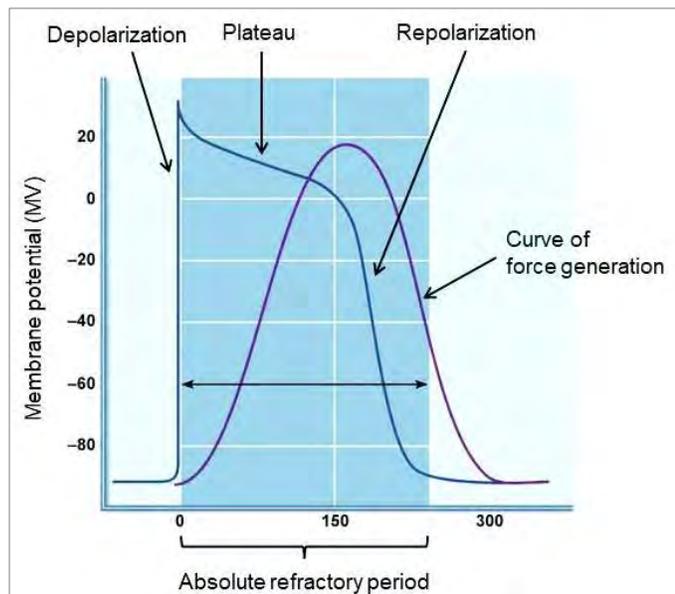
**Depolarization** of the sarcolemma leads to opening of **voltage-gated fast  $\text{Na}^+$  channels** and an **inflow of  $\text{Na}^+$**  into the cell. This inflow of positive ions causes **reversal of the membrane potential from  $-90 \text{ mV}$  to  $+30 \text{ mV}$ .**

The depolarization wave opens the **slow  $\text{Ca}^{2+}$  channels** in the sarcolemma, leading to  $\text{Ca}^{2+}$  influx. The surge of  $\text{Ca}^{2+}$  into the cell prolongs the depolarization phase, which can be seen as a **plateau** in the **action potential diagram**, and causes an even stronger release of  $\text{Ca}^{2+}$  from the **sarcoplasmic reticulum**. The  $\text{Ca}^{2+}$  influx is also the basis of the **long absolute refractory period**

(250 ms) of cardiac muscle cells, which prevents the cardiac muscle from developing a tetanus (i.e., continuous contraction) and limits the heart rate to a maximum of 250 beats per minute.

Unlike in skeletal muscle, where **repolarization** is due to an inactivation of  $\text{Na}^+$  channels and an outflow of  $\text{K}^+$  ions, repolarization in cardiac muscle is due to a combination of inactivation of the  $\text{Ca}^{2+}$  channels and opening of voltage-

Figure 17.6 Action potential and force generation



gated  $K^+$  channels.

Because of the slow-to-open  $Ca^{2+}$  channels, contraction initiation and cross-bridge cycles are slower to occur than in skeletal muscle. The **curve of the force generation** reflects this slow excitation-contraction coupling.

### Cardiac Conduction System

The heart developed long ago in primitive animals without a brain to regulate their heart or other organs; therefore, the heart has its own control system as its cells cannot depend on the brain to tell them when to contract or not. **Depolarization** of the heart muscle cells is **rhythmic** and **spontaneous**. About **1% of cardiac cells are self-excitabile**, i.e., they generate an action potential without activation from a neuron. Gap junctions that connect the cells ensure the heart contracts as a unit. **Autorhythmic cells are noncontractile**, but they initiate and distribute impulses to coordinate depolarization and contraction of the heart.

The cardiac conduction system consists of cells that can generate electric signals and spread them to all areas of the heart to achieve contraction of the heart muscle cells. These **cells have unstable resting potentials** because their **slow  $Na^+$  channels never close**. This leads to an inflow of  $Na^+$  into the cells and depolarization of the membrane potential toward zero. At **threshold**,  $Ca^{2+}$  channels open and cause an **action potential**.

**Repolarization** results from inactivation of  $Ca^{2+}$  channels and opening of voltage-gated  $K^+$  channels.

As this process sets the pace for depolarization of other heart cells, the **unstable potential** is also referred to as **pacemaker potential** or **pre-potential**.

The **sinoatrial node** or **SA node** is the physiological pacemaker of the heart as it depolarizes faster than any other part of the autorhythmic system.

As long as it sets the rhythm of contraction, the heart is said to be in **normal sinus rhythm (NSR)**. On its own, the SA node generates 90-100 action potentials (= heart beats) per minute.

The **atrioventricular** (or **AV**) **node** is located at the junction of right atrium and ventricle. It depolarizes slower than the SA node (40-60 potentials per minute). The AV node also slows down transmission of the excitation from the atrium to the ventricle by about 0.1 second.

The **atrioventricular (AV) bundle** (or **bundle of His**) is the only electrical connection between atria and ventricles. It splits into **right** and **left bundle branches** that run inside the interventricular septum toward the apex of the heart.

The final leg of the conduction system consists of fine **Purkinje fibers** that spread throughout the myocardium of both ventricles. On their own, i.e., without any signals from the SA node, the AV bundle and Purkinje fibers depolarize 30-40 times per minute.

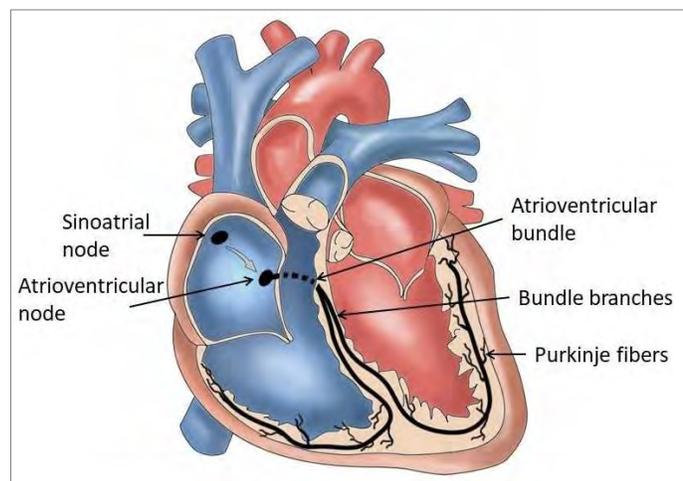
**Defects in the cardiac conduction system** may be the cause of an **irregular heartbeat (arrhythmia)** and even lead to **fibrillations**, i.e., rapid, irregular contractions that do not pump blood.

If the SA node is not able to generate a pacemaker potential, an abnormal pacemaker, called an **ectopic focus**, will take over. If the pace-making task is given to the **AV node**, a so-called **junctional rhythm** with **40-60 beats per minute** develops. If the transmission of the signal is inhibited at the AV node, a **partial or total heart block** may develop and few or no impulses from the SA node may reach the ventricles. In a heart block, the atria and ventricles may beat at a different and uncoordinated rhythm.

This **intrinsic basic heart rhythm** set by the SA node is **modified by signals from the autonomic nervous system**. There are **two cardiac centers** located in the **medulla oblongata**:

1. The **cardioacceleratory center** sends signals via **sympathetic fibers** to the **SA and AV node**, **cardiac muscle cells**, and **coronary arteries**. It can **increase the heart rate** by opening up more  $Na^+$  channels in the SA node, **increase the contractility**, i.e., force generation, of heart muscle cells, and **increase the blood flow to the heart muscle**.

Figure 17.7 Intrinsic cardiac conduction system



- The **cardioinhibitory center**, on the other hand, **only inhibits the SA and AV nodes** through parasympathetic fibers in the vagus nerve, i.e., all it can do is slow down the heart rate.

### Electrocardiography

The electric signals generated and spread by the cardiac conduction system excite the cardiac muscle cells and lead them to contract. This process involves the flow of charged particles (ions) into and out of the cardiac muscle cells. The **flow of ions across the sarcolemma during depolarization and repolarization creates electric currents** that can be measured and displayed in the form of static or dynamic recordings called an **electrocardiogram (ECG, EKG)**. Depending on the placement of electrodes recording the flow of ions, the ECG looks differently. The standard ECG uses three electrodes (right arm, left arm and leg).

**Atria and ventricles are electrically separated** by the fibrous skeleton of the heart. Because of that fibrous tissue, the **delay of the AP in the AV node leads to independent electrical events in atria and ventricles**.

Of the four electrical events (atrial and ventricular depolarization and repolarization), only three create a wave in the ECG:

- The first wave, the **P wave**, depicts **atrial depolarization** caused by a signal from the SA node.
- Ventricular depolarization** shows up as the **QRS complex**. This complex is so strong, due to the muscle mass of the ventricle, that **atrial repolarization**, which happens at the same time, is not visible on the standard ECG.
- The last wave, the **T wave**, is caused by  $K^+$  outflow during **ventricular repolarization**.

Release of  $Ca^{2+}$  from the SR does not create an electric current because the ions move from one compartment of the cell to another one inside the cell. Only ions moving into and out of the cell generate an electric current and, thus, a visible change in the ECG. This is also the reason why the **generation of force** via the sliding filament mechanism **cannot be seen on the ECG**.

The contraction of the atrial muscle starts after the end of the P wave, it forms the so-called **PQ segment** of the ECG, while ventricular contraction happens during the **ST segment**.

The interval between the beginning of the P wave and the QRS complex is called the **PR interval** and the interval from the onset of the QRS complex until the end of the T wave is called the **QT interval**.

### Heart Sounds

Opening and closing of the heart valves is a passive process as the valves do not move on their own but are opened or closed by blood flowing into or out of the ventricles. **Heart sounds are not closing sounds of the valves**, like the closing sound of a door, but **are caused by turbulent blood flow** caused by the closure of the valves. That's why we say heart sounds are associated with the closure of the valves.

**Heart auscultation** is listening to heart sounds, usually by using a stethoscope (*steth(o)-chest-scope* instrument). Because of the location of the heart and the valves and the flow of blood during the cardiac cycles, the best places to listen to the heart valves are not over the anatomical location of the valves, but areas where the sound projects to because of the blood flow through the valves:

- Second intercostal space to the right of the sternum for the **aortic valve**.
- Second intercostal space to the left of the sternum for the **pulmonary valve**.

Figure 17.8 Standard ECG

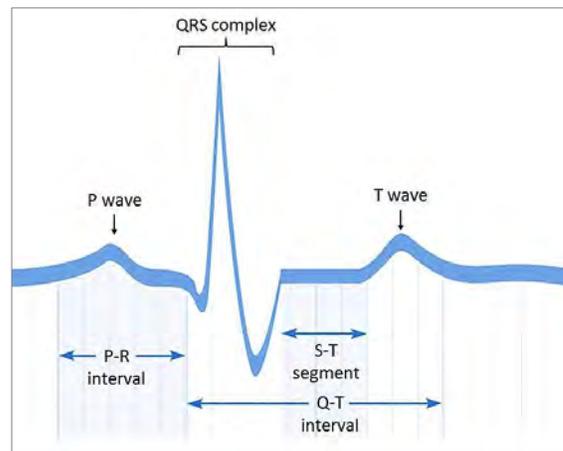
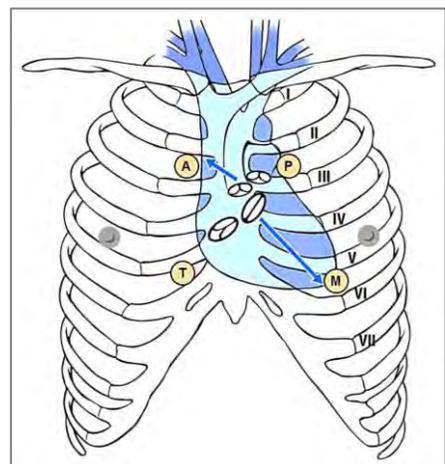


Figure 17.9 Heart valve auscultation points



- Fifth intercostal space to the left of the sternum near the apex of the heart for the **mitral valve**.
- Fifth intercostal space to the right of the sternum for the **tricuspid valve**.

There are **two heart sounds** (lub dub). The **first heart sound** (S1, lub) is caused by turbulent blood flow when the atrioventricular valves have closed. The blood attempting to flow from a ventricle back(ward) into atrium pushes the cusps of the AV valves up and the valves close. This leads to a turbulent blood flow, which can be heard using a stethoscope or similar device. The **second heart sound** (S2, dub) occurs later in the heart cycle and is associated with the closure of the semilunar valves. Blood from the aorta and pulmonary trunk tries to flow back into the ventricles and pushes the semilunar valves shut. This leads to turbulent blood flow and a heart sound.

There may be additional heart sounds; but, as a rule, any additional sounds must be considered as abnormal. Abnormal sounds are caused by changes to the anatomy or function of the heart or heart valves and are called **heart murmurs**. Murmurs are always pathologic.

### Check Your Understanding

- Cardiac muscle cells \_\_\_\_\_.
  - have Ca<sup>2+</sup> channels
  - are connected by tight junctions
  - are organized in motor units
  - have Z discs that are called intercalated discs
- The third wave/complex of the ECG is called the \_\_\_\_\_.
  - P wave
  - QRS complex
  - U wave
  - T wave
- The \_\_\_\_\_ is the natural pacemaker of the heart.
  - AV node
  - bundle of His
  - SA node
  - Purkinje fibers
- Which heart valve is best heard over the 2<sup>nd</sup> intercostal space to the left of the sternum?
  - Mitral valve
  - Tricuspid valve
  - Pulmonary valve
  - Aortic valve

1.A.2.D.3.C.4.C

### Cardiac Cycle

The heart muscle goes through a cycle of force generation (contraction) and relaxation with every single heartbeat, the so-called **cardiac cycle**. However, the atria and ventricles must relax and contract at opposite times of the cycle for the blood to flow in the right direction at the right time. Contraction of cardiac muscles is called **systole**; relaxation is called **diastole**.

The **first step** of the cardiac cycle, the **ventricular filling**, takes place during the **mid-to-late diastole of a heart cycle**. The **atrioventricular valves are open**, but the **semilunar valves are closed**. The pressure inside both ventricles is zero and **blood flows passively from the atria into the ventricles** through the open AV valves.

Once the ventricle is filled to about 80%, an action potential from the SA node causes **atrial systole**, which pushes an additional 20% of blood into the ventricle. The volume of blood in a ventricle at the end of this filling cycle is called the **end-diastolic volume (EDV)**.

While the atrial cells relax and go through repolarization, the electric signal is transmitted down to the ventricular cells, leading to a **ventricular systole**.

Contraction of the myocardium increases the pressure inside the ventricle, which pushes the blood against the AV and semilunar valves. The **AV valves close** because the pressure in the atria is lower than the pressure in the ventricles. This causes turbulent blood flow and the audible **first heart sound**.

But, the semilunar valves are also closed and no blood is leaving the ventricles, despite the increase in pressure. Therefore, this phase is called **isovolumetric contraction**.

When the pressure inside the ventricle exceeds the pressure behind the **semilunar valves**, the valves **open and blood can flow through the pulmonary valve** into the pulmonary trunk and through the **aortic valve** into the aorta. This phase is called the **ejection phase** of ventricular systole.

Once the ventricular muscle cells relax, the pressure inside the ventricles falls rapidly and blood starts flowing backward from the aorta and pulmonary trunk toward the ventricle. This leads to a **closure of the semilunar valves** and

the audible **second heart sound**. The volume of blood still in the ventricle at this stage is called the **end-systolic volume (ESV)**.

**All four heart valves are closed** again and **no blood flows into or out of the ventricles**. This phase, the **isovolumetric relaxation**, ends once the pressure inside the ventricle falls below the pressure in the atria and the atrioventricular valves open again, allowing blood to flow from the atria into the ventricles once more.

**Defects of the heart valves** can lead to heart murmurs (see above). Depending on when they are heard, they can be classified as **systolic** (heard during ventricular systole) or **diastolic murmurs** (heard during ventricular diastole). **If a valve does not close completely**, the condition is called **regurgitation** because the valve did not close enough to stop blood from flowing back through the valve.

- **Mitral and tricuspid regurgitation lead to systolic murmurs** as they allow blood to flow back into the atrium during ventricular contraction.
- Both **aortic and pulmonary regurgitation cause diastolic murmurs** as the blood will flow back into the ventricle during ventricular relaxation.

**If a valve does not open completely**, the condition is called **stenosis** as the pathway through the valve is partially blocked.

- **Mitral and tricuspid stenosis cause diastolic murmurs** due to turbulent flow caused by blood flowing from the atrium down into the ventricle.
- **Aortic and pulmonary stenosis are marked by systolic murmurs** due to turbulent blood flow during the ejection phase.

### Cardiac Output

The amount of blood ejected from the heart during the ejection phase of the ventricular systole is called **stroke volume**. However, more important for supplying all body organs and tissues with blood is the **amount (volume) of blood pumped by each ventricle in one minute** – the so-called **cardiac output (CO)**. Cardiac output is **calculated by multiplying the heart rate by the stroke volume**.

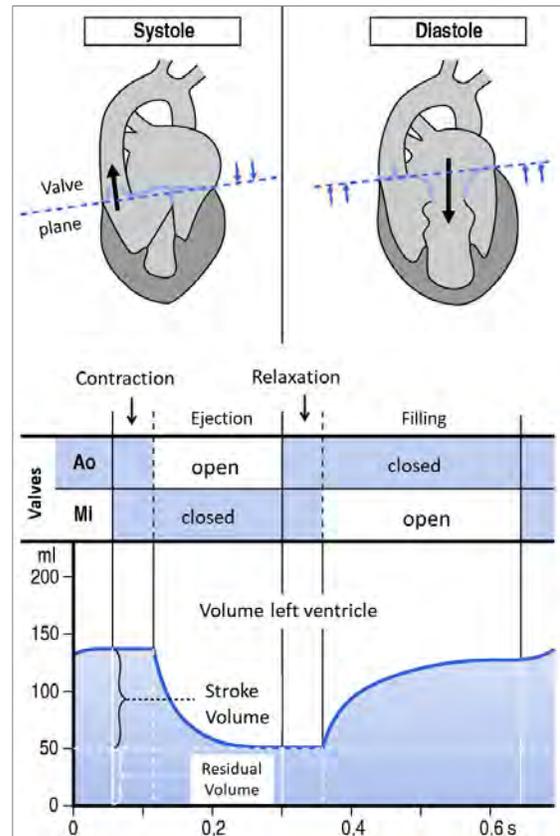
- The **heart rate (HR)** is the **number of beats per minute (bpm)**. **At rest**, our heart beats approx. **65-75** times per minute.
- The **stroke volume (SV)** is the **amount of blood ejected** from each ventricle **with each beat**, i.e., the difference between end-diastolic and end-systolic volume of the ventricles. The **average is about 70 ml/beat**.

The average **cardiac output at rest** is 5.25 l/min for men and 4.5 l/min for women. For most people, the CO can increase 4-5 times during activity or hard work. This is called the **maximal CO**. The difference between the resting and the maximal CO is called **cardiac reserve**. The greater this value, the more the cardiac output can increase in times of demand.

Three **factors affect the size of the stroke volume**:

1. **Preload** is the **degree of stretch of cardiac muscle cells before they contract**. How an increase in stretch affects the muscle is explained by the **Frank-Starling law of the heart**. It stipulates that increased filling of the ventricle stretches the cardiac muscles cells, which in turn increases the contraction force and, thus, the volume of blood ejected with each stroke, i.e., the stroke volume.
2. The **contractility** of cardiac muscle can be increased or decreased by a number of factors. Any factor that increases the contractility is said to be **positive inotropic**, whereas factors that reduce contractility are called **negative inotropic**. Some hormones, such as **epinephrine** from the adrenal medulla, increase contractility as

Figure 17.10 Events of the cardiac cycle (left ventricle)



does an increased inflow of  $\text{Ca}^{2+}$  into the cardiac muscle cells. Agents that prevent  $\text{Ca}^{2+}$  from flowing into the cardiac cells have the opposite effect; these drugs are called **calcium channel blockers** or **Ca antagonists**.

3. **Afterload is the pressure the ventricles have to overcome** to force the semilunar valves to open so that blood can be ejected. The higher this pressure, the harder the heart has to work with each beat. This is one of the reasons why hypertension is so damaging to the heart over a longer period of time (see also **Chapter 17 Blood Vessels and Circulation**).

The **heart rate** can also be adjusted up or down depending on the demand for blood flow. Any factor that increases the heart rate is called **positive chronotropic**; any factor slowing down the heart rate is termed **negative chronotropic**.

The two parts of the autonomic nervous system (ANS) have opposite effects on the heart rate. **At rest, the heart** is slowed down by the parasympathetic signals that arrive in fibers of the vagus nerve and thus **exhibits a vagal tone**.

- The **sympathetic** (fight-or-flight) **system releases norepinephrine**, which causes the SA node to fire more rapidly. It also increases the contractility of the cardiac muscle, i.e., the sympathetic system is **positive chronotropic and positive inotropic**.
- The **parasympathetic** (rest-and-relaxation) **system** slows down the heart rate by opening  $\text{K}^+$  channels which leads to hyperpolarization of the pacemaker cells. The parasympathetic system is **negative chronotropic** and has no inotropic effect.

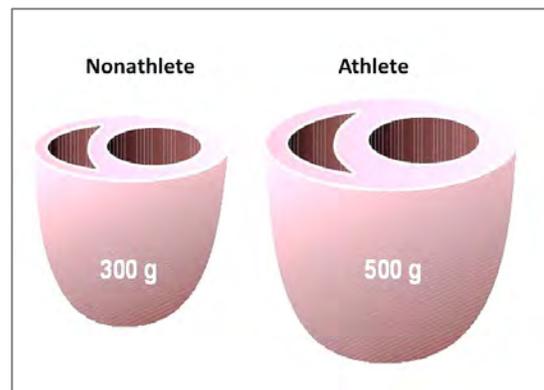
**Normal heart rate** at rest is 60-100 bpm, and the rhythm is set by the sinoatrial node in the right atrium. Increased return of venous blood into the right atrium stretches the cells there, which leads to activation of the SA node as well as to a sympathetic reflex that increases the heart rate. This is called the **atrial** or **Bainbridge reflex**.

The **heart rate** is also positively or negatively **influenced by other factors such as hormones** from the adrenal medulla and thyroid. **Epinephrine** from the adrenal medulla increases the heart rate and the myocardial contractility, while **thyroid hormone** from the thyroid leads to an increase in the heart rate and sensitizes the cardiac cells for both norepinephrine and epinephrine.

**The heart can adjust** to a chronic demand for an increased cardiac output **by gradually increasing in size**. Endurance athletes may have hearts that are 60% heavier and larger than the heart of the average adult.

Figure 17.11 Comparison of cardiac parameters of a nonathletic adult and an endurance athlete

Parameter	Nonathlete	Endurance athlete
Heart rate at rest [BPM]	75-80	40-50
Stroke volume at rest [ml]	70	120-140
Maximal stroke volume [ml]	100	190
Cardiac output at rest [l/min]	5.6	5.6
Maximal cardiac output [l/min]	18	35(-50)
Heart weight [g]	300	500



## 17.6 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	vein	_____	vas(o)-
2.	aorta	_____	arteri(o)-

3.	vessel	_____	atri(o)-
4.	heart	_____	valvul(o)-
5.	atrium	_____	aort(o)-
6.	valve	_____	veni-
7.	artery	_____	card(o)-

**True/False**

Write "T" on the line if the statement is true and "F" if the statement is false.

1. The myocardium receives its blood supply from the coronary arteries. \_\_\_\_\_
2. Cardiac muscle has more mitochondria and depends less on a continual supply of oxygen than skeletal muscle. \_\_\_\_\_
3. Trabeculae carneae are found in the ventricles only. \_\_\_\_\_
4. The heart is enclosed by a double sac of serous membrane known as the peritoneum. \_\_\_\_\_
5. Chordae tendineae anchor the semilunar valves to the walls of the ventricles. \_\_\_\_\_
6. The coronary sulcus is also known as the atrioventricular groove. \_\_\_\_\_
7. Arteries transport blood away from the heart. \_\_\_\_\_
8. The atria are pumping chambers with thick muscular walls. \_\_\_\_\_
9. The interventricular septum separates right and left ventricle. \_\_\_\_\_
10. All heart valves have two cusps. \_\_\_\_\_
11. The Purkinje node is the natural pacemaker of the heart. \_\_\_\_\_
12. Cardiac output can increase 4-5 times in healthy nonathletic people. \_\_\_\_\_
13. During ventricular diastole, the bicuspid and tricuspid valves are closed. \_\_\_\_\_
14. The second heart sound represents semilunar valves closing. \_\_\_\_\_
15. The P wave indicates ventricular depolarization. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |    |                 |  |          |
|----|-----------------|--|----------|
| 1. | Left ventricle  | a) pumps blood through the tricuspid valve   | 1. _____ |
| 2. | Left atrium     | b) heart muscle                              | 2. _____ |
| 3. | Right ventricle | c) prevents backflow into the left ventricle | 3. _____ |
| 4. | Right atrium    | d) chamber with the thickest wall            | 4. _____ |

- |     |                             |    |   |     |       |
|-----|-----------------------------|----|---|-----|-------|
| 5.  | Endocardium                 | e) | prevents backflow into the right atrium                 | 5.  | _____ |
| 6.  | Myocardium                  | f) | relaxation of heart muscle                              | 6.  | _____ |
| 7.  | Aortic valve                | g) | delays signal on its way to the AV bundle               | 7.  | _____ |
| 8.  | Mitral valve                | h) | atrioventricular valves have closed                     | 8.  | _____ |
| 9.  | Tricuspid valve             | i) | positive chronotropic                                   | 9.  | _____ |
| 10. | Epicardium                  | j) | ejected during one systole                              | 10. | _____ |
| 11. | Diastole                    | k) | pumps blood to the pulmonary trunk                      | 11. | _____ |
| 12. | Epinephrine                 | l) | AV valve with two flaps/cusps                           | 12. | _____ |
| 13. | AV node                     | m) | serous layer covering the heart muscle                  | 13. | _____ |
| 14. | Stroke volume               | n) | pulmonary veins return oxygenated blood to this chamber | 14. | _____ |
| 15. | 1 <sup>st</sup> heart sound | o) | inner lining of the heart                               | 15. | _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- To which side of the body is the apex of the heart pointed?
  - At the midline
  - To the left hip
  - To the right hip
  - To the back
- Which of the following statements is **not** correct?
  - The heart has four chambers
  - The atria pump oxygen-depleted blood
  - The left ventricle has a thicker wall than the right
  - The interventricular septum is part of the left ventricle
- Which of the following marks the exterior boundary between the ventricles?
  - Coronary sulcus
  - Anterior interventricular sulcus
  - Coronary sulcus and posterior interventricular sulcus
  - Anterior and posterior interventricular sulcus
- Which of the valves prevents blood from flowing back from the pulmonary trunk?
  - Tricuspid valve
  - Bicuspid valve
  - Pulmonary valve
  - Aortic valve
- Which vessel distributes oxygenated blood to the myocardium?
  - Coronary artery
  - Coronary vein
  - Pulmonary artery
  - Myocardial vein

6. As each atrium contracts where does blood move?
- Into an auricle
  - Into a vein
  - Through an atrioventricular valve
  - Through a semilunar valve
7. The right ventricle \_\_\_\_.
- pumps less blood than the left
  - is closed by mitral and pulmonary valve
  - forms the apex of the heart
  - pumps blood into the pulmonary trunk
8. Stimulation of which nerve reduces heart rate?
- Cardiac accelerator nerve
  - Hypoglossal nerve
  - Vagus nerve
  - Phrenic nerve
9. Which of the factors below would increase stroke volume?
- Increased preload, increased afterload, increased contractility
  - Decreased preload, decreased afterload, decreased contractility
  - Increased preload, decreased afterload, increased contractility
  - Decreased preload, increased afterload, increased contractility
10. Which electrical event precedes contraction of the atria?
- R wave
  - T wave
  - S wave
  - P wave
11. Which of the following statements is **not** correct?
- The SA node is the natural pacemaker of the heart
  - In sinus rhythm the AV node is the pacemaker
  - The parasympathetic system slows down the heart beat
  - In tachycardia the heart beats too fast at rest
12. The Bainbridge reflex describes \_\_\_\_.
- the increase in ventricular volume on heart rate
  - the effect of  $\text{Ca}^{2+}$  on heart rate
  - the inverse of effect of afterload on heart rate
  - the effect of increased atrial filling on rate heart
13. The sympathetic system \_\_\_\_.
- has a positive chronotropic and positive inotropic effect on the heart
  - has a positive chronotropic and negative inotropic effect on the heart
  - has a positive chronotropic effect on the heart and decreases the afterload
  - increases the preload and has a negative chronotropic effect
14. Which of the following factors does **not** influence the heart rate?
- Epinephrine
  - Preload
  - $\text{Ca}^{2+}$  blood levels
  - Afterload

15. The stroke volume is affected by \_\_\_\_.
- a. heart muscle contractility
  - b.  $\text{Ca}^{2+}$  blood levels
  - c. defective heart valves
  - d. all of the above

## Chapter 18 Blood Vessels and Circulation

### 18.1 Chapter Outline

Blood vessels assist in the regulation of blood pressure, regulate blood flow, and allow for the exchange of nutrients, respiratory gases, and waste products between the blood and the tissues. The blood vessels of the pulmonary circulation carry blood to and from the lungs; blood vessels of the systemic circulation carry blood to and from all body organs and tissues.

### 18.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the three layers that typically form the wall of a blood vessel.
- Define vasoconstriction and vasodilation.
- Compare and contrast the structure and function of the two types of arteries.
- Describe the structure and function of a capillary bed.
- Define blood flow, blood pressure, and resistance, and explain the relationships between these factors.
- List and explain the factors that influence blood pressure.
- Describe mechanism of short-term and long-term blood pressure regulation.
- Explain how blood flow is regulated in the body in general and in specific organs.
- Trace the pathway of blood through the pulmonary circuit.
- Name and give the location of the major arteries and veins in the systemic circulation.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 18.3 Combining Forms

Table 18.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 18.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
angi(o)-	(blood) vessel	<i>angiostenosis</i> = narrowing of a blood vessel
arteri(o)-	artery	<i>arteriolar</i> = relating to arterioles
ather(o)-	plaque or fatty substance	<i>atherosclerotic</i> = affected by or associated with atherosclerosis
hyper-	more than normal, excessive	<i>hypertensive</i> = relating to or exhibiting high blood pressure (hypertension)
hyp(o)-	less than normal	<i>hypotensive</i> = relating to or exhibiting low blood pressure (hypotension)
phleb(o)-	vein	<i>phlebitis</i> = inflammation of a vein or veins
vas(o)-, vascul(o)-	vessel	<i>vasodilator</i> = a drug that dilates blood vessels
ven(o)-, veni-	vein	<i>venipuncture</i> = puncture of a vein, for example, in order to withdraw a blood sample

### 18.4 Blood Vessel Anatomy

Unlike water pipes that have only one function, the blood vessels of our body are multitasking organs. Their major tasks are to carry blood from the heart to the organs and tissues of the systemic and pulmonary circulations and re-

turn it the heart. Blood vessels also assist in the regulation of the blood pressure overall. In the tissues, they help regulate blood flow into areas that have a need for increased blood supply, and allow for the exchange of nutrients, respiratory gases (oxygen, carbon dioxide), and waste products between the blood and the tissues.

There are **three types of blood vessels**:

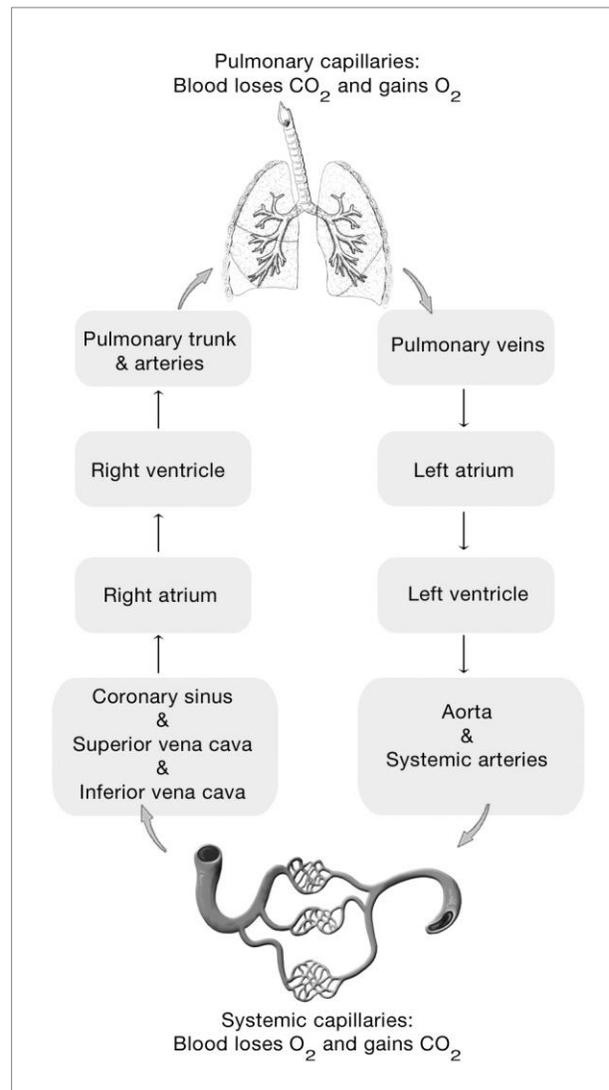
1. **Arteries carry blood away from the heart.** In the **systemic circulation**, they carry bright red, **oxygen-rich** (oxygenated) blood; in the **pulmonary system**, they carry dark, **oxygen-depleted** (deoxygenated) blood. Small arteries are called **arterioles**.
2. **Veins carry blood back to the heart.** Because of the opposite direction of flow, they contain **oxygen-rich** (oxygenated) blood in the **pulmonary system** and **oxygen-depleted** (deoxygenated) blood in the **systemic circuit**. Small veins are called **venules**.
3. **Capillaries** are microscopic vessels that are the site of the exchange of gases, nutrients, water, ions, and waste products inside the tissue.

**Arteries and veins have three-layered walls** consisting of a tunica intima, tunica media, and tunica externa. The vessel wall surrounds the **lumen**, i.e., the central blood-containing space. The innermost layer, the **tunica intima**, is covered by an epithelium called the **endothelium** (*endo-* inside, *thelium* tissue). The middle layer, called the **tunica media**, has smooth muscle and elastic fibers. The smooth muscle cells allow the vessels to change their size (contraction of the muscle cells leads to a narrowing of the lumen; relaxation leads to widening), while the elastic fibers enable them to stretch when the pressure increases and to recoil when the pressure drops. The outer **tunica externa** has strong collagen fibers that stop the vessel from dilating under pressure.

Because the blood pressure is higher in arteries than in veins (see below), **the walls of the arteries are thicker**, especially the middle layer. There are **two types of arteries**:

1. **Elastic or conducting arteries** have thick walls with **elastic fibers in all three layers**. These elastic fibers allow the arteries to expand under pressure from the inside and to recoil once the pressure decreases, which is why they act as **pressure reservoir**. The large lumen of these arteries offers hardly any resistance to the blood flow. The **aorta and its major branches** are made of this type of tissue.
2. **Muscular or distributing arteries** have fewer elastic fibers but possess a **thick tunica media with a high percentage of smooth muscle cells**. This muscular tissue allows them to actively change their diameter to larger (**vasodilation**) or smaller (**vasoconstriction**), which helps regulating the blood flow to organs.

**Figure 18.1 Pulmonary and systemic circulation**

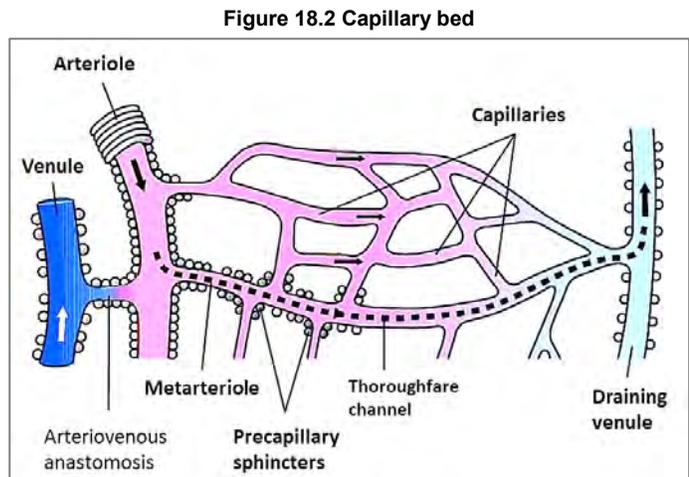


Once they are inside organs, arteries become smaller and smaller. The smallest arteries with diameter of less than 1 mm are called **arterioles**. Arterioles contain enough smooth muscle to change their diameter and to **control the blood flow into the tissues** and the **capillary bed** where the exchange processes take place.

**Capillaries** are **microscopic blood vessels** with thin walls that only consist of the **endothelium** and a supporting **basal lamina**. The lumen of capillaries is just big enough for one single red blood cell to pass through at a time. Capillary walls are very thin and have special cells (**pericytes**) that help stabilize their walls and control permeability.

Capillaries are found in every tissue but cartilage, epithelia, cornea, and the lens of the eye. There are **three types of capillaries**:

1. **Continuous capillaries** have **tight junctions** that connect their endothelial cells and **intercellular clefts** that allow the passage of fluids and small solutes. Continuous capillaries are found in the skin and muscles, for example.
2. **Fenestrated capillaries** contain **pores** (fenestrations) that make them more permeable than continuous capillaries. They function in absorption or filtrate formation (e.g., in the kidney).
3. **Sinusoidal capillaries** allow large molecules and blood cells to pass. They are found in the liver, bone marrow, and spleen only.



**Capillary beds are the structural backbone of the microcirculation of the tissues.** They are made of a **network of capillaries that connects a terminal arteriole** on the arterial side of the circulation **with a venule** on the venous side.

Capillary beds consist of two types of vessels:

1. The **metarteriole** or **vascular shunt** directly connects the terminal arteriole and a postcapillary venule.
2. **True capillaries** branch off the metarteriole or the terminal arteriole. There are about 10-100 true capillaries in each capillary bed.

Blood flow into the capillary bed is regulated by **precapillary sphincters** that open or close to allow blood to flow through the true capillaries or to shut it off. These sphincters are controlled by changes in the local chemical environment or vasomotor nerves from the sympathetic nervous system.

**Veins** have thinner walls with less smooth muscle and larger lumens compared to arteries. Still, they are able to change their diameter and, thus, help regulate blood flow in the venous system. Overall, veins hold more blood at rest than arteries (up to 65% of the total blood volume). Therefore, veins are considered capacitance vessels and said to form a **blood reservoir**.

Unlike arteries, **veins can have valves** that help with directing the flow of the blood toward the heart and prevent backflow into organs or tissues.

Flattened veins with very thin walls are called **venous sinuses**. They are found in the heart (for example, the **coronary sinus**) and the brain (the **dural sinuses**).

**Venules** are the smallest vessels of the venous part of the circulation. Like capillaries, their walls are still rather porous and allow fluid and white blood cells to move in and out. Venules gradually become bigger with thicker walls that are not permeable anymore and contain smooth muscle cells.

Connections of blood vessels that usually are not connected with each other are called **anastomoses**. Such connections are common for arteries and veins as they allow for alternate pathways for blood into or out of organs and tissues. Vascular shunts between the arterial and venous side of the circulation (**arteriovenous anastomoses**) are normal on a capillary level but can be pathologic and lead to clinical symptoms when bigger vessels are involved.

There are noticeable **differences between the pulmonary and systemic circulations** and the arteries and veins that they encompass. The **pulmonary circulation** is a **short loop** consisting of **arteries that carry oxygen-depleted blood** from the right ventricle to the lungs and **veins that carry oxygen-rich blood** back to the left atrium.

The **systemic circulation** is a much longer loop with a higher blood pressure. The overall combined length of the blood vessels in the systemic circuit is approximately 50,000 miles, but it can run greater than 100,000 miles in obese persons. Its main artery **carrying oxygen-rich blood away from the left ventricle** is the **aorta**; the two main veins **returning oxygen-depleted blood to the right atrium** are the **inferior and superior vena cava**.

## 18.5 Blood Pressure

**Blood flows** through our vessels **because of a pressure gradient**. This gradient leads to a flow from areas of high pressure to areas of low pressure. The pressure is generated by the myocardium of the ventricles. The blood forced out during contraction (systole) pushes on the inside of the blood vessel walls, thus generating pressure. Unlike other pressures that are measured in PSI (pounds per square inch), **blood pressure (BP) is given in mm Hg** because the first instruments used to measure blood pressure were filled with mercury (Hg; hydrargyrum is the chemical name for mercury).

**The two main circulations have different blood pressures.** The **pulmonary circulation** is a **low-pressure system**; the **systemic circulation** is a **high-pressure system**.

Most of the time, health professionals deal with **pressure in the systemic circulation**. The pressure in this system is **generated by the left ventricle pumping blood into the aorta**. The highest pressure is found in the aorta, just behind the aortic valve. The pressure then gradually decreases and falls down to zero in the right atrium. Because of this gradual pressure drop, blood keeps flowing back to the heart no matter what our body position is. We can stand, sit, or lie down; yet, the blood will keep flowing.

The pressure in the arterial side of the systemic circulation depends mainly on the **volume of blood** forced out of the heart within a given time period; the **higher** the **cardiac output**, the **higher** the **systemic arterial pressure**. This explains why blood pressure goes up when our heart rate goes up. The blood pressure also reflects the **elasticity of the aorta and the other big arteries close to the heart**. If the elasticity of these arteries decreases, they become stiff and the blood pressure goes up. This is one reason why older people have higher blood pressure on average than younger people.

The **blood pressure in the arteries**, especially close to the heart, is **pulsatile**; meaning, it rises and falls because the left ventricle has alternating systolic (contraction) and diastolic (relaxation) phases. The highest pressure is found during ventricular systole and is, thus, called **systolic pressure**; the lower pressure during ventricular diastole is called **diastolic pressure**.

The difference between those two pressures is the **pulse pressure**. The pulse pressure enables us to feel a pulse over arteries, such as the radial artery at the wrist.

- In a BP of 120/80, the systolic pressure is 120 mm Hg, the diastolic pressure is 80 mm Hg, and the pulse pressure is 40 mm Hg.

The pressure that pushes the blood along through the system is the **mean arterial pressure (MAP)**. At rest, the diastole last longer than the systole and, therefore, the MAP is closer to the diastolic pressure than the systolic pressure (MAP = diastolic pressure + 1/3 pulse pressure).

- In a BP of 160/100, MAP is  $100 + 1/3 \cdot 60 = 120$  mm Hg.

**Normal values for arterial systemic blood pressure** are different for men and women and change with age. However, **as a rule, a rested, healthy adult should have a systolic BP of less than 120 mm Hg and a diastolic BP of less than 80 mm Hg**. Any long-term elevation of values above 120 mm Hg for the systolic pressure and/or 80 mm Hg for the diastolic pressure puts more strain on the heart and causes long-term damage.

Our **blood pressure is not constant** but changes in a circadian rhythm. It peaks early in the morning under the influence of adrenocortical hormones and is lower late at night. Blood pressure further depends on age, sex, body weight, race, mood, physical and mental activity, and so on.

**Table 18.2 Blood Pressure Classification for Adults**

Category	Systolic BP (mm Hg)		Diastolic BP (mm Hg)
Normal blood pressure	< 120	and	< 80
Elevated blood pressure (prehypertension)	120-129	and	< 80
Stage 1 hypertension	130-139	or	80-89
Stage 2 hypertension	≥ 160	or	≥ 90

The **pressure in the capillaries** is lower than the arterial pressure; it usually ranges from 35-15 mm Hg. Capillaries have thin walls and high pressure would damage them easily.

The **pressure in the venous system** is even lower; otherwise, blood would not continue to flow towards the heart. Two major factors aiding the return flow, especially from the lower parts of our body, are the respiratory and the muscular pumps.

1. **Respiratory pump:** Every time we breathe in, the pressure inside the thorax decreases, which leads to the blood being sucked upwards from the abdominal cavity.
2. **Muscular pump:** Contraction of skeletal muscles compresses veins. Because of the valves in the veins, the blood can only flow toward the heart.

### Maintenance and Control of Blood Pressure

Maintenance and control of blood pressure is a joint effort of the heart and blood vessels, the autonomic nervous system, the kidneys, and the endocrine system. They all work together to make certain that the average blood pressure in the arteries (mean arterial pressure, MAP) is sufficiently high at any given time.

The **three main factors that influence blood pressure** are **cardiac output**, **resistance to the blood flow** (mainly, the diameter of the blood vessels), and **blood volume**.

Blood pressure varies directly with each of them - any increase in any factor will lead to an increase in blood pressure if the other two factors remain constant. Conversely, if one or more of these factors decreases, blood pressure will decrease.

To keep blood pressure constant, changes in one variable must be compensated for by opposite changes in one or both of the other variables. **Short-term, immediate control of blood pressure** is accomplished by the **autonomic nervous system**. The diameter of the blood vessels, especially of the arteries and arterioles, can be changed very quickly by signals from sympathetic nerve fibers. These signals cause the smooth muscle cells in the tunica media to contract, leading to a narrowing of the blood vessels and an increase in blood pressure. On the other hand, the same fibers can cause the smooth muscle cells to relax, leading to a drop in the blood pressure.

These short-term **neural controls** operate via a reflex arc involving sensors (**baroreceptors**), a control center (**vasomotor center**), and effectors (**vascular smooth muscle**). Baroreceptors react to changes in pressure. They are found in the carotid sinuses, aortic arch, and the walls of large arteries of the neck and thorax.

The **baroreceptors in the carotid sinuses** protect the blood flow to the brain. The **receptors in the aortic arch** help maintain an adequate pressure in the rest of the systemic circulation.

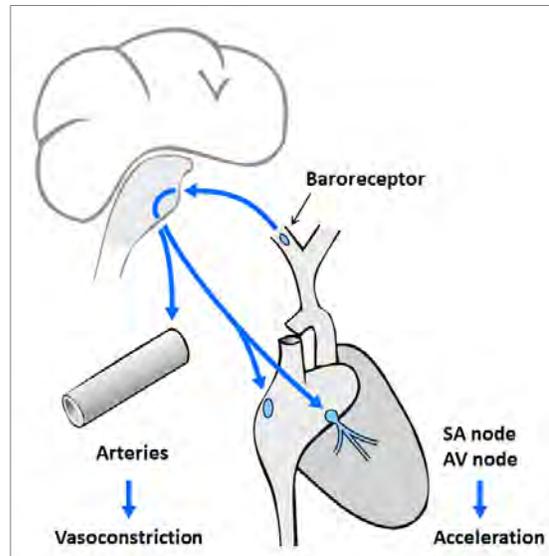
There are also **chemoreceptors** at the same locations that react to an increase in CO<sub>2</sub> or a decrease in either pH or O<sub>2</sub>. These receptors are, however, more important for the regulation of the respiratory system (see **Chapter 22 Respiratory System**).

The **vasomotor center in the medulla oblongata** receives input from baroreceptors, chemoreceptors, and higher brain centers, such as the cortex and hypothalamus. It is part of the

**cardiovascular center together with the cardiac center**. Its task is to adjust the tone of the blood vessels (mainly of arterioles) to keep the blood pressure constant. For example, if baroreceptors sense an increase in blood pressure, they will send more signals to the vasomotor center. These signals inhibit the center and stop signals from going out to the smooth muscle cells of arterioles, causing dilation and a decrease in blood pressure. The same signals from the baroreceptor will also stimulate the cardioinhibitory center, causing a decrease in the heart rate as well.

**Five hormones** play a role in **short-term regulation of blood pressure**. However, with the exception of epinephrine and norepinephrine, they are overall more important for long-term blood pressure regulation (see below).

Figure 18.3 Baroreceptors and BP control



- **Epinephrine and norepinephrine** are released by the adrenal medulla. Both cause generalized vasoconstriction and increase the cardiac output by increasing the heart rate and stroke volume.

**Angiotensin II** is part of the renin-angiotensin-aldosterone mechanism. It increases the blood pressure directly by causing vasoconstriction.

- **Atrial natriuretic peptide (ANP)** is released by the heart in response to high blood pressure. It accomplishes a decrease in blood volume and blood pressure, and causes generalized vasodilation.
- **Antidiuretic hormone (ADH)** causes intense vasoconstriction in cases of extremely low blood pressure, which is why it is also called **vasopressin**.

**Long-term regulation of blood pressure** is a task mainly performed by the **kidneys** using direct and indirect mechanisms.

**Direct renal mechanisms alter the blood volume independent of hormones.** The kidney can directly change the volume of blood by increasing its urinary output when blood pressure is high and by slowing down urine formation and secretion when blood pressure is low (for more see **Chapter 23 Urinary System**).

**Indirect renal mechanisms** use hormones to achieve the same result. **Renin** is released by the kidney when the blood pressure drops, starting the so-called **renin-angiotensin-aldosterone system (RAAS)**. As a result of the RAAS, our body keeps more salt in our blood and produces less urine. This increased salt concentration in the blood leads to an increased plasma osmolality, which in turn prompts the hypothalamus to release **antidiuretic hormone (ADH)**. ADH helps increase the blood volume by further decreasing urine output.

In high blood pressure, the heart releases **atrial natriuretic peptide (ANP)**. ANP has the opposite effect of the RAAS; it leads to more urine production as well as a loss of salt and water from the body. The subsequent reduction in blood volume lowers the blood pressure.

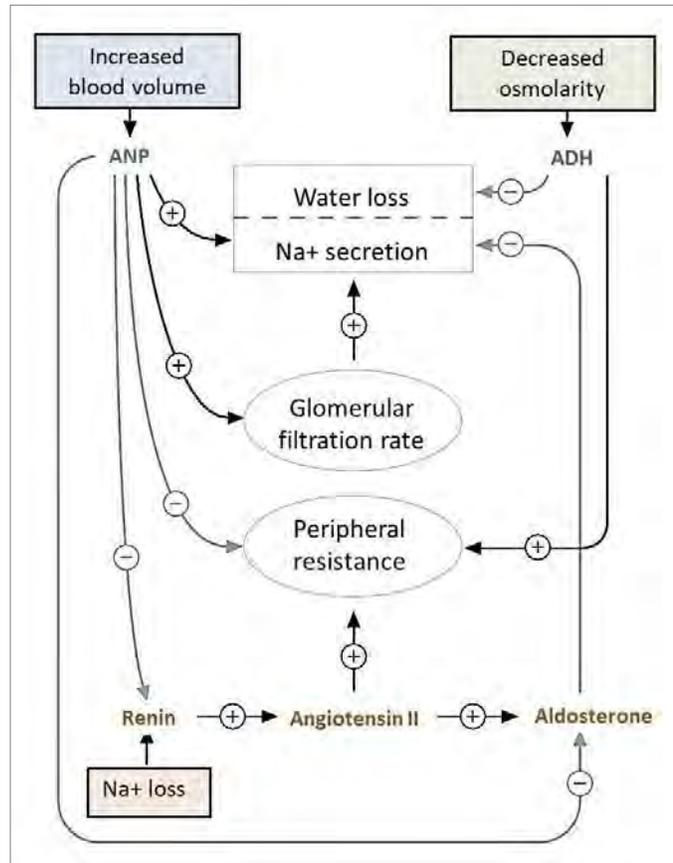
### Vital Signs

The vital signs **pulse, blood pressure, respiratory rate, and body temperature** give health professionals a quick snapshot of the circulatory efficiency and overall condition of the patient.

**Pulse** is the **pressure wave caused by the expansion and recoil of the arteries** due to the pumping action of the ventricles. Most arteries are located deep to the body's surface and it takes invasive techniques to measure the pulse. There are only a few arteries that are superficial enough for us to feel a pulse, such as the carotid artery, brachial artery, femoral artery, popliteal artery, and the dorsal artery of the foot. The most commonly used artery for taken the pulse is the **radial artery**. It **can be felt over the lateral side of the wrist**. Usually, we only count the **pulse rate** (the number of pulses in one minute) as it is the same as the heart rate. However, experienced health professionals also judge the quality of the pulse as it can give them information about the condition of the heart and blood vessels.

**Direct measurement of blood pressure** is an invasive technique that requires insertion of a probe into a blood vessel. The most commonly used **indirect method** is the **auscultatory** (from Latin meaning "listen") **method** using a **sphygmomanometer** (*sphygm(o)-* pulse). This method is based on the fact that compression of an artery from the outside will close the lumen and stop the blood flow through the compressed segment completely. Slow release of

Figure 18.4 Hormonal control of blood pressure



the pressure (usually of a pneumatic cuff) will allow the blood to start flowing again. This first blood flow is turbulent and causes the so-called **Korotkoff sounds** that can be heard with a stethoscope. The pressure reading at this moment, when the sound is heard for the first time, is the **systolic arterial blood pressure** in this specific artery. The sounds last until the pressure in the cuff is not strong enough to constrict the lumen of the vessels anymore. The blood flows freely and in a laminar fashion, i.e., the Korotkoff sounds disappear. The pressure reading the moment the sound falls silent is the **diastolic arterial blood pressure** in this specific artery.

The artery closest to the left ventricle, to which we have access for an indirect blood pressure measurement, is the **left brachial artery**. However, it is approximately 10-12 inches away from the aortic valve and the pressure is already slightly lower than just above the valve. The right brachial artery is even further away, and the pressure is even lower, although by only 1-2 mm Hg.

### Check Your Understanding

- In the systemic circulation, arteries carry \_\_\_\_ blood.
  - bright red
  - dark red
  - blue blood
  - oxygen-depleted
- A device used to measure BP is called a \_\_\_\_\_.
  - cuff
  - stethoscope
  - sphygmomanometer
  - Korotkoff apparatus
- Which hormone increases BP by reducing water loss?
  - ANP
  - Aldosterone
  - ADH
  - Renin
- A rested healthy adult should have a systolic BP of \_\_\_\_ and a diastolic BP of \_\_\_\_\_.
  - 100-140mm Hg; 100 and higher
  - 100-140mm Hg; 70-90 mm Hg
  - <140mm Hg; <90 mm Hg
  - <120mm Hg; <80 mm Hg
- The aorta \_\_\_\_\_.
  - is the largest vein of the body
  - is an elastic artery
  - is a muscular artery
  - carries blood toward the lungs
- Which of the following is not found in arteries?
  - smooth muscle cells
  - elastic fibers
  - endothelium
  - valves

1.A.2.D.3.C.4.B.5.C.6.D.

## 18.6 Physiology of Circulation

**Blood flow** (perfusion) is the **volume of blood flowing** through a vessel, an organ, or the entire circulation **in a given period of time** (usually one minute). **For the whole body it is equivalent to cardiac output (CO)** and is also measured in ml/min or l/min.

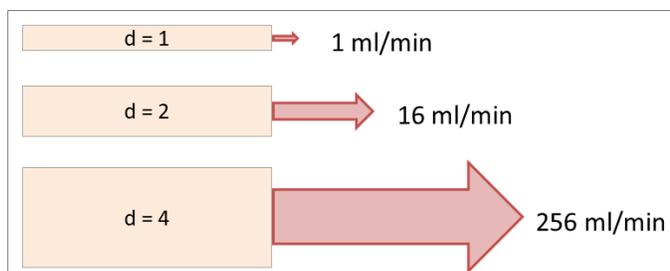
Just like cardiac output, **blood flow is relatively constant at rest but has to increase when we start to become active**. Yet, even at rest the blood flow through individual organs and tissues varies widely depending on the specific needs. Blood moving through the cardiovascular system encounters **resistance**. The three major sources of this opposition to flow are: **viscosity, total blood vessel length, and blood vessel diameter**.

Two of those three factors, **blood viscosity and total blood vessel length are fairly constant over shorter periods of time**, but can be changed over longer periods.

The **blood vessel diameter**, on the other hand, can be changed easily because of the presence of smooth muscle cells in the vessel walls. **Changes to the diameter of a blood vessel**, or its lumen to be precise, **have an inverse effect on the resistance to flow**. If the lumen is doubled, resistance goes down to 1/16 of its original value.

Constricting vessel diameter to half its size, increases resistance 16 times and if the diameter of a blood vessel quad-

### 18.5 Blood vessel diameter and blood flow



rules, the blood flow through the vessel will increase by 256 times!

The vast majority of blood vessels in the arterial system are **arterioles**. They are the major determinants of peripheral resistance and, thus, **have the most immediate impact on blood pressure**.

Because resistance varies inversely with the fourth power of vessel size, which is easily changed by the smooth muscle cells in the tunica media, **resistance is more important in influencing local blood flow than the pressure gradient**.

### Blood Flow through Organs and Tissues

Oxygen and nutrients are two of the survival needs of the body that need to be met at all times to avoid cell damage and death. Most cells can go without nutrient supplies for some time; however, most of them cannot be without oxygen for long. Active cells, such as the neurons of the nervous system and cardiac muscle cells, will start suffering from a lack of oxygen (hypoxia) within a few minutes. **Making sure that all cells are sufficiently supplied with oxygen at any given time is the number one job of the cardiovascular system**. This task is split between the heart (pumping enough blood) and the blood vessels (getting the blood to the organs and tissues that need it most).

The **velocity of the blood flow changes** as the blood travels through the systemic circulation. Blood flow is fastest in the aorta, slower in the smaller arteries and arterioles, slowest in the capillaries, and picks up speed again in the venules and veins.

At rest, the heart pumps about 5.25L/min in men and 4.5L/min in women (**cardiac output at rest**). This amount of blood is sufficient for all organs to function properly. Once we become active, we need more oxygen to power our muscles and, thus, overall blood flow must increase. Our cardiac output will double or triple if we play a ball game and it may even increase by 4-5 times if we exercise or work extremely hard.

This increase in cardiac output automatically leads to an increase in the blood pressure (see above) and the blood zooms with greater speed through the system. But, not all organs need more blood when we are active. The heart will need more blood as it must work harder and so will the muscles we use to run around and play basketball, for example. The kidneys and the liver, on the other hand, will not be more active and will not need more blood.

**Blood flow to the brain is independent of our activity level**. It has to be kept constant as neurons are intolerant of ischemia. Blood flow to the skin can vary tremendously. When we are cold and slow down perfusion of the skin to prevent us from losing heat, the amount of blood flowing through our entire skin can be as low as 50 mL/min (fewer than 2 fluid ounces). When our muscles work hard and produce excess heat that needs to be transported to the body surface for removal, blood flow can be as high as 2500 mL/min (1.5 gallons).

**Blood flow to each tissue has to be regulated depending on the actual needs of the tissue**. The easiest way to achieve that is via **autoregulation** of the speed of blood flow **by adjusting the diameter of arteries and arterioles** feeding blood into the tissue capillaries where the exchange processes take place. If the diameter of a blood vessel doubles, the blood flow increases 16-times (see above). This process is independent of the mean arterial pressure, which is controlled as needed to maintain constant pressure.

There are **two types of short-term autoregulation of tissue perfusion**:

1. In **metabolic control**, changes in the chemical environment, such as a decrease in tissue oxygen or an increase in ions ( $K^+$ ,  $H^+$ ), lead to changes in the blood vessel diameter. **Vasodilation**, i.e., a relaxation of vascular smooth muscle, **slows down the speed of blood flow**, whereas **vasoconstriction speeds up blood flow**.
2. **Myogenic control** is based on changes to the muscle tone of the arterioles caused by changes in blood pressure. An increase in intravascular pressure leads to passive stretch, which increases the muscle tone and causes vasoconstriction. A drop in blood pressure promotes vasodilation, which increases tissue perfusion.

**Every time the heart muscle contracts strongly, it cuts off blood flow to the coronary arteries**. But, thanks to the myoglobin that stores oxygen inside of the muscle cells, the myocardium can survive these short periods of time (about 0.25 seconds) without damage. However, the faster the heart beats and the more power it generates, the more oxygen its cells need. Healthy coronary arteries have the ability to dilate in response to low oxygen level around them, and the perfusion may increase three to four times. Hardening of the coronary arteries in atherosclerosis takes away the arteries' ability to dilate, leading to a lack of oxygen and potential myocardial infarction.

**Long-term autoregulation** of tissue perfusion depends on **angiogenesis**, i.e., the formation of more blood vessels. This is common in skeletal muscle tissue as a response to exercise and in the coronary arteries of the heart in coronary artery disease.

**Table 18.3 Perfusion Regulation of Major Organs**

Organ	Perfusion Regulation
Skeletal Muscles	<ul style="list-style-type: none"> <li>• At <b>rest</b>, myogenic and general neural mechanisms predominate.</li> <li>• During <b>muscle activity</b> blood flow increases in direct proportion to the metabolic activity (<b>active or exercise hyperemia</b>). <ul style="list-style-type: none"> <li>• Local controls override sympathetic vasoconstriction.</li> <li>• Muscle blood flow can increase 10x or more during physical activity.</li> </ul> </li> </ul>
Brain	<ul style="list-style-type: none"> <li>• <b>Blood flow to the brain is constant, as neurons are intolerant of ischemia!</b></li> <li>• <b>Metabolic controls:</b> <ul style="list-style-type: none"> <li>• Declines in pH, and increased carbon dioxide cause marked vasodilation.</li> </ul> </li> <li>• <b>Myogenic controls:</b> <ul style="list-style-type: none"> <li>• Decreases in MAP cause cerebral vessels to dilate.</li> <li>• Increases in MAP cause cerebral vessels to constrict.</li> <li>• The brain is vulnerable under extreme systemic pressure changes: <ul style="list-style-type: none"> <li>• <b>MAP below 60 mm Hg can cause syncope</b> (fainting).</li> <li>• <b>MAP above 160 can result in cerebral edema.</b></li> </ul> </li> </ul> </li> </ul>
Skin	<ul style="list-style-type: none"> <li>• Blood flow to venous plexuses below the skin surface <b>varies from 50 ml/min to 2500 ml/min</b>, depending on body temperature.</li> <li>• Controlled by sympathetic nervous system reflexes initiated by temperature receptors and the central nervous system.</li> <li>• As <b>temperature rises</b> (e.g., heat exposure, fever, vigorous exercise) <ul style="list-style-type: none"> <li>• Hypothalamic signals reduce vasomotor stimulation of the skin vessels.</li> <li>• Heat radiates from the skin.</li> <li>• Sweat also causes vasodilation via bradykinin in perspiration.</li> <li>• Bradykinin stimulates the release of nitric oxide.</li> </ul> </li> <li>• As <b>temperature decreases</b>, blood is shunted to deeper, more vital organs.</li> </ul>
Lungs	<ul style="list-style-type: none"> <li>• Arteries/arterioles are thin walled with large lumens.</li> <li>• Arterial resistance and pressure are low (24/8 mm Hg).</li> <li>• Autoregulatory mechanism is opposite of that in most tissues: <ul style="list-style-type: none"> <li>• Low O<sub>2</sub> levels cause vasoconstriction; high levels promote vasodilation.</li> <li>• Allows for proper O<sub>2</sub> loading in the lungs.</li> </ul> </li> </ul>
Heart	<ul style="list-style-type: none"> <li>• During <b>ventricular systole</b> coronary vessels are compressed: <ul style="list-style-type: none"> <li>• Myocardial blood flow ceases.</li> <li>• Stored myoglobin supplies sufficient oxygen.</li> </ul> </li> <li>• At <b>rest</b>, control is (probably) myogenic.</li> <li>• During <b>strenuous exercise</b> coronary vessels dilate in response to local accumulation of vasodilators. Blood flow may increase three to four times.</li> </ul>

### Microcirculation

**Blood flow through capillaries** (microcirculation) is **slow**, because of the low pressure gradient along the blood vessel, **and intermittent**, because of the opening and closing of precapillary sphincters.

The **capillaries are the site of all exchanges between the blood and the tissues**. Most of the exchange is based on passive transport from an area of high concentration to an area of low concentration. This passive transport is the basis for movement of oxygen and nutrients from the blood into the tissue and of carbon dioxide and waste products from the tissue into the blood.

**Lipid-soluble substances** diffuse directly through endothelial membranes; **water-soluble substances** pass through clefts and fenestrations between cells. Larger molecules, e.g., proteins, have to be transported actively using pinocytosis.

otic vesicles.

The majority of **water and ions move in and out of the capillaries via bulk flow**, which is described in the **Frank-Starling law of bulk flow**.

The main forces determining the direction and amount of flow are **hydrostatic pressure** and **colloid osmotic pressure**.

**Capillary hydrostatic pressure** (or **capillary blood pressure**) forces fluid from the capillary into the tissue, whereas the **hydrostatic pressure of the interstitial fluid** pushes fluid back into the capillary. However, under normal conditions, the hydrostatic pressure of the interstitial fluid is zero because of lymphatic vessels draining fluid from the tissue.

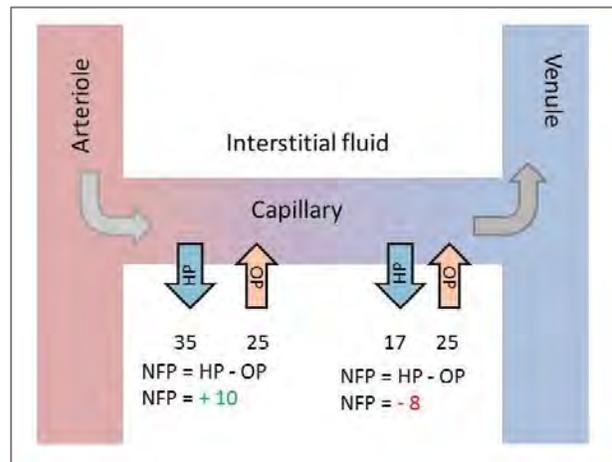
The **capillary colloid osmotic pressure**, also known as **oncotic pressure (OP)**, is caused by plasma proteins (mainly albumin) that do not move out of the capillary into the interstitial space. They stay back and draw water back into the vessel. Because of the normally low protein content of the **interstitial fluid**, its osmotic pressure is much lower than in the plasma and, thus, cannot hold water back from moving into the vessel.

All those forces taken together create the **net filtration pressure (NFP)**, which can cause whether water to move into or out of the capillary.

- At the **arterial end of the capillary**, the **NFP is positive (+10 in above diagram) and water moves out of the vessel**.
- Because of this loss of fluid, the capillary hydrostatic pressure goes down, and at the **venous end of the capillary the NFP is negative (-8 in above diagram), i.e., water moves into the vessel**.

A small amount of fluid, 1.25 ml/min or 3 l/day, is not returned into the capillary, but will be drained via the **lymphatic system** (see **Chapter 20 Lymphatic System and Immunity**).

Figure 18.6 Frank-Starling law of bulk flow



### Check Your Understanding

- Which of the following statements is correct?
  - The pulmonary circulation is longer with a higher blood pressure
  - The average cardiac output at rest is about 5 L/min
  - Capillaries carry blood back to the heart
  - Our normal heart rate at rest is > 100 bpm
- Which of the following is *not* a major source of resistance to blood flow?
  - Viscosity
  - Total blood vessel length
  - Afterload
  - Blood vessel diameter
- The blood flow through an organ in a certain time period is called \_\_\_\_\_.
  - cardiac output
  - perfusion
  - resistance
  - minute flow
- Blood flow to the brain \_\_\_\_\_.
  - increases with mental activity
  - decreases during physical activity
  - slows down during sleep
  - is independent of our activity level

1.B.2.B.3.C.4.D

## 18.7 Major Arteries of the Systemic Circulation

The **aorta** is the largest blood vessel of the human body. It starts at the exit of the left ventricle, just behind the aortic valve. The aorta first travels upwards for about two inches (**ascending aorta**), goes over into the **aortic arch**, before continuing its journey downwards towards the abdominopelvic cavity as the **descending aorta**. The descending aorta is the longest part of the aorta. Its first part, the **thoracic aorta**, heads downward along the vertebral column before entering the abdominal cavity. The part of the descending aorta below the diaphragm is called the **abdominal aorta**.

The **ascending aorta** gives off two arteries, the **right** and **left coronary arteries**. The **aortic arch** has three major branches that supply the head, brain, and upper limbs with blood: the **brachiocephalic trunk**, **left common carotid artery**, and **left subclavian artery**. The **thoracic aorta** only gives off small branches to the thoracic organs and wall. The **abdominal aorta** supplies all organs below the diaphragm and the lower limbs with blood. Its first branch, the **celiac trunk**, almost immediately splits into three branches: the **common hepatic artery**, **splenic artery**, and **left gastric artery**. The **superior** and **inferior mesenteric arteries** supply blood to the small and large intestines, while smaller branches go to the adrenal glands (**suprarenal arteries**), kidneys (**renal arteries**), and gonads (**testicular arteries** in men, **ovarian arteries** in women arteries). The abdominal aorta splits at the level of L<sub>4</sub> into the **right** and **left common iliac arteries**.

Figure 18.7 Arteries of the upper limb

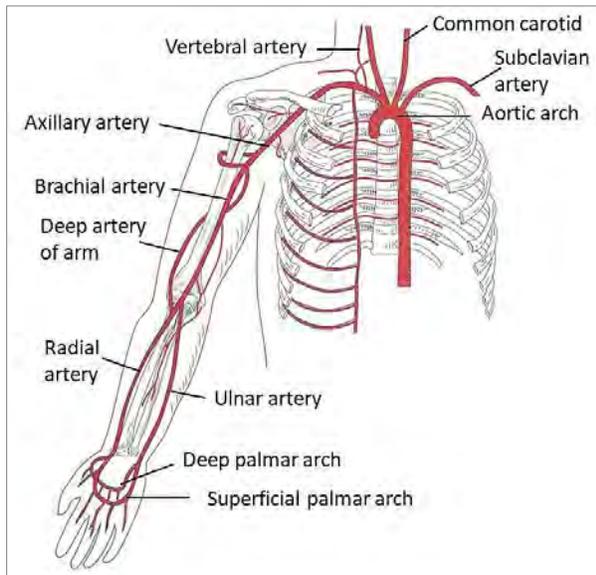


Figure 18.8 Arteries of the neck and head

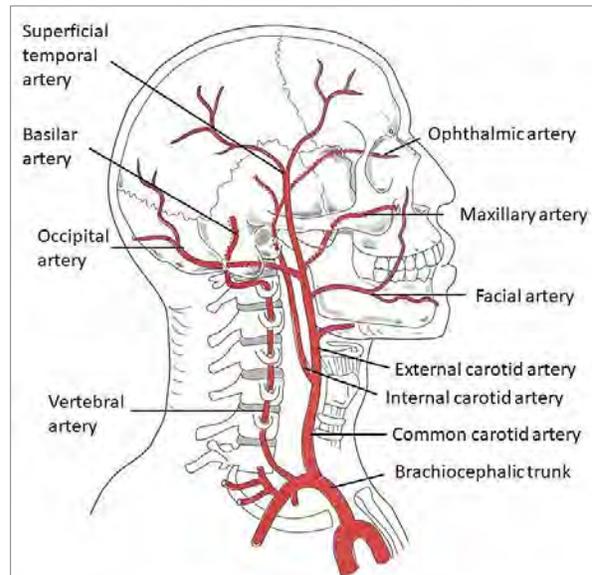


Table 18.4 Major Arteries of the Systemic Circulation

Artery	Description
Coronary arteries	<ul style="list-style-type: none"> <li>• Branch off of the aorta just behind the aortic valve.</li> <li>• Supply the myocardium of ventricles and atria.</li> </ul>
Brachiocephalic trunk	<ul style="list-style-type: none"> <li>• Major branches are <b>right and left coronary arteries</b>, <b>marginal artery</b>, <b>circumflex artery</b>, <b>anterior and posterior interventricular arteries</b>.</li> <li>• First branch of the aortic arc.</li> <li>• Splits into right common carotid artery and right subclavian artery.</li> </ul>
Common carotid artery	<ul style="list-style-type: none"> <li>• Branches off of the brachiocephalic trunk (right side) and the aortic arch (left side).</li> <li>• Splits into external and internal carotid arteries.</li> </ul>
External carotid artery	<ul style="list-style-type: none"> <li>• Branches off of the common carotid arteries.</li> <li>• Supplies most of the head, but not the brain.</li> </ul>
Internal carotid artery	<ul style="list-style-type: none"> <li>• Branches off of the common carotid arteries.</li> <li>• Supplies 80% of the brain.</li> </ul>
Subclavian artery	<ul style="list-style-type: none"> <li>• Branches off the brachiocephalic trunk (right side) and the aortic arch (left side).</li> <li>• Supplies the tissue of the upper limb.</li> <li>• Changes its name to <b>axillary artery</b> when entering the axilla, and to <b>brachial artery</b> once it emerges from the axilla.</li> <li>• Splits just below the elbow into its two end branches: the <b>radial artery</b> on the lateral side and the <b>ulnar artery</b> on the medial side of the arm.</li> </ul>

	<ul style="list-style-type: none"> <li>The <b>radial artery</b> is rather superficial at the root of the thumb, which makes this spot the most commonly used site for pulse palpation.</li> </ul>
Vertebral artery	<ul style="list-style-type: none"> <li>Branches off of the subclavian artery.</li> <li>Ascends and enters the skull through the foramen magnum. Supplies 20% of the brain, including the cerebellum.</li> </ul>
Celiac trunk	<ul style="list-style-type: none"> <li>First branch of the abdominal aorta just below the diaphragm.</li> <li>Splits almost immediately into three branches: <b>common hepatic artery</b> (for the liver), <b>splenic artery</b> (for the spleen), and <b>left gastric artery</b> (for the stomach).</li> </ul>
Superior mesenteric artery	<ul style="list-style-type: none"> <li>Second branch of the abdominal aorta.</li> <li>Supplies the pancreas, small intestine and part of the large intestine.</li> </ul>
Inferior mesenteric artery	<ul style="list-style-type: none"> <li>Third branch of the abdominal aorta.</li> <li>Supplies the second part of the large intestine.</li> </ul>
Renal artery	<ul style="list-style-type: none"> <li>Branches off of the abdominal artery and supplies the kidney.</li> </ul>
Common iliac artery	<ul style="list-style-type: none"> <li>Splits into the <b>right</b> and <b>left common iliac arteries</b> that supply <b>the lower limbs</b> (via the <b>femoral artery</b>) and <b>pelvic organs</b>.</li> <li>Branches off of the common iliac artery.</li> </ul>
External iliac artery	<ul style="list-style-type: none"> <li>Called <b>femoral artery</b> once it has passed under the inguinal ligament and called <b>popliteal artery</b> one it reaches the knee area.</li> <li>Splits into the <b>anterior tibial artery</b> for the anterior part of the leg and the <b>posterior tibial artery</b> for the posterior part.</li> </ul>

Figure 18.9 Arteries of the abdominopelvic cavity

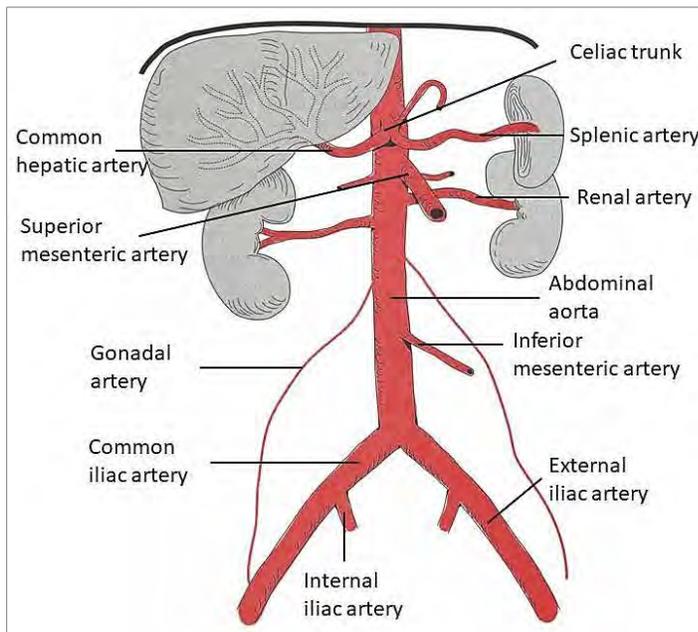
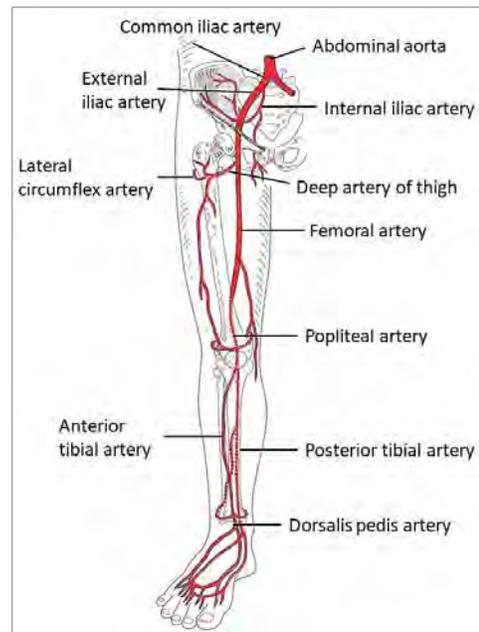


Figure 18.10 Arteries of the lower limb



The **neck and head** are supplied by four pairs of arteries. The **common carotid arteries** branch off the **brachiocephalic trunk** on the right side and the **aortic arch** on the left side. They split into the **external carotid arteries** that supply most of the head, but not the orbits and the brain, and the **internal carotid arteries** that supply the orbits and 80% of the brain. The other three arteries are branches of the **subclavian artery**. The first branch, the **vertebral artery**, ascends through the transverse foramina in the transverse processes of the cervical vertebrae and enters the skull through the foramen magnum. It supplies 20% of the brain, including the cerebellum, and has connections with the internal carotid arteries via the **cerebral arterial circle** (also known as the **circle of Willis**). The other two arteries, the **thyrocervical trunk** and the **costocervical trunk**, mainly supply the neck and part of the spinal cord and thoracic muscles.

The major artery supplying blood to the **upper limb** is the **subclavian artery**, which changes its name to **axillary artery** when entering the axilla and to **brachial artery** once it emerges from there. It gives off one major branch, the **deep artery of the arm**. Just below the elbow, the brachial artery splits into its two end branches, the **radial artery** on the lateral side and the **ulnar artery** on the medial side of the arm. The radial artery is rather superficial at the root of the thumb, which makes this spot the most commonly used site for pulse palpation.

The lower limb is supplied by the **external iliac artery**, which changes its name to **femoral artery** once it passes under the inguinal ligament. Its first branch is the **deep artery of the thigh**. Once the **femoral artery** has passed through the adductor hiatus into the popliteal fossa, it is called the **popliteal artery**. This artery splits into the **anterior tibial artery** for the anterior part of the leg and the **posterior tibial artery** for the posterior part. The posterior tibial artery gives off the **fibular or peroneal artery**.

### 18.8 Major Veins of the Systemic Circulation

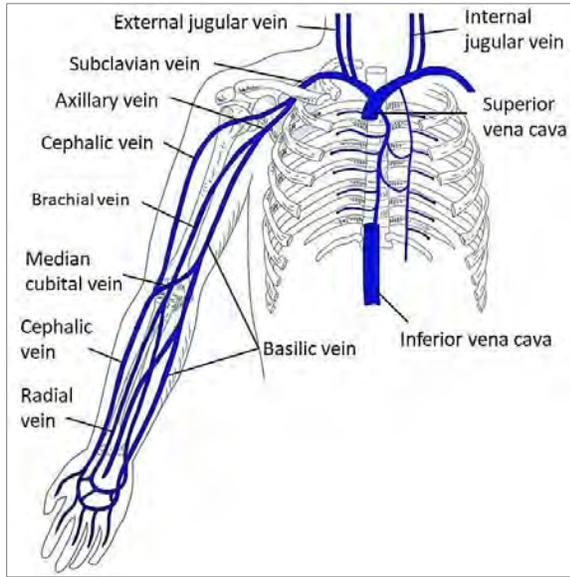
**Blood flow in the venous system is opposite to the flow in the arterial system** because it drains the blood out of the tissues and carries it back towards the heart. All blood from areas below the diaphragm is carried back by the **inferior vena cava**, while all blood from the areas above the diaphragm is carried back by the **superior vena cava**. The **coronary circulation** is an exception to this rule as it uses the **coronary sinus** to return its oxygen-depleted blood to the right atrium.

**Table 18.5 Major Veins of the Systemic Circulation**

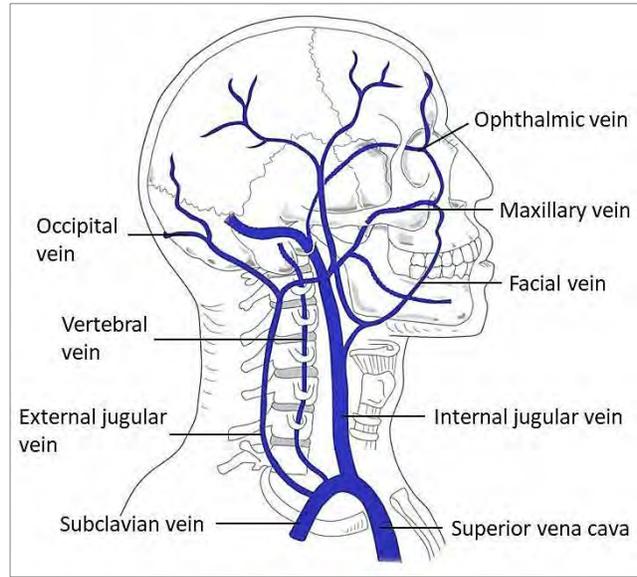
Vein	Description
Inferior vena cava	<ul style="list-style-type: none"> <li>Collects blood from all organs and tissues located below the diaphragm.</li> <li>Empties into the right atrium.</li> </ul>
Superior vena cava	<ul style="list-style-type: none"> <li>Collects blood from all organs and tissues located above the diaphragm.</li> <li>Empties into the right atrium.</li> </ul>
Coronary sinus	<ul style="list-style-type: none"> <li>Collects the blood from the cardiac tissue.</li> <li>Empties into the right atrium.</li> </ul>
Subclavian vein	<ul style="list-style-type: none"> <li>Collects blood from the head (via <b>external jugular vein</b> and <b>vertebral vein</b>) and upper limb (veins of the upper limb).</li> </ul>
Internal jugular vein	<ul style="list-style-type: none"> <li>Collects blood from the head (<b>facial vein</b>, <b>ophthalmic veins</b>) and brain (<b>dural venous sinuses</b>).</li> </ul>
Brachiocephalic vein	<ul style="list-style-type: none"> <li>Formed by fusion of <b>subclavian vein</b> and <b>internal jugular vein</b>.</li> </ul>
Azygos vein	<ul style="list-style-type: none"> <li>Drains blood from the abdominal and thoracic wall via the <b>hemiazygos vein</b> and <b>accessory hemiazygos vein</b>.</li> </ul>
Veins of upper limb	<ul style="list-style-type: none"> <li>The forearm has five main veins called <b>radial</b>, <b>ulnar</b>, <b>basilic</b>, <b>cephalic</b>, and <b>median antebrachial vein</b>.</li> <li>The radial and ulnar veins unite to form the <b>brachial vein</b> of the arm.</li> <li>The <b>median cubital vein</b> connects basilica and cephalic veins on the anterior side of the elbow.</li> <li>The three veins of the arm unite to form the <b>subclavian vein</b>.</li> </ul>
Veins of lower limb	<ul style="list-style-type: none"> <li>The <b>lower leg</b> has two main deep veins (<b>anterior</b> and <b>posterior tibial veins</b>) and two superficial veins (<b>small</b> and <b>great saphenous veins</b>).</li> <li>The deep veins and the small saphenous vein form the <b>popliteal vein</b>, which is called <b>femoral vein</b> above the popliteal fossa.</li> <li>Once <b>inside the pelvis</b>, the femoral vein is called the <b>external iliac vein</b>.</li> <li>It unites with the <b>internal iliac vein</b> to form the <b>common iliac vein</b>, and the two common iliac veins join to form the <b>inferior vena cava</b>.</li> </ul>

Most **blood from the brain, head and neck** is drained by three veins: **internal jugular vein**, **vertebral vein**, and **external jugular vein**. Unlike the vertebral artery, its namesake vertebral vein does not drain much of the brain. Most veins of the brain drain into **dural venous sinuses**, which in turn drain into the internal jugular veins.

**Figure 18.11 Veins of the upper limb**



**Figure 18.12 Veins of the neck and head**

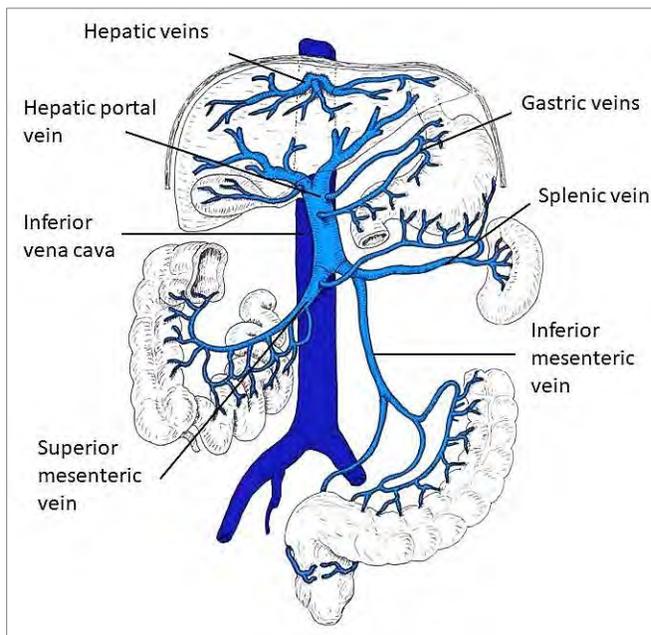


Blood from the abdominal and thoracic walls is drained by two veins that run along the vertebral column; the **azygos vein** on the right side of the column and the **hemiazygos vein** on the left. They are complemented by the **accessory hemiazygos veins** in the thorax.

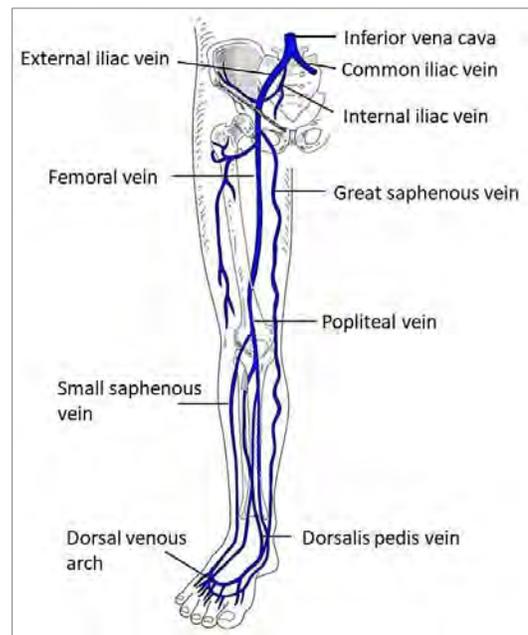
Blood from the digestive organs (small and large intestine, stomach, pancreas, gallbladder) and the spleen is drained to the liver via the **hepatic portal system**. The **hepatic portal vein** is formed when the **splenic vein** joins the **superior mesenteric vein**. The **inferior mesenteric vein** drains into the splenic vein just prior to that.

After flowing through and being processed by the liver, the blood exits via the **hepatic veins**, which carry the blood into the **inferior vena cava** just below the diaphragm.

**Figure 18.13 Veins of the abdominopelvic cavity**



**Figure 18.14 Veins of the lower limb**



The **venous system of the limbs is more complicated and varied than the arterial supply**. We have **deep veins** that run close to the arteries (although the blood flows in opposite directions) and **superficial veins** close to the surface. When we need to cool down the blood (and the body), the blood is directed to the superficial veins; when we are cold and want to prevent further heat loss, the blood stays in the deep veins.

The forearm has five main veins called **radial**, **ulnar**, **basilic**, **cephalic**, and **median antebrachial vein**. Radial and ulnar veins unite to form the **brachial vein** of the arm. The **median cubital vein** connects the basilica and cephalic veins on the anterior side of the elbow.

The three veins of the arm unite to form the **right** and **left subclavian veins**, which also take in blood from the head and neck (**external** and **internal jugular veins**), before they unite to form the **superior vena cava**, which drains into the right atrium.

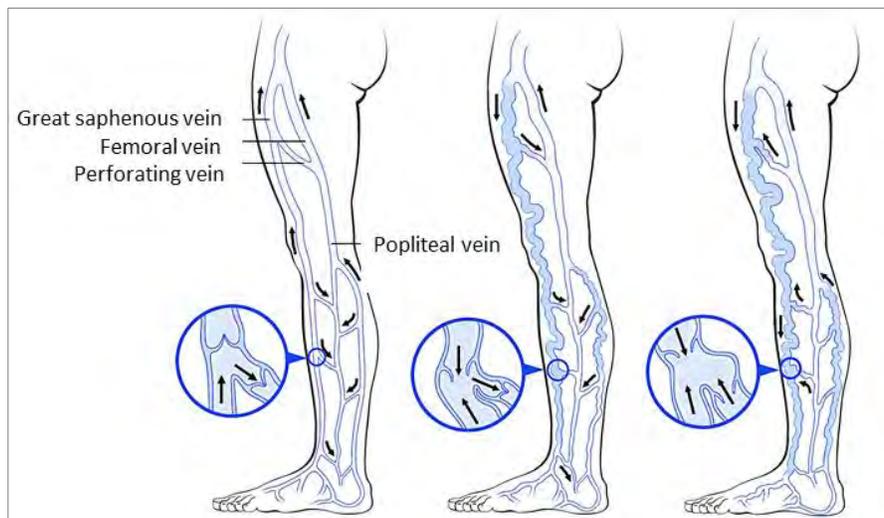
The **lower leg** has two main deep veins (**anterior** and **posterior tibial veins**) and two superficial veins (**small** and **great saphenous veins**). The deep veins and the small saphenous vein form the **popliteal vein**, which is called **femoral vein** above the popliteal fossa.

Once it is inside the pelvis, the femoral vein is called **external iliac vein**. It unites with the **internal iliac vein** to form the **common iliac vein**.

The two common iliac veins join to form the **inferior vena cava**, which collects blood from abdominal organs that are not located inside the peritoneal cavity, such as the kidneys and ovaries, on its way up toward the heart.

**Perforating veins** connect the deep and superficial veins. Normally, the valves in the deep and superficial veins of the leg direct the venous flow upwards towards the external iliac veins. If the valves become incompetent the blood will not flow upwards but collect in the superficial veins that enlarge and form visible **varicose veins**.

**Figure 18.15 Development of varicose veins of the lower limb**



## 18.9 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	fast	_____	hyp(o)-
2.	plaque	_____	hyper-
3.	more than normal	_____	phleb(o)-
4.	vein	_____	brady-
5.	less than normal	_____	angi(o)-
6.	vessel	_____	ather(o)-
7.	slow	_____	tachy-

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

1. A vein is a blood vessel that carries blood from the tissues back to the heart. \_\_\_\_\_
2. Venules play a key role in regulating blood flow into capillaries. \_\_\_\_\_
3. Continuous capillaries can be found in skeletal muscles. \_\_\_\_\_
4. Venules and capillaries make up the largest blood reservoir. \_\_\_\_\_
5. The myogenic response makes smooth muscle contract more forcefully when stretched. \_\_\_\_\_
6. The renin-angiotensin mechanism increases blood pressure directly and indirectly. \_\_\_\_\_
7. The larger arteries contain valves to prevent the backflow of blood. \_\_\_\_\_
8. Blood flow to the brain is independent of our activity level. \_\_\_\_\_
9. Maintenance and control of blood pressure is mainly performed by the kidneys. \_\_\_\_\_
10. The baroreceptors in the aortic arch protect the blood flow to the brain. \_\_\_\_\_
11. Blood viscosity is the most important factor determining resistance to blood flow. \_\_\_\_\_
12. The velocity of the blood flow is slowest in the capillaries. \_\_\_\_\_
13. Capillary hydrostatic pressure is higher at the arterial end of the capillary than at the venous end. \_\_\_\_\_
14. The superior and inferior mesenteric arteries supply blood to the intestines. \_\_\_\_\_
15. The popliteal artery is an extension of the femoral artery. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                     |   |          |
|---------------------|---|----------|
| 1. Artery           | a) widening of the lumen due to smooth muscle relaxation              | 1. _____ |
| 2. Large veins      | b) outermost layer of a blood vessel                                  | 2. _____ |
| 3. Liver            | c) gives rise to the right common carotid and right subclavian artery | 3. _____ |
| 4. Tunica externa   | d) site where blood pressure is greatest                              | 4. _____ |
| 5. Vasodilation     | e) sinusoidal capillaries   | 5. _____ |
| 6. Baroreceptor     | f) carries oxygen-rich blood from the lungs                           | 6. _____ |
| 7. Large arteries   | g) carries blood away from the heart                                  | 7. _____ |
| 8. Respiratory pump | h) drains the upper extremities                                       | 8. _____ |
| 9. Sphygmomanometer | i) site where the blood volume is greatest                            | 9. _____ |

- |                             |   |           |
|-----------------------------|---|-----------|
| 10. Angiotensin             | j) major supplier to the cerebral hemispheres | 10. _____ |
| 11. Brachiocephalic trunk   | k) supplies the liver, stomach and spleen     | 11. _____ |
| 12. Subclavian vein         | l) measures blood pressure                    | 12. _____ |
| 13. Celiac trunk            | m) increases blood pressure                   | 13. _____ |
| 14. Internal carotid artery | n) short-term control of blood pressure       | 14. _____ |
| 15. Pulmonary vein          | o) sucks blood upwards into thorax            | 15. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Which of the following are the blood vessels that distribute blood to organs?
  - Arteries
  - Venules
  - Arterioles
  - Veins
- Which part of the artery wall is responsible for vasoconstriction?
  - Tunica interna
  - Tunica media
  - Tunica externa
  - Tunica albuginea
- Which of the following does **not** increase blood pressure?
  - Increased blood volume
  - Increased sympathetic stimulation
  - Increased heart rate
  - Decreased cardiac output
- The cardiovascular center is located in the \_\_\_\_\_.
  - cerebral cortex
  - cerebellum
  - medulla oblongata
  - hypothalamus
- Which of the following hormones does **not** cause an increase in blood pressure?
  - Atrial natriuretic peptide
  - Antidiuretic Hormone
  - Aldosterone
  - Angiotensin
- Which of the following control the flow of blood through a capillary bed?
  - Thoroughfare channels
  - Precapillary sphincters
  - Postcapillary sphincters
  - Venules
- Which of the following statements is incorrect?
  - Aldosterone is an antagonist to ANP.
  - Angiotensin I converts renin to angiotensin II.
  - ANP is released in response to increase right atrial pressure.
  - ADH increases peripheral resistance in high concentration.

8. Which of the following helps force fluids out of the blood into the tissues?
- Colloid osmotic pressure
  - Capillary hydrostatic pressure
  - Interstitial hydrostatic pressure
  - Interstitial osmotic pressure
9. Which of the below is the most important capillary exchange method?
- Diffusion
  - Bulk flow
  - Active transport
  - Primary transport
10. Blood flow to the skin \_\_\_\_\_.
- increases when environmental temperature rises
  - increases when body temperature drops so that the skin does not freeze
  - is not an important source of nutrients and oxygen for skin cells
  - is controlled mainly by decreasing pH
11. The hepatic portal vein \_\_\_\_\_.
- carries blood from the liver to the inferior vena cava
  - carries nutrient-rich blood to the liver
  - is actually an artery
  - carries oxygen-rich blood from the liver to the viscera
12. Which of these arteries is **not** a branch of the abdominal aorta?
- Common iliac arteries
  - Inferior mesenteric artery
  - Gonadal arteries
  - Left common carotid artery
13. The external iliac vein receives blood from all of the following **except** the \_\_\_\_.
- anterior tibial vein
  - vertebral vein
  - femoral vein
  - fibular vein
14. The brachial vein \_\_\_\_.
- drains blood from the popliteal vein, then empties that blood into the femoral vein
  - drains blood from the internal jugular vein, then empties that blood into the superior vena cava
  - drains blood from the axillary vein, then empties that blood into the superior vena cava
  - drains blood from the radial and ulnar veins, then empties that blood into the axillary vein
15. Which one of the following arteries is **not** a superficial artery?
- Dorsalis pedis artery
  - Renal artery
  - Posterior tibial artery
  - Radial artery

## Chapter 19 Blood, Hemostasis, and Blood Groups

### 19.1 Chapter Outline

The blood transports nutrients, respiratory gases, and wastes to and from the cells and tissues, and prevents bleeding. It also works together with the immune system to protect and maintain the health and integrity of the body.

### 19.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the composition and physical characteristics of whole blood.
- Discuss the composition and functions of plasma.
- Describe the structure, function, and formation of erythrocytes.
- List the classes, structural characteristics, and functions of leukocytes.
- Explain white blood cells formation.
- Describe the structure and function of platelets.
- Explain the processes of hemostasis.
- Describe the ABO and Rh blood groups.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 19.3 Combining Forms

Table 19.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 19.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
-blast	immature cell	<i>leukoblast</i> = immature leukocyte
coagul(o)-	clotting or coagulation	<i>coagulopathy</i> = a disorder of blood clotting
-cyte	(mature) cell	<i>leukocyte</i> = (mature) leukocyte
embol(o)-	embolus	<i>embolectomy</i> = surgical removal of an embolus
eosin(o)-	red or rosy	<i>eosinophil</i> = red-staining leukocyte
erythr(o)-	red	<i>erythrocyte</i> = red blood cell
granul(o)-	granule or grain	<i>granulocyte</i> = leukocyte with granules in the cytoplasm
hem(o)-, hema-, hemat(o)-	blood	<i>hematopoiesis</i> = blood cell formation
leuk(o)-	white	<i>leukopoiesis</i> = formation of white blood cells
lymph(o)-	lymph	<i>lymphoid</i> = relating to or resembling lymph or lymphatic tissue
myel(o)-	bone marrow	<i>myeloid</i> = relating to or derived from bone marrow
thromb(o)-	clot or thrombus	<i>thrombocytic</i> = relating to thrombocytes

### 19.4 Blood

The blood is a truly unique and special tissue. Not only is it vital for supplying all body cells and tissue with oxygen and nutrients, but it is also important for the removal and transport of waste products from our metabolism and of heat

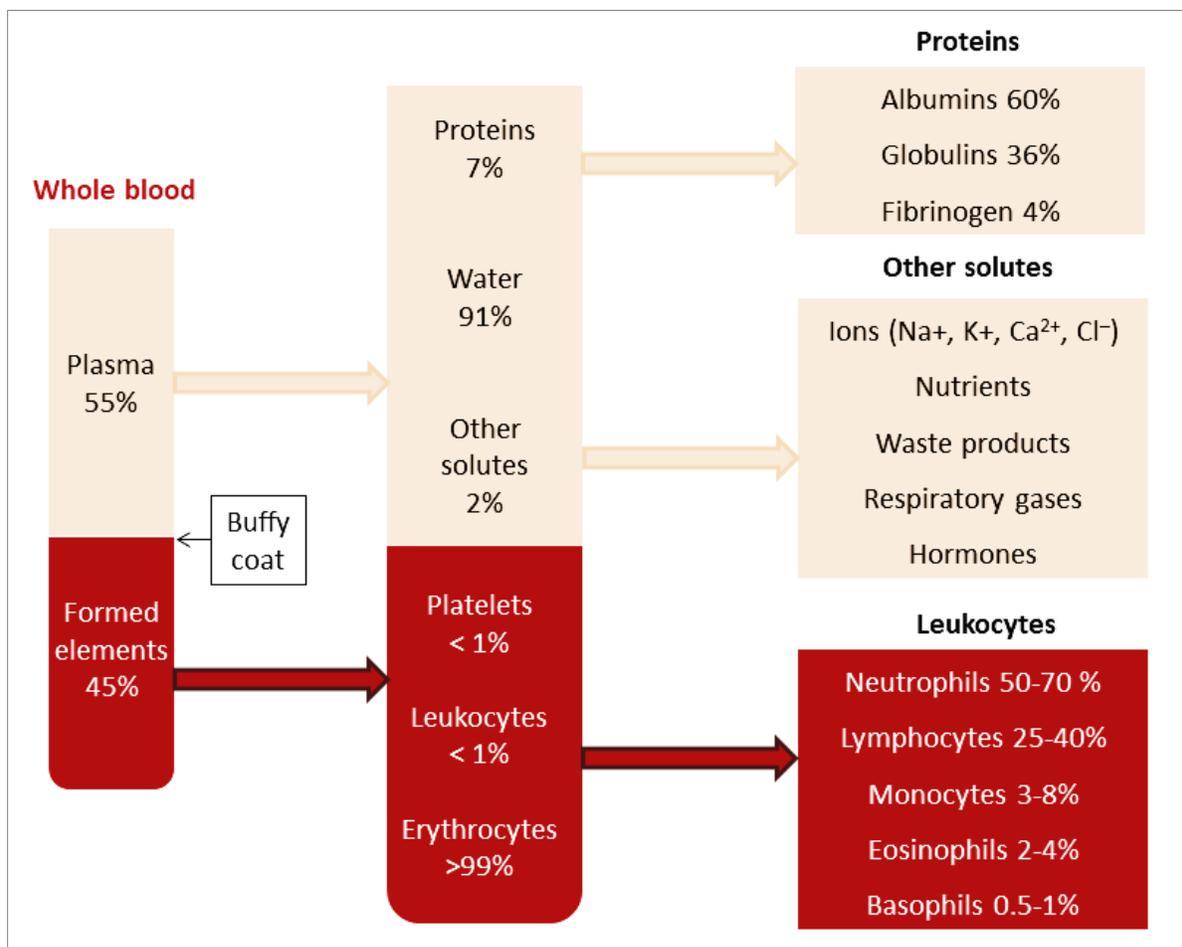
from our muscles. Equally vital is the role white blood cells (WBCs) play in the protection of our body from external invaders and from rogue cells developing internally. To find those threats, white blood cells leave the blood stream and check all areas of our body. As a matter of fact, more than 90% of our white blood cells are found outside the blood vessels in the tissues of lymphoid organs and the lymphatic vessels (see **Chapter 20 Lymphatic System & Immunity**).

**Blood has many functions**, such as transport of respiratory gases (oxygen, carbon dioxide), nutrients, metabolic waste products, and hormones; regulation of body temperature, pH, and blood volume; and protection against blood loss and infection.

Blood is **the only liquid tissue of the body**. It is **considered a connective tissue** because it consists of **cells** surrounded by an **extracellular matrix**. However, of the three types of cells (red blood cells, white blood cells, platelets) **only white blood cells are complete cells**. Therefore, it is better to talk about **formed elements** than cells.

Blood makes up **approximately 8% of our body weight** or 5-6 L (1.25-1.5 gallons) for men and 4-5 L (1-1.25 gallons) for women. Its color depends on its oxygen saturation; dark red blood has a low oxygen saturation, while bright red blood has a high oxygen saturation. The **blood pH** should be between **7.35 and 7.45**. At **100.4°F**, blood is warmer than the body shell temperature.

Figure 19.1 Composition of whole blood



**Red blood cells (RBCs)** are by far the most numerous of the formed elements. Therefore, the thickness or **viscosity of blood** is largely determined by the amount of red blood cells.

The **percentage of blood volume that consists of red blood cells** is called the **hematocrit**. Its **normal value** is 45% ( $\pm$  5%); men have a slightly higher normal value (47%) than women (42%). The higher the hematocrit, the higher the viscosity of the blood.

The white layer that separates red blood cells (lower layer) and plasma (upper layer) after centrifugation is called the **buffy coat**. It is made of **white blood cells** and **blood platelets**.

The liquid part of the blood, the **plasma**, makes up about **55% of the total blood volume**. Plasma consists mainly of water (90%), which acts as a solvent for other substances, the so-called **solutes**. **Proteins** make up the majority of solutes (9% of 10%); most plasma proteins are produced in the liver.

**Albumins** make up **60% of the plasma proteins**. Their major function is **maintaining the colloid osmotic or oncotic pressure** (see **Chapter 18 Blood vessels & Circulation**). **Globulins** (40% of the plasma proteins) are functional proteins, such as enzymes or antibodies. **Fibrinogen** (4%) is an important globulin and part of the blood clotting system (see below).

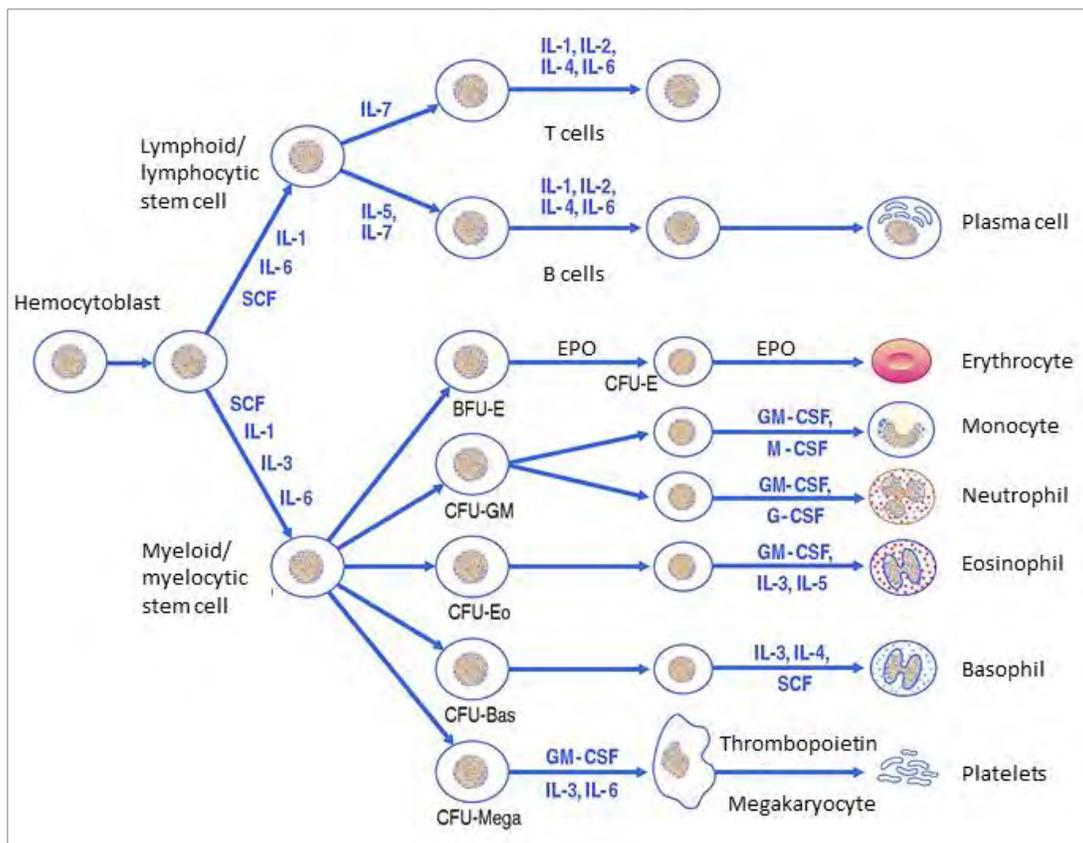
**Other solutes found in the plasma** are nutrients (glucose, carbohydrates, amino acids), electrolytes ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ), respiratory gases ( $\text{O}_2$ ,  $\text{CO}_2$ ), hormones, and metabolic waste products (lactic acid, urea, creatinine).

### Blood Formation

The formation of blood cells is called **hemopoiesis** (*hem(o)-* blood, *-poiesis* formation) or **hematopoiesis** (*hemat(o)-* blood, *-poiesis* formation) and occurs in the red bone marrow. All formed blood elements derive from a **common stem cell**, the so-called **hemocytoblast**. The different blood cells are produced under the influence of hormones and growth factors, depending on the needs of the body.

In **red blood cell formation**, or **erythropoiesis** (*erythr(o)-* red, *-poiesis* formation), a stem cell gradually transforms over a period of 15 days into a **reticulocyte**, which forms the last stage of the development before full maturity of the red cell. Reticulocytes can transport oxygen. They are released into the blood, where they develop into **erythrocytes** within 24-36 hours.

Figure 19.2 Formation of formed blood elements in the bone marrow



Because transport of oxygen is the major function of red blood cells, a lack of RBCs will lead to oxygen deficiency (**hypoxia**) in the tissues. Cells in the kidneys and the liver sense this lack of oxygen and secrete the hormone **erythropoietin** (EPO). EPO has a direct influence on erythropoiesis in the red bone marrow, leading to an increased maturation of RBC progenitors and an **increase of reticulocytes in the blood within 1-2 days**.

Likewise, the male sex hormone **testosterone** also influences red cell production. It increases EPO production and release. As a result, men have a higher hematocrit than women.

The required **raw materials** for RBC production are **major nutrients** (lipids, proteins, and carbohydrates), **vitamins** (B<sub>12</sub>, folic acid), and **iron** (for the heme pigment in hemoglobin). On average, our **food contains approximately 7 mg iron per 1000 calories**, of which about 10% (1-1.5 mg) are absorbed each day. Absorption is enhanced by meat, poultry, fish, and gastric acid (HCl), but inhibited by carbonates, tannate (tea), oxalate (spinach, rhubarb), and phosphates (vegetables). The duodenum and upper jejunum are the major absorption sites for iron.

This iron intake is equal to the average daily loss in men but may not be sufficient for menstruating women. Their iron loss may be up to 15 mg per month.

**Transferrin** is an iron-carrier protein in the plasma; **ferritin** is an iron-storage protein in the tissue. **Hemosiderin** is a water-insoluble storage form in cells.

Just like red blood cells, leukocytes originate from the hemopoietic stem cell in the bone marrow. However, **white cell formation** or **leukopoiesis** (*leuk(o)*- white, *-poiesis* formation) is of greater complexity because there are more subpopulations (see below). Chemical messengers, such as **interleukins** (ILs) and **colony-stimulating factors** (CSFs), stimulate the formation and release of specific leukocytes from existing colonies in the bone marrow.

**Blood platelets** (thrombocytes) are also formed in the bone marrow in a process called **thrombopoiesis** (*thromb(o)*- clot, *-poiesis* formation). Platelets split off as small fragments from giant precursor cells called **megakaryocytes**. Platelet formation is regulated by the hormone **thrombopoietin**, which is produced in liver and kidneys.

### Red Blood Cells (Erythrocytes)

Erythrocytes (*erythr(o)*- red, *-cytes* cells) are by far the most numerous cells in the blood with approximately **5 million per  $\mu\text{L}$  of blood**. Red blood cells are **biconcave discs** with a thin center and a thick rim, and a **diameter of approx. 7.4 $\mu\text{m}$** .

Their red color comes from the protein **hemoglobin**, which makes up approx. 97% of its content (not counting water). Erythrocytes do not have nuclei or mitochondria and, thus, cannot produce new proteins and cannot use oxygen to generate ATP.

The **main function** of red blood cells is the **transport of oxygen** from the lungs to the tissues. At the center of this function is **hemoglobin** (Hb), which consists of **four chains: two alpha and two beta chains**. These protein chains make up the protein portion (*globin*) of the molecule. The *hemo*- portion comes from a red pigment (*heme*) that contains one atom of **iron** at its core. **Each molecule of Hb is able to transport four molecules of oxygen** (O<sub>2</sub>).

Loading of hemoglobin with oxygen in the lungs is called **oxygenation** and leads to the formation of bright red **oxygenated Hb** or **oxyhemoglobin**. However, this is a not a chemical but a physical process, and oxygen can be unloaded again in the tissue. Unloading is called **deoxygenation**; it produces dark red **deoxygenated Hb** or **deoxyhemoglobin**. Other gases can bind to Hb too, such as carbon dioxide, which binds with Hb forming **carbaminohemoglobin**.

Erythrocytes have a **life span of 100-120 days**, i.e., **every day approximately 1% of red blood cells are replaced**. Because of that, approximately 1% of red blood cells circulating in the blood are reticulocytes, and the **reticulocyte index** (RI) is 1. Increased red blood cell formation will lead to an increased RI as long as the red bone marrow is fully functional and the body is well nourished (see above).

**Damaged or old RBCs are destroyed by macrophages in the spleen and liver**. Iron and proteins are salvaged and reused. Heme is degraded to a yellow pigment called **bilirubin**, which is transported to the liver where it is me-

Figure 19.3 Distribution of red bone marrow in the adult skeleton

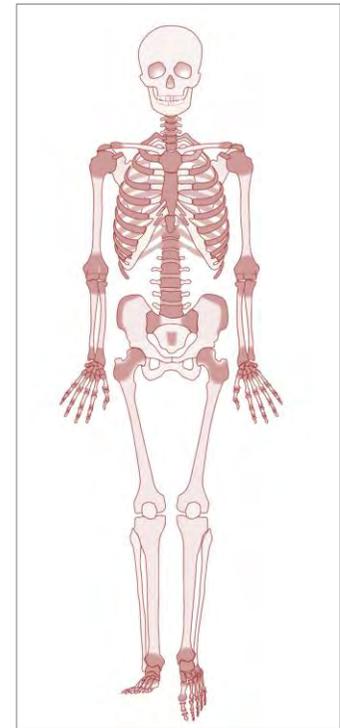
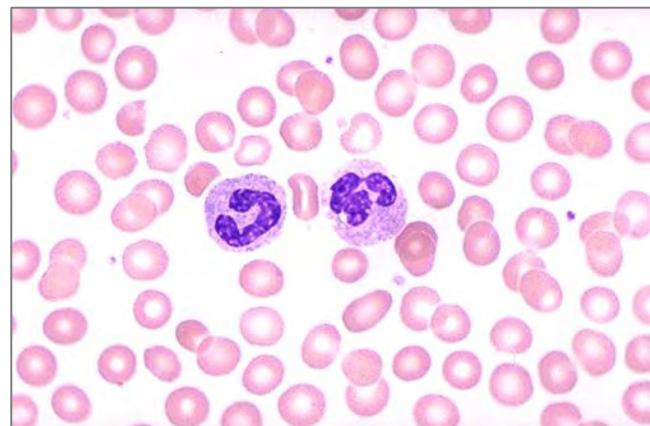


Figure 19.4 Red blood cells and white blood cells



tabolized into a water-soluble form and secreted with the bile into the small intestine. Some of the bilirubin is changed to **stercobilin**, which gives the feces its brown color.

### White Blood Cells (Leukocytes)

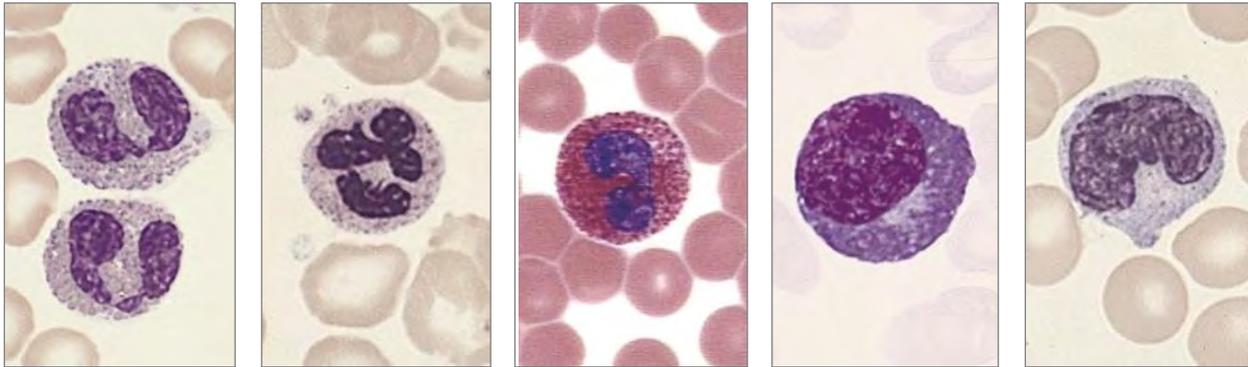
Leukocytes (*leuk(o)*- white, *-cytes* cells) are far less numerous than red blood cells. With **4,500 to 11,000 cells per  $\mu\text{L}$**  of blood, leukocytes make up less than 1% of the total blood volume. If that number increases above 11,000 per  $\mu\text{L}$ , in response to an infection for example, it is called **leukocytosis**. An abnormally low white blood cell (WBC) count is known as **leukopenia** (*leuk(o)*- white, *-penia* deficiency). Most of the time, leukopenia is caused by drug therapy.

Unlike RBCs, **leukocytes are complete cells** with a nucleus and cell organelles. What sets them apart from almost all other body cells is their ability to actively move in response to a chemical signal (**chemotaxis**). Moreover, leukocytes are able to leave the blood stream via a process called **diapedesis**.

Leukocytes are subdivided based on the presence or absence of granules in the cytoplasm. Leukocytes with granules are called **granulocytes**; those without, are called **agranulocytes** (*a-* without). The granulocytes consist of three subpopulations called **neutrophils**, **eosinophils**, and **basophils**; agranulocytes have two subpopulations: **lymphocytes** and **monocytes**.

All **granulocytes** possess **cytoplasmic granules** that give them their names, contain **lobed nuclei**, and are **phagocytic** (i.e., they can take in bacteria and other cells and destroy them; *phag(o)*- eat, swallow, *cyt(o)*- cell).

**Figure 19.5 Leukocytes.** Neutrophil (left), basophil (center left), eosinophil (center), lymphocyte (center right), and monocyte (right)



**Neutrophils** are the **most numerous of all WBCs**, making up 50-70% of WBCs (3000-7000 per  $\mu\text{L}$ ). Their granules are lilac, and the nuclei have many different shapes. Neutrophils are **very phagocytic, especially toward bacteria**.

The red-staining **eosinophils** are far less common. Usually, there are only 100-400 per  $\mu\text{L}$  (**2-4% of WBCs**). Their job is to help **attack and digest parasitic worms** that are too large to be destroyed by phagocytosis. Eosinophils play an additional role as **modulator of the immune system**.

**Basophils** are the rarest of WBCs with 20-50 per  $\mu\text{L}$  (**0.5-1% of WBCs**). Their dark blue-purplish-black granules contain **histamine** and other mediators of inflammation.

**Agranulocytes** do not have visible granules but still can be phagocytic. **Monocytes are the largest WBCs**. Their nucleus is either U-shaped or kidney-shaped and is surrounded by a pale-blue cytoplasm. Typically, there are 100-700 cells per  $\mu\text{L}$  (3-8% of WBCs). Monocytes are **especially effective against viruses, intracellular bacteria, and chronic infections**. However, most **monocytes** are found **outside the circulation**. They are then called **macrophages** because of their size and their ability to phagocytize foreign material or tissue debris.

Monocytes also help activate **lymphocytes**, the other subpopulation of agranulocytes. Lymphocytes can be identified by their large, dark-purple nucleus that is surrounded by a very thin rim of blue cytoplasm. Although they are the **second most common type of WBC** (1500-3000 in 1  $\mu\text{L}$ ; **25-40% of WBCs**), **most lymphocytes are found outside the circulation in lymphoid tissues**. Both types of lymphocytes, **B lymphocytes** and **T lymphocytes**, are crucial to immunity (see **Chapter 20 Lymphatic System & Immunity**).

### Blood Platelets (Thrombocytes)

Platelets or thrombocytes (*thromb(o)*- clot, *-cytes* cells) are microscopically small fragments of precursor cells called **megakaryocytes**. Platelets have granules containing a variety of bioactive substances, such as **serotonin**, calcium ( $\text{Ca}^{2+}$ ), **ADP**, and **platelet-derived growth factor (PDGF)**.

Thrombocytes play a key role in **hemostasis**, where they form a temporary platelet plug that helps seal breaks in blood vessels and activate the blood clotting cascade (see below).

**Table 19.2 Normal Values for Blood and Blood Elements**

Blood volume	8% of body weight; 5-6 l for men and 4-5 l for women
Color	bright red (oxygen-rich blood) to dark red (oxygen-depleted blood)
pH	7.35 – 7.45
Plasma	55% of total blood volume; 3 l for men and 2.5 l for women
Red blood cell (RBC) count	4.7 – 6.1 million/ $\mu$ L blood male 4.2 – 5.4 million/ $\mu$ L blood female
Hematocrit (HCT)	47% (42 – 52%) male 42% (37 – 47%) female
Hemoglobin (Hb)	16 (14 – 18) g/100 mL blood male 14 (12 – 16) g/100 mL blood female
White blood cell (WBC) count	4,800 – 10,800/ $\mu$ L blood
Neutrophils	3,000 – 7,000/ $\mu$ L blood (50 – 70% of WBC)
Lymphocytes	1,500 – 3,000/ $\mu$ L blood (25 – 40% of WBC)
Monocytes	150 – 800/ $\mu$ L blood (3 – 8% of WBC)
Eosinophils	100 – 400/ $\mu$ L blood (2 – 4% of WBC)
Basophils	20 – 50/ $\mu$ L blood (0.5 – 1% of WBC)
Platelet count	140,000 – 450,000/ $\mu$ L blood

### Check Your Understanding

- Blood makes up approximately \_\_\_\_% of our body weight.
  - 55
  - 15
  - 8
  - 25
- Which of the following statements is correct?
  - Plasma makes up about 5% of the total blood volume.
  - Only WBCs are considered complete cells.
  - The formation of blood cells is called hemocytosis.
  - WBCs are the most numerous cells in the blood.
- Erythrocytes have a life span of \_\_\_\_\_.
  - 1-2 days
  - 100-120 days
  - 9 months
  - 2-4 weeks
- Which of the following is **not** a granulocyte?
  - Neutrophil
  - Eosinophil
  - Basophil
  - Monocyte
- \_\_\_\_\_ are the most numerous of all WBCs.
  - Basophils
  - Lymphocytes
  - Monocytes
  - Neutrophils
- The percentage of blood volume that consists of RBCs is called \_\_\_\_\_.
  - hematocrit
  - buffy coat
  - red blood count
  - hemoglobin

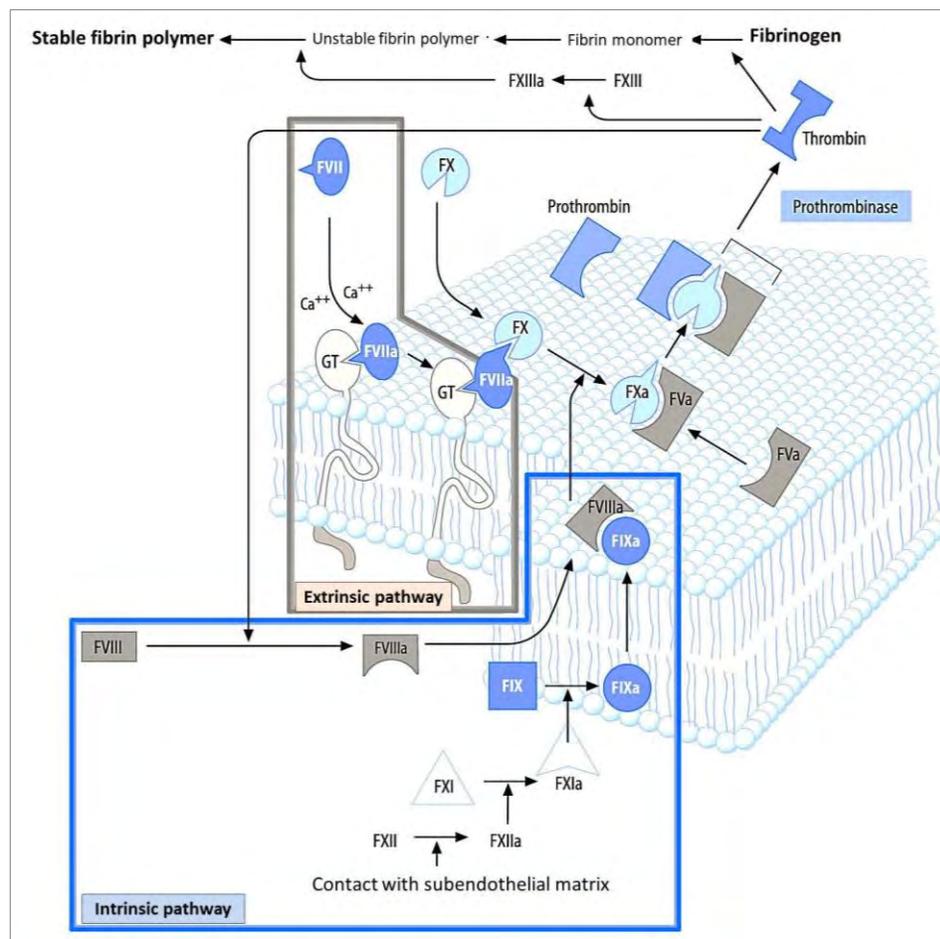
1.C 2.B 3.B 4.D 5.D 6.A

## 19.5 Hemostasis

Any bleeding that cannot be stopped is potentially fatal. The series of reactions that is set in motion to stop bleeding is called **hemostasis**. It consists of three steps:

1. **Vascular spasm** is the constriction of the damaged blood vessel. It cannot stop the bleeding, but it will slow down the loss of blood. Factors that can trigger the spasm are injury of the vessel, chemicals released by endothelial cells and platelets, and pain reflexes.
2. **Formation of a platelet plug** temporarily plugs a damage to the vessel wall. Platelets stick to exposed collagen fibers at the site of vessel injury. They swell, become sticky, and release the content of their granules. **ADP** from the granules causes other platelets to stick together and release their content; **serotonin** and **thromboxane A<sub>2</sub>** further enhance the vascular spasm and increase platelet aggregation, respectively.
3. **Coagulation or blood clotting** consists of a set of reactions involving 14 coagulation factors that lead to the **formation** of a gel-like **blood clot**. Most **clotting factors** are produced in the liver; vitamin K is essential for the formation of most factors.

Figure 19.6 Intrinsic and extrinsic pathways of blood clotting



Blood clotting itself is divided into three steps:

- **Step 1: Formation of the so-called prothrombin activator.**
- **Step 2: Conversion of prothrombin to thrombin** by the prothrombin activator.
- **Step 3: Transformation of fibrinogen into fibrin.** This step is catalyzed by thrombin.

Step 1 can be initiated by factors from outside of the blood vessel (**extrinsic pathway**) or by factors in the blood itself (**intrinsic pathway**). In damage to a blood vessel, both pathways will work together.

- The **extrinsic pathway** is triggered by release of **tissue factor (TF)** from the damaged blood vessel wall. This pathway is faster than the intrinsic pathway as it skips several steps.

- The **intrinsic pathway** is most often initiated by platelets after they have been activated by endothelial damage or collagen fibers. The platelets activate coagulation factors and release **platelet factor 3 (PF3)**.

Both pathways depend on sufficient levels of **calcium** in the blood. Each pathway is a succession of reactions, involving a number of coagulation factors that lead to the activation of factor X.

**Activated factor X** combines with **Ca<sup>2+</sup>** from the plasma, **PF3** from platelets, and **factor V** to form the **prothrombin activator** (or **prothrombinase**).

In step 2, **prothrombin activator** catalyzes the transformation of **prothrombin** (factor II) to the active enzyme **thrombin**, which in step 3 **converts soluble fibrinogen into insoluble fibrin**.

**Fibrin molecules** spontaneously form long polymer strands that **form a mesh**, which **traps red blood cells** and platelets to form a **blood clot**. This mesh formation is supported by activated factor XII, which formed under the influence of **thrombin** and **Ca<sup>2+</sup>**.

Within **30 to 60 minutes**, **actin and myosin** inside the platelets lead to shortening of the fibrin strands, squeezing out of serum, and shrinking of the clot in a process called **clot retraction**.

The **mature clot** will cover the damaged area while repair processes take place. Two chief factors in this repair process are:

1. The **platelet-derived growth factor (PDGF)** stimulates division of smooth muscle cells and fibroblasts to rebuild blood vessel wall.
2. The **vascular-endothelial growth factor (VEGF)** stimulates endothelial cells to multiply and restore the endothelial lining.

The **growth of the blood clot must be limited** to prevent uncontrolled clotting or unnecessary closure of blood vessels. The main growth-limiting factors are swift removal and dilution of clotting factors, as well as inhibition of activated coagulation factors by other coagulation factors.

The fibrin clot is only a temporary solution and will be removed within a few days. As this process involves enzymatic breakdown of fibrin, it is called **fibrinolysis**. It begins with the conversion of **inactive plasminogen to active plasmin**. This step is catalyzed mainly by **tissue plasminogen activator (tPA)** and thrombin. The active plasmin is an enzyme that digests fibrin and dissolves the clot.

The most efficient method to **prevent undesirable or accidental clotting** is to inhibit platelet adhesion. This is accomplished by the smooth endothelial lining of the blood vessels as well as by substances released by the endothelium, such as nitric oxide and prostacyclin.

## 19.6 Blood Groups

Blood groups are **based on the presence or absence of** specific substances on the outside of the plasma membrane of red blood cells. These so-called **antigens** tell the body whether a red blood cell belongs to the body or comes from another body and, therefore, is considered foreign (see also **Chapter 20 Lymphatic System & Immunity**).

Because these antigens can lead to agglutination (clumping) of blood cells, they are also called **agglutinogens**. If mismatched blood is given to a patient, agglutination of erythrocytes is the cause of potentially fatal transfusion reactions.

Of the more than **30 blood groups**, **only two play a major role**: the ABO and the RH systems. Others, such as MNS, Duffy, Kell, and Lewis, can still cause minor transfusion reactions, though.

### ABO system

The ABO system is **based on the presence or absence of** two antigens, **A and B**, on the surface of red blood cells. If red blood cells carry **antigen A**, then the **blood group** is **A**; red blood cells with **antigen B** give us **blood group B**. If both antigens are present, we have **blood group AB**; in **blood group O**, neither antigen is present.

Figure 19.7 Step 2 and 3 of blood coagulation

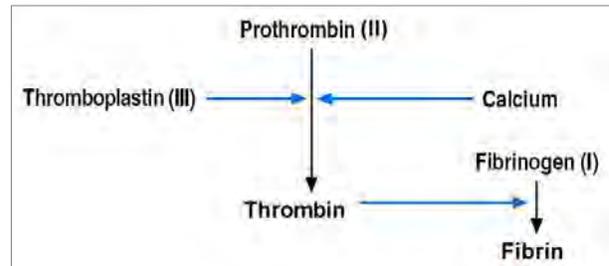


Table 19.3 ABO Blood Groups

Blood Group	Antigen on RBC	Antibody in Plasma	Can Donate Blood to	Can Receive Blood From
A	A	Anti-B	A, AB	A, O
B	B	Anti-A	B, AB	B, O
AB	AB	None	AB	A, B, AB, O
O	None	Anti-A & Anti-B	A, B, AB, O	O

Our bodies produce so-called **antibodies** against the ABO antigen(s) we don't have. These antibodies are designed to recognize and destroy foreign red blood cells. Consequently, a person with **blood group A has antibodies against antigen B** and vice versa. A person with **blood group AB has no antibodies**, whereas a person with **blood group O has antibodies against A and B**. Ergo, we can say:

- **A person with blood group A** has antibodies against erythrocytes of blood group B. This person can receive blood from another person with blood group A or from a person with blood group O.
- **A person with blood group B** has antibodies against erythrocytes of blood group A. This person can receive blood from another person with blood group B or from a person with blood group O.
- **A person with blood group AB** has no antibodies against other red blood cells and can receive blood from any another blood group. Thus, people with blood group AB are called **universal recipients**.
- **A person with blood group O** has antibodies against both, antigen A and B of the blood groups A, B, and AB. As a result, a person with blood group O can only receive blood from another person with blood group O. However, people with blood group O are **universal donors** because the other blood groups so not possess antibodies against blood group O.

**Blood typing is the determination of the blood group of a person.** It uses serum containing a known antibody, e.g., anti-A or anti-B. When this serum is added to a blood sample, agglutination will occur between the antibody and the antigen, if the antigen is present. Therefore, agglutination is a positive reaction and lack of agglutination, a negative reaction.

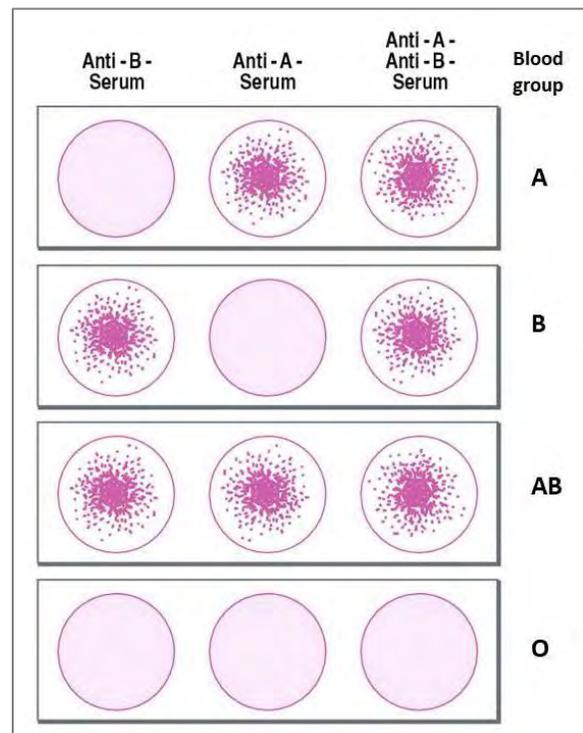
### Rhesus system

The Rh (rhesus) blood group system is far more complex: yet, of the many antigens only three (C, D, E) are common, and usually **only D is of clinical importance**. If **D is present**, the blood group is **Rh<sup>+</sup>** (rhesus positive); if **D is absent**, the blood group is **Rh<sup>-</sup>** (rhesus negative). A person with blood group A<sup>+</sup> has antigens A and D on the surface of their RBC, while a person with blood group A<sup>-</sup> only has antigen A.

Unlike the ABO blood groups, **antibodies against Rh antigens are only formed after our body is exposed to these antigens**, maybe during birth or via a blood transfusion. Due to this fact, a person without D (Rh<sup>-</sup>) will not react to Rh<sup>+</sup> erythrocytes upon first exposure to it. However, the person will start producing antibodies against Rh<sup>+</sup> blood, and **a second exposure will lead to a reaction**.

If a **Rh<sup>-</sup> woman** has antibodies against Rh<sup>+</sup> blood in her blood, these antibodies can cross the placenta during pregnancy. If the baby she carries is Rh<sup>+</sup>, the antibodies against Rh<sup>+</sup> red blood cells will attack the baby's erythrocytes, which can lead to a severe disorder called **hemolytic disease of the newborn** or **erythroblastosis fetalis**. Administration of serum containing anti-Rh<sup>+</sup> antibodies to Rh<sup>-</sup> mothers can prevent them from becoming sensitized.

Figure 19.8 Blood typing for ABO blood groups



### Blood transfusion

A blood transfusion is the transfer of whole blood or parts of blood, such as erythrocytes only, from one person to another. If the transferred blood does not match with the blood of the recipient, the immune system of the recipient will attack the transfused blood and vice versa.

A **transfusion reaction** will occur if mismatched blood is transfused. The donor cells in the blood product are attacked by the recipient's antibodies. The donated red blood cells agglutinate, clog small vessels, and rupture and release free hemoglobin into the bloodstream. This may lead to renal failure and death.

### 19.7 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	rosy	_____	erythr(o)-
2.	white	_____	-blast
3.	clot	_____	coagul(o)-
4.	red	_____	leuk(o)-
5.	clotting	_____	embol(o)-
6.	immature cell	_____	eosin(o)-
7.	embolus	_____	thromb(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Approximately 55% of plasma is water. \_\_\_\_\_
- A megakaryocyte produces leukocytes. \_\_\_\_\_
- All lymphocytes are leukocytes, but not all leukocytes are lymphocytes. \_\_\_\_\_
- If the mom is Rh positive and the fetus is Rh negative, maternal antibodies may attack the baby's red blood cells. \_\_\_\_\_
- Lymphocytes are agranular, phagocytic leukocytes. \_\_\_\_\_
- All formed elements arise from a common type of stem cell called a hemocytoblast. \_\_\_\_\_
- The male sex hormone testosterone influences red cell production. \_\_\_\_\_
- The ABO system is based on the presence or absence of three antigens, A, B, and O. \_\_\_\_\_
- Basophils contain histamine and other mediators of inflammation. \_\_\_\_\_
- People with blood group O are universal recipients. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                 |   |           |
|-----------------|---|-----------|
| 1. Monocytes    | a) contributes to plasma osmotic pressure         | 1. _____  |
| 2. Eosinophils  | b) forms the structural framework of a blood clot | 2. _____  |
| 3. Erythrocytes | c) blood type that has no antigens                | 3. _____  |
| 4. Albumin      | d) found in all blood types but A                 | 4. _____  |
| 5. Fibrinogen   | e) transport CO <sub>2</sub> and O <sub>2</sub>   | 5. _____  |
| 6. Fibrin       | f) function in attacking parasitic worms          | 6. _____  |
| 7. Blood type O | g) initiate intrinsic pathway of coagulation      | 7. _____  |
| 8. anti-A       | h) graveyard of old red blood cells               | 8. _____  |
| 9. Platelets    | i) phagocytes that become macrophages             | 9. _____  |
| 10. Spleen      | j) target of thrombin                             | 10. _____ |

**Multiple choice**

Choose the one alternative that best completes the statement or answers the question.

- The normal average temperature of blood is around \_\_\_\_\_.
  - 98.6 °F
  - 100.4 °F
  - 90.8 °F
  - 101.6 °F
- The normal pH range for blood is \_\_\_\_\_.
  - 7.15-7.35
  - 6.35-6.45
  - 7.35-7.65
  - 7.35-7.45
- Which of the following plasma proteins plays a role in blood clotting?
  - Albumin
  - Globulin
  - Fibrinogen
  - Prostaglandin
- The process by which formed elements of the blood develop is called \_\_\_\_\_.
  - hemocreation
  - hemopoiesis
  - hematocrit
  - hemogenesis
- Which organ produces most of the plasma proteins?
  - Red bone marrow
  - Liver
  - Kidney
  - Thymus

6. Which of the following is a phagocyte?
  - a. Monocyte
  - b. Platelet
  - c. Lymphocyte
  - d. Erythrocyte
  
7. Which of the following help reduce blood loss?
  - a. Erythrocytes
  - b. Platelets
  - c. Basophils
  - d. Neutrophils
  
8. Which steps belong to hemostasis?
  - a. Vascular spasm, clotting, hematoma
  - b. Hemolysis, vascular spasm, platelet plug formation
  - c. Migration, clotting, hemolysis
  - d. Platelet plug formation, vascular spasm, coagulation
  
9. Once \_\_\_ is formed, the intrinsic and extrinsic pathways are identical.
  - a. factor I
  - b. prothrombin activator
  - c. fibrin
  - d. calcium
  
10. Which antigens does a person have on their RBCs if their plasma has anti-A only?
  - a. A
  - b. B
  - c. O
  - d. A and B

## Chapter 20 Lymphatic System and Immunity

### 20.1 Chapter Outline

The two tasks of the lymphatic system are to return interstitial fluid and protein that leak out of capillaries back into the circulation and to provide the structural basis for the immune system. The immune system protects us from outside invaders as well as from threats developing inside our body.

### 20.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- List the functions of the lymphatic vessels.
- Describe the structure and distribution of lymphatic vessels.
- Explain the source of lymph and mechanism(s) of lymph transport.
- Describe the basic structure and cellular population of lymphoid tissue.
- Give the general location, histological structure, and functions of lymph nodes.
- Name and describe other lymphoid organs of the body.
- Define immunity and explain the difference between innate and adaptive defense.
- Explain the importance of phagocytosis and natural killer cells in innate defense.
- Describe the inflammatory process and name the body's antimicrobial substances and describe their function.
- Define antigen and describe how antigens affect the adaptive defenses.
- Compare and contrast the origin, maturation process, and general function of B and T lymphocytes.
- Name antigen-presenting cells and describe their roles in adaptive defenses.
- Define humoral immunity.
- Recount the roles of plasma cells and memory cells in humoral immunity.
- Compare and contrast active and passive humoral immunity.
- Explain the function(s) of antibodies and describe clinical uses of monoclonal antibodies.
- Define cell-mediated immunity and describe the process of activation and clonal selection of T cells.
- Describe T cell functions in the body.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 20.3 Combining Forms

Table 20.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 20.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
anti-	effective against, opposing, or opposite	<i>antitoxin</i> = a substance that counteracts a toxin
immun(o)-	immune system	<i>immunotherapy</i> = treatment with substances that stimulate the immune response
lymph(o)-	lymph	<i>lymphoid</i> = relating to or resembling lymph or lymphatic tissue
lymphaden(o)-	lymph node	<i>lymphadenitis</i> = inflammation of a lymph node
lymphangi(o)-	lymph vessel	<i>lymphangiitis</i> = inflammation of a lymph vessel

myel(o)-	bone marrow	<i>myeloid</i> = relating to or derived from bone marrow
splen(o)-	spleen	<i>splenomegaly</i> = enlargement of the spleen
tonsill(o)-	tonsil	<i>tonsillitis</i> = inflammation of a tonsil

## 20.4 Lymphatic System

The lymphatic system consists of three parts: **lymphatic vessels** or **lymphatics**, **lymph nodes**, and **lymph**. Its two tasks are to **return interstitial fluid and protein** that leak out of capillaries back **into the circulation** and to **provide the structural basis for the immune system**. Once the interstitial fluid enters lymph vessels, it is called **lymph**.

The tiniest lymph vessels are called **lymphatic capillaries**. They are found in all tissues and organs except the bones, teeth, bone marrow, and central nervous system. Specialized lymph capillaries that drain the fluid from the intestinal mucosa are called **lacteals** because the lymph they carry is milky after meals (*lacto-* milk).

The lymph capillaries empty into **collecting ducts**, which unite to form trunks. The trunks then form two large **lymphatic ducts**.

- The **thoracic duct** arises from the bladder-like **cisterna chyli** just below the diaphragm and ascends through the thoracic cavity. There, it empties into the **left subclavian vein** at the vein's junction with the left internal jugular vein. The thoracic duct carries the lymph from the lower body, the left side of the upper body, and the neck and head.
- The **right lymphatic duct** drains the right arm and the right side of the head and thorax.

**Lymph is transported** away from the tissues **toward the heart**. This transport is propelled by pulsations of nearby arteries as well as contractions of smooth muscle in the wall of the lymphatics.

The group of **lymphoid cells** consists of five different cells.

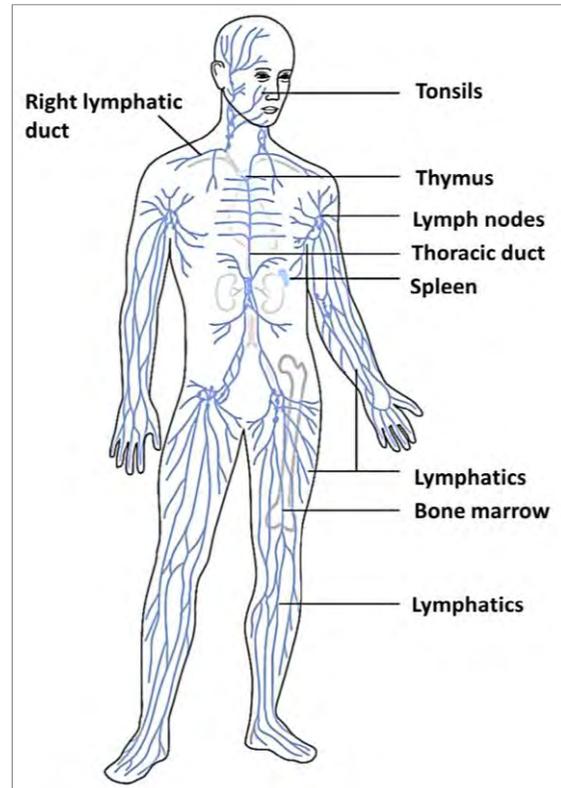
- **B and T lymphocytes** are the main cells of the adaptive immune system (see below).
- **Macrophages** phagocytize foreign substances and help activate T lymphocytes.
- **Dendritic cells** capture antigens and deliver them to lymph nodes.
- **Reticular cells** produce the **reticular connective tissue** that forms the skeleton of lymphoid organs

**Lymphoid tissues** house lymphoid cells and provide a proliferation point for lymphocytes. There are two types of lymphoid tissues:

1. **Diffuse lymphatic tissues** are reticular tissue elements that are scattered through all internal organs. Larger collections are found in mucous membranes and lymphoid organs.
2. **Lymphatic follicles** are solid, spherical bodies of tightly packed reticular elements and cells. They contain **germinal centers** composed of B lymphocytes and dendritic cells. Lymphatic follicles may form part of larger lymphoid organs, such as the tonsils and spleen.

There are also lymphatic follicles outside of lymphoid organs. These follicles form aggregates in the wall of the small intestine (called **Peyer's patches**) and the appendix, which is part of the large intestine; they are also found in the mucosa of the respiratory tract. They are collectively known as **mucosa-associated lymphatic tissue** or **MALT**. The tonsils (see below) are also made of MALT.

Figure 20.1 Lymphatic system and lymphoid organs



## Lymphoid Organs

The **bone marrow** and the **thymus** are **primary lymphoid organs** because they are the sites of maturation of the B and T lymphocytes (see below). However, these two organs are not involved in the actual process of fighting pathogens.

All lymphoid organs contain **lymphoid tissue** in the form of **lymphatic follicles**. However, **diffuse lymphoid tissues** are found scattered throughout all organs (see MALT above).

**Lymph nodes are the principal lymphoid organs of the body.** Although each of them is small, together they form the majority of lymphoid tissue and house the majority of the white blood cells of the immune system. Of the **lymphoid organs**, only the **lymph nodes** are a part of the lymphatic system. Lymph nodes are arranged in clusters along lymphatic vessels. Their **function** is to **filter lymph** (macrophages destroy microorganisms and debris) and to be the **backbone of the immune system**. Lymphocytes are generally activated in lymph nodes.

Lymph nodes are bean-shaped with an external **fibrous capsule** and **trabeculae** that extend inward, dividing the interior into compartments. There are two distinct regions, an outer **cortex** with **germinal centers**, and an inner **medulla**, consisting of so-called **cords**. The cords contain lymphoid cells and **sinuses** with macrophages in them.

Lymph is carried toward a lymph node by **afferent vessels**. Inside the lymph node, the lymph travels slowly through the **subcapsular** and **medullary sinuses** before leaving the node at the **hilus** via **efferent vessels**.

Having fewer efferent vessels causes the flow of lymph to stagnate, allowing lymphocytes and macrophages time to identify and destroy bacteria, rogue cells, and foreign proteins.

Most lymph nodes are deep inside our body; but, in the **inguinal**, **axillary**, and **cervical** regions, **lymph nodes are superficial and can be palpated**.

Figure 20.2 Lymph node, cross-section

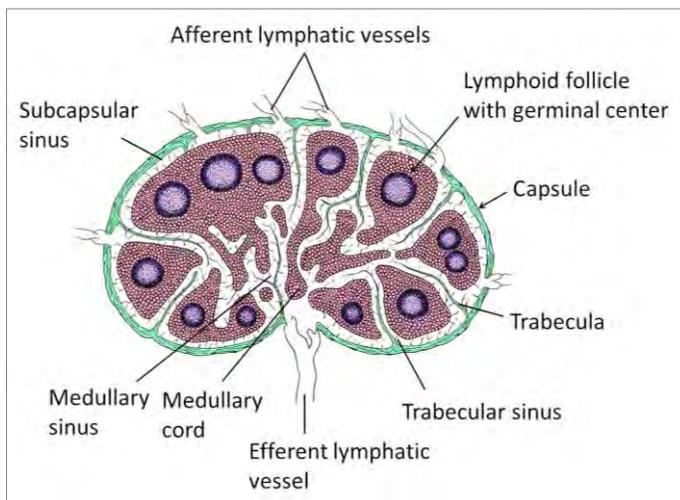
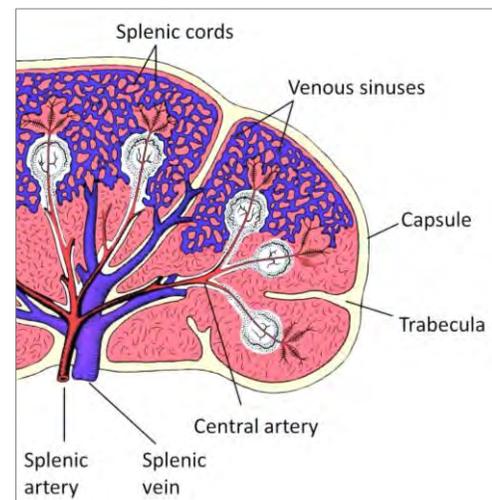


Figure 20.3 Spleen, cross-section



Unlike the other lymphoid organs and tissues, the **thymus is not involved in the actual process of fighting antigens or pathogens**. The thymus **increases in size during the childhood** years, while our immune system matures, and gradually **atrophies after adolescence**.

The **thymic lobes** have an outer **cortex** and an inner **medulla**. The cortex contains mainly lymphocytes that mature under the influence of hormones produced by **thymocytes**. The medulla has so-called **thymic** or **Hassall corpuscles** that are involved in regulatory T cell development. The thymus **produces hormones** (thymulin, thymopoietin, and thymosin) that are important for the **normal development of the immune system**. People born without a thymus will not develop a fully functional immune system and die early.

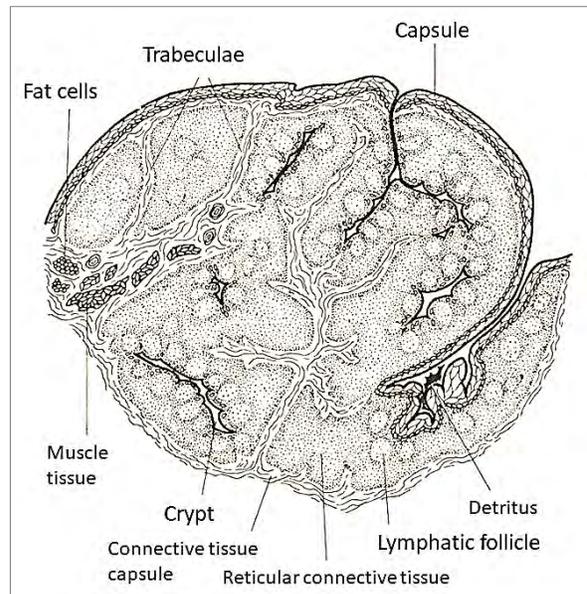
The **spleen** is the largest lymphoid organ of the body. It functions as a site of proliferation of lymphocytes and immune surveillance. The spleen removes aged erythrocytes and platelets from the blood, stores iron and platelets, and hosts blood formation during the fetal period.

Just like lymph nodes, the spleen has a strong, protective **fibrous capsule** as well as **trabeculae**. It also has so-called **cords** and **sinuses** that collectively form the **red pulp**. The red pulp is where macrophages destroy worn-out erythrocytes and blood-borne pathogens. The **white pulp** around **central arteries** consists mostly of lymphocytes and is involved in immune functions.

**Tonsils**, the **simplest lymphoid organs**, form a ring of lymphatic tissue around the pharynx. They do not have a fully developed capsule but deep **tonsillar crypts** that trap and destroy bacteria and other pathogens. All tonsils contain **follicles** with **germinal centers**. The task of the **pharyngeal lymphoid ring** is to protect us from pathogens and toxins in the food and drinks we swallow, and in the air we breathe in.

- The **palatine tonsils** are found on the left and right side at the posterior end of the oral cavity; the **lingual tonsil** sits at the base of the tongue. Together, they are in a prime location to screen for pathogens in food and drinks.
- The **pharyngeal tonsil** is found in the posterior wall of the nasopharynx. Sometimes, the pharyngeal tonsil is also called **adenoids**; although, the term should be used only for an enlarged pharyngeal tonsil. The pharyngeal tonsil is charged with cleaning the air we breathe in through the nose.
- The **tubal tonsils** surround the openings of the auditory tubes into the pharynx. They stop pathogens from making their way into the middle ear (see **Chapter 14 General & Special Senses**).

Figure 20.4 Tonsil, cross-section



### Check Your Understanding

- The \_\_\_ is the largest lymphoid organ of the body.
  - thymus
  - spleen
  - liver
  - bone marrow
- An enlarged pharyngeal tonsil is called \_\_\_\_\_.
  - Peyer's patch
  - MALT
  - red pulp
  - adenoids
- Lymph from the left side of the upper body is transported to the heart via the \_\_\_\_\_.
  - cisterna chyli
  - thoracic duct
  - left lymphatic duct
  - left subclavian duct
- The two primary lymphoid organs are \_\_\_\_\_.
  - thymus and tonsils
  - spleen and lymph nodes
  - spleen and bone marrow
  - thymus and bone marrow

1.B.2.D.3.B.4.D

## 20.5 Immune System

The immune system has two intrinsic systems called **innate or nonspecific defense** and **adaptive or specific defense**. Both systems work together and depend on each other. If one system fails, the other will not be able to make up for it, leading to an immunodeficiency.

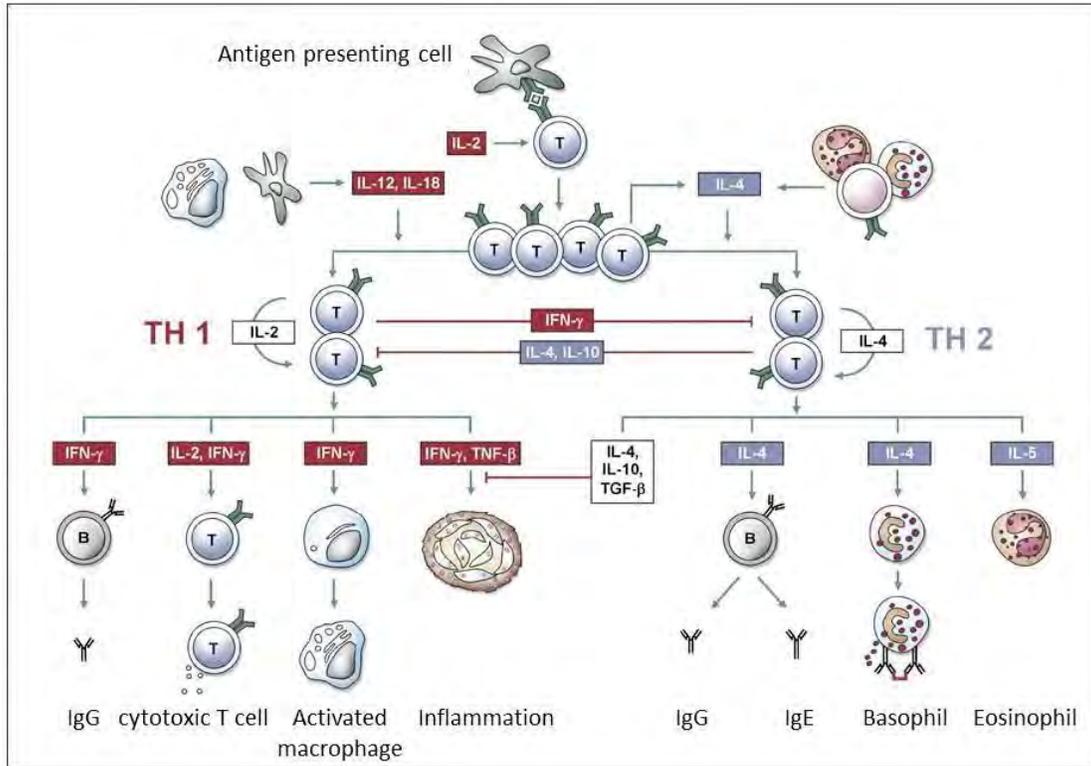
### Cytokines

Cytokines are chemical messengers that mediate cell development, differentiation of cells, interactions and communications between cells, and responses in the immune system. They are crucial in controlling the growth and activity of immune cells and blood cells. The group includes **interferons** (see below), **lymphokines** (cytokines made by lymphocytes), **monokines** (cytokines made by monocytes), **chemokines** (cytokines with chemotactic activities), **interleukins** (cytokines made by one leukocyte and acting on other leukocytes), and **colony-stimulating factors**.

There are both **pro-inflammatory cytokines** and **anti-inflammatory cytokines**, cytokines that recruit and activate neutrophils and eosinophils, and cytokines that activate T lymphocytes and growth factors.

Cytokines and anti-cytokine therapies have been used in recent years to treat autoimmune disorder and viral infections, such as HIV.

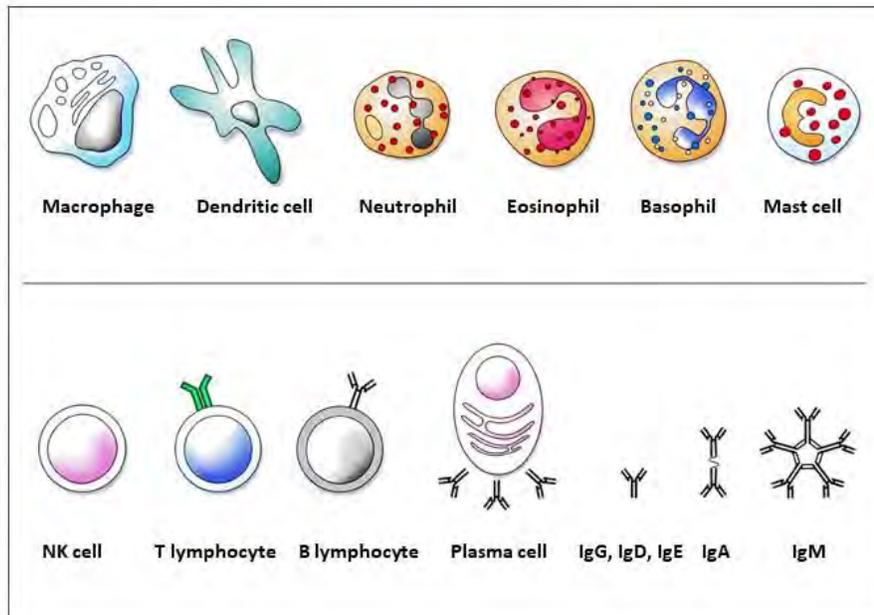
Figure 20.5 The role of cytokines in the regulation of the immune system



### Cells of the Immune Response

In addition to granular and agranular leukocytes (see **Chapter 19 Blood, Hemostasis, and Blood groups**), the immune system uses two white blood cells that are usually only found in the tissue and not the blood.

Figure 20.6 Cells and antibodies of the innate and adaptive immune response



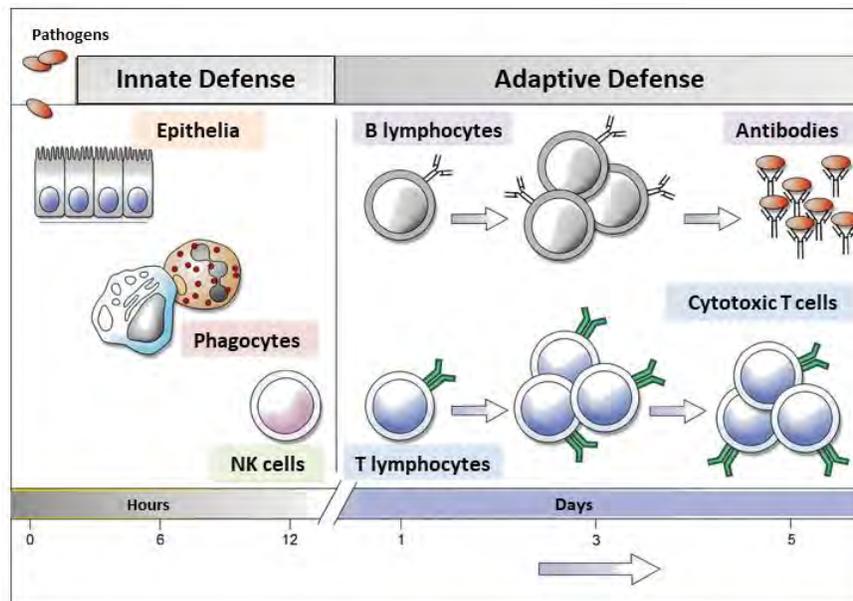
**Natural killer (NK) cells** are large granular lymphocytes that **target cells lacking “self” cell-surface receptors**, i.e., cells that don’t seem to belong into our body. NK cells induce apoptosis (cell death) in cancer cells and virus-infected cells, and enhance the inflammatory response.

**Mast cells** (a.k.a. **mastocytes**) are granular leukocytes that are found outside the blood. Because the cells contain histamine and heparin in their granules and are involved in allergic reactions, they were originally considered to be tissue-based basophils. However, we now know that they develop from their own line of myeloid stem cells.

### Innate or Nonspecific Defense

The job of the innate or nonspecific defense is to prevent pathogens from entering the body and from spreading once they are inside. The **first line of defense** consists of our **external body membranes**, such as skin and mucosae, while the **second line** consists of five elements: **phagocytes**, **natural killer cells**, **inflammation**, **antimicrobial proteins**, and **fever**.

Figure 20.7 Innate and adaptive defense system



The main task of the **surface barriers** (skin, mucous membranes and their secretions) is to stop pathogens from entering the body. They are **physical barriers** to most microorganisms. Keratin in the epidermis is resistant to weak acids and bases, bacterial enzymes, and toxins. Mucosae provide similar barriers.

Mucus-coated hairs in the nose and the cilia of upper respiratory tract that move dust- and bacteria-laden mucus from lower respiratory passages toward the mouth are special modifications in the **respiratory tract**.

**Protective chemicals** inhibit or destroy microorganisms: lipids in sebum and dermcidin in sweat, gastric acid and protein-digesting enzymes of the stomach, lysozyme of saliva and lacrimal fluid, and mucus.

The **internal defense mechanisms** of the second line use **cells and chemicals** to prevent pathogens from spreading once they are past the surface barriers. The cells employed are **two types of phagocytes**: **neutrophils**, which are the most common type of leukocyte, and **macrophages** that develop from monocytes to become the chief phagocytic cells.

- **Neutrophils** become phagocytic on encountering infectious material, especially bacteria, in tissues.
- **Free macrophages** wander through tissue spaces, for example, as alveolar macrophages in the lungs and macrophages in areolar connective tissue.
- **Fixed macrophages** are permanent residents of some organs, for example, as Kupffer cells in the liver and microglia in the brain.

**Phagocytosis** (*phag(o)*- eat, swallow, *cyt(o)*- cell, *-osis* condition) is the process of a cell actively taking external matter and destroying it using enzymes stored in lysosomes. Phagocytosis has five steps:

- **Step 1: Adherence of a phagocyte to a pathogen** is facilitated by opsonization, i.e., the coating of pathogen by complement proteins or antibodies (see below).
- **Step 2:** The phagocyte forms pseudopods that eventually engulf the particles forming a **phagosome** (endocytosis).

- **Step 3:** A **lysosome** fuses with the phagosome, forming a **phagolysosome**.
- **Step 4:** **Lysosomal enzymes digest the particles**, leaving a residual body.
- **Step 5:** **Exocytosis** removes indigestible and residual material.

An **inflammatory response** (or **inflammation**) is triggered whenever body tissues are injured or infected. The task of inflammation is to prevent the spread of damaging agents, disposing of cell debris and pathogens, and to set the stage for repair. The **four cardinal signs of an acute inflammation** are:

1. Redness (Latin *rubor*)
2. Heat (Latin *calor*)
3. Swelling (Latin *tumor*)
4. Pain (Latin *dolor*)

Macrophages and epithelial cells of boundary tissues bear so-called **Toll-like receptors (TLRs)** that recognize specific classes of infecting microbes. Activated TLRs trigger the release of **cytokines** that promote inflammation, such as histamine (from mast cells) and blood proteins. Kinins, prostaglandins (PGs), leukotrienes, and complement are released by injured tissues, phagocytes, lymphocytes, basophils, and mast cells.

The **inflammatory mediators cause** dilation of arterioles, resulting in **hyperemia** - which leads to redness and heat - **and increased permeability of local capillaries**. The leaked fluid is called an **exudate**. It contains proteins, clotting factors, and antibodies. Exudate formation leads to local swelling.

The flow of fluid into the damaged area flushes foreign material into lymphatic vessels and the lymph nodes, where it can be destroyed by lymphoid cells. Exudate also delivers clotting proteins to isolate the area and to form a scaffold for repair.

As a response to cytokine signals, first neutrophils, and later macrophages flood the inflamed site. These cells can phagocytize pathogens and cell debris, and clear the path for repair and healing. This **phagocyte activation happens** in four steps:

1. **Leukocytosis:** Release of neutrophils from bone marrow in response to leukocytosis-inducing factors from injured cells.
2. **Margination:** Neutrophils cling to the walls of capillaries in the inflamed area.
3. **Diapedesis:** Neutrophils move actively through the wall of the capillaries.
4. **Chemotaxis:** Inflammatory chemicals (chemotactic agent) promote positive chemotaxis, i.e., movement towards the damaged area.

The **two major groups of antimicrobial proteins** are **interferons** and **complement**. The **complement system** encompasses approximately 20 blood proteins that circulate in an inactive form in body fluids. It is a major mechanism for destroying foreign substances, and has the ability to enhance nonspecific and specific defenses. The complement system's mode of action is to kill bacteria and certain other cell types by inducing cell lysis (bursting of cells).

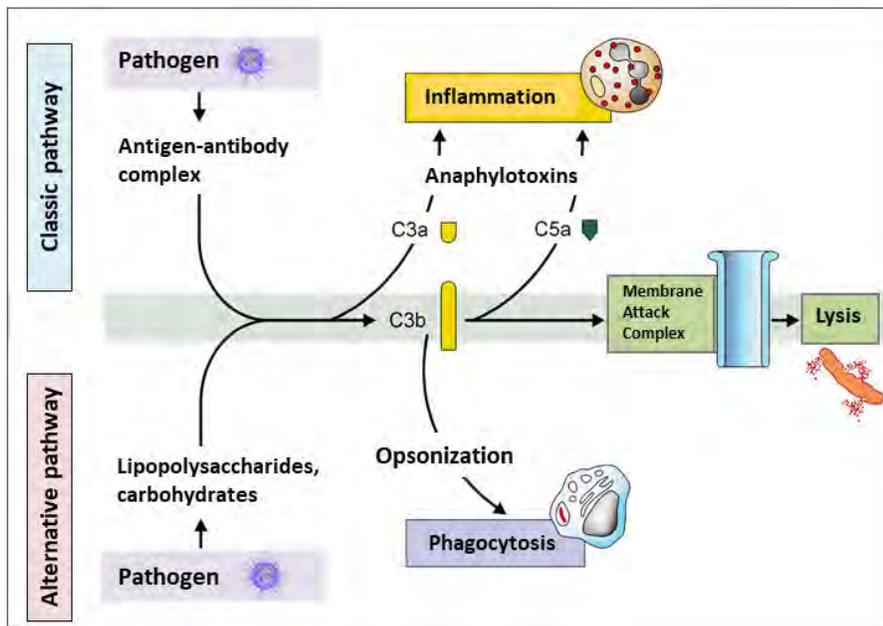
Both pathways of complement activation, the **classic pathway** and the **alternative pathway**, lead to the formation of the so-called **membrane attack complex (MAC)**. In the **classic pathway**, antigen-antibody complexes activate complement; in the **alternative pathway**, the pathogens have surface structures that trigger complement activation.

The two pathways converge on C3, which splits into **C3a** and **C3b**. **C3b** initiates the formation of the MAC, which leads to inflow of water into the pathogen and cell lysis. To make sure the cell debris created will be removed by phagocytic cells, C3b also covers the debris with substances that attract phagocytes. This process is called **opsonization**. **C3a** causes an inflammatory response.

**Interferons (IFNs)** are produced and released by virus-infected cells. Interferons enter other body cells and interfere with (i.e., block) the reproduction of competing viruses. Overall, interferons protect us by accident only. Our body cannot produce them at will but must first wait for a viral infection. However, once produced, interferons reduce inflammation and activate macrophages and NK cells.

Interferons can be produced by a variety of body cells, such as lymphocytes (produce **gamma ( $\gamma$ )**, or **immune interferon**), leukocytes (produce **alpha ( $\alpha$ ) interferon**), and fibroblasts (produce **beta ( $\beta$ ) interferon**). **Genetically engineered IFNs** are used in the treatment of acute and chronic hepatitis and multiple sclerosis, for example.

Figure 20.8 Pathways of complement activation



**Fever** is a systemic response to invading microorganisms. It is caused by substances called **pyrogens** (*pyr(o)-* fever, *-gen* producing) that reset the body's thermostat upward. **Moderate fever** is beneficial for our body. It causes the liver and spleen to sequester iron and zinc (needed by microorganisms), and increases the metabolic rate, which speeds up repair processes. **High fever** (above 105 °F) is dangerous because heat denatures enzymes, which can lead to death.

### Adaptive or Acquired Defense

As the third line of defense, the adaptive or acquired immune system attacks particular foreign substances, which is a complicated process that takes longer to activate than innate defenses. Unlike the innate defense system, which is more or less fully functional at birth, the adaptive immune system develops over time, and becomes stronger and more competent in the early years of our life.

The adaptive immune system **can protect against infectious agents and abnormal body cells**. It uses parts of the innate defense, such as phagocytes, complement system, and inflammation. **Its most valuable asset is its ability to create a memory of identified threats**. This memory is the basis of a permanent, life-long immunity against specific pathogens.

The adaptive defense also has two branches: the **humoral** or **antibody-mediated immunity** is based on the release of specific proteins (antibodies); the **cellular** or **cell-mediated immunity** uses specific cells to combat pathogens or other threats.

### Antigens

The **adaptive defense depends upon the ability of its cells to recognize antigens**. The cells bind to an antigen and communicate with one another so that the whole system mounts a specific response against a defined antigen. Both the humoral and the cellular immune system have the ability to recognize antigens, i.e., large, complex molecules that can mobilize the adaptive defenses and provoke an immune response. The term **antigen** comes from "**an-** antibody **g**enerating substance". Antigens found on our body cells are considered **self-antigens**, whereas antigens not normally found in the body are called **non-self-antigens**.

Foreign protein and polysaccharides are usually **complete antigens**, because they have two important functional properties:

- **Immunogenicity** or the ability to stimulate proliferation of specific lymphocytes and antibodies.
- **Reactivity** or the ability to react with products of activated lymphocytes and antibodies.

**Incomplete antigens** or **haptens** are small molecules that are immunogenic only when attached to body proteins. They are a common cause of allergic reactions (see below).

**Antigenic determinants** or **epitopes** are the specific parts of an entire antigen that are immunogenic. Most naturally occurring antigens have numerous antigenic determinants that mobilize several different lymphocyte populations that form different kinds of antibodies against it. Large, chemically simple molecules (e.g., plastics) have little or no immunogenicity.

### Self-antigens

To make sure our immune system can distinguish self from non-self, **all cells of the body have surface antigens that identify them as self**. **MHC proteins** are an **example of self-antigens**. MHC proteins are coded by genes of the so-called **major histocompatibility complex** (MHC) and are unique to an individual. MHC proteins are also known as human leukocyte antigens (HLA).

**Class I MHC proteins** are displayed by **all body cells except red blood cells** (they have their own blood group antigens). They bind with a fragment of a protein synthesized in the cell (**endogenous antigen**), which can be either a self-antigen in a normal cell or a non-self-antigen in an infected or abnormal cell. They inform cytotoxic T cells of the presence of microorganisms hiding inside cells.

**Class II MHC proteins** are displayed by **antigen-presenting cells only** (see below). They bind with fragments of **exogenous antigens** that have been engulfed and broken down in a phagolysosome. They are recognized by helper T cells.

### Cells of the adaptive immunity

The adaptive immune system uses two types of lymphocytes: **B lymphocytes** or **B cells** mature in the **red bone marrow** and are part of the **humoral immunity**. **T lymphocytes** or **T cells** mature in the **thymus** and are part of the **cell-mediated immunity**.

**Mature lymphocytes** are able to recognize and bind to a specific antigen, i.e., they are **immunocompetent**. They are also unresponsive to self-antigens that mark our body cells, i.e., they exhibit **self-tolerance**. Cells that lack one or both of these characteristics must be destroyed before they can attack our own cells. Lack of self-tolerance is the main cause of autoimmune disorders.

In order to ensure self-tolerance, T lymphocytes undergo a two-step selection process:

1. **Positive selection** selects T cells capable of recognizing self-MHC proteins.
2. **Negative selection** prompts destruction of T cells that bind to self-antigens displayed by cell.

To create a huge number of different lymphocytes with different antigen receptors, the cells use ~25,000 genes to randomly create receptors. This **antigen receptor diversity** determines which foreign antigens the body will react to. **Only antigens that match an existing antigen receptor will be recognized and start an immune response**.

**Antigen-presenting cells (APCs)** play essential auxiliary roles in immunity, although they do not respond to specific antigens. However, they **present fragments of antigens to be recognized to T cells**. APCs are found in connective tissues and the epidermis (**dendritic cells**), connective tissues and lymphoid organs (**macrophages**), or throughout all tissues (**B cells**).

### Check Your Understanding

1. Which part of the innate immune system targets cells that do **not** belong into our body?
  - a) Skin
  - b) Fever
  - c) Natural killer cells
  - d) Inflammation
2. Which of the following is **not** an immune defense system?
  - a) Innate defense
  - b) Adaptive defense
  - c) Nonspecific defense
  - d) Required defense
3. Which of the following is **not** a sign of acute inflammation?
  - a) Redness
  - b) Bleeding
  - c) Pain
  - d) Swelling
4. B lymphocytes or B cells mature in the \_\_\_\_\_.
  - a) bone marrow
  - b) thymus
  - c) spleen
  - d) lymph nodes

## Humoral Immune Response

Mature **B lymphocytes** leave the bone marrow to settle mainly in the lymphoid tissue of lymph nodes and the spleen. Each of the billions of B lymphocytes created has a unique receptor for one specific non-self-antigen.

The first encounter between an antigen and a naive immunocompetent B lymphocyte is called the **antigen challenge**. Most of the time, it occurs in a lymph node or the spleen. The encounter leads to the **formation of a clone of specialized lymphocytes**, most of which are **plasma cells** that **secrete specific antibodies** (at a rate of 200 molecules per

second!) against the antigen encountered. Due to the secretion of these antibodies into body fluids, this type of immune response is called **humoral immune response** (humor = fluid).

B cells that do not form plasma cells become **memory cells** and create an **immunological memory**, which helps the body mount an immediate response to future exposure to the same antigen.

This response to the first exposure to a specific antigen is called the **primary immune response**. It takes about 3-6 days for antibodies to appear, and peak plasma antibody levels are reached in 10 days.

A **secondary immune response** occurs on **re-exposure to the same antigen**. Memory cells respond within hours, antibody levels peak in 2-3 days at much higher levels, and can remain high for weeks to months.

## Antibodies

Antibodies or **immunoglobulins** are proteins secreted by plasma cells. They are capable of binding specifically with antigens detected by B cells. Antibodies form the **gamma globulin** portion of blood proteins.

Each antibody consists of four protein chains: two **heavy chains** and two **light chains**. Antibodies have a **variable region** that **functions as the antigen-binding site**. The **constant region**, a part of the stem, **determines the antibody class**, which cells and chemicals the antibody can bind to, and how the antibody functions in antigen elimination.

Antibodies can change between a **T or Y shape** because of a hinge region at the base of the arms.

There are **five classes of antibodies**:

1. **IgM** (immunoglobulin M): The first antibody released is made of five subunits forming a pentamer with 10 antigen-binding sites, which make it a potent agglutinating agent. It readily fixes and activates complement.
2. **IgA** (immunoglobulin A): Secreted into mucus, tears, sweat, and other body fluids, it helps prevent entry of pathogens by stopping them before they can cross the first line of defense.

Figure 20.9 Primary and secondary immune response of the humoral immune system

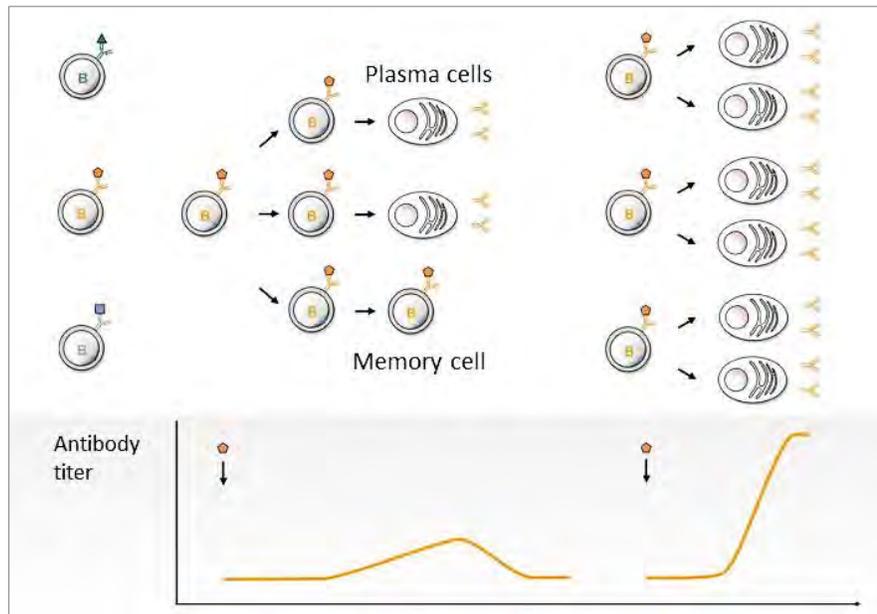
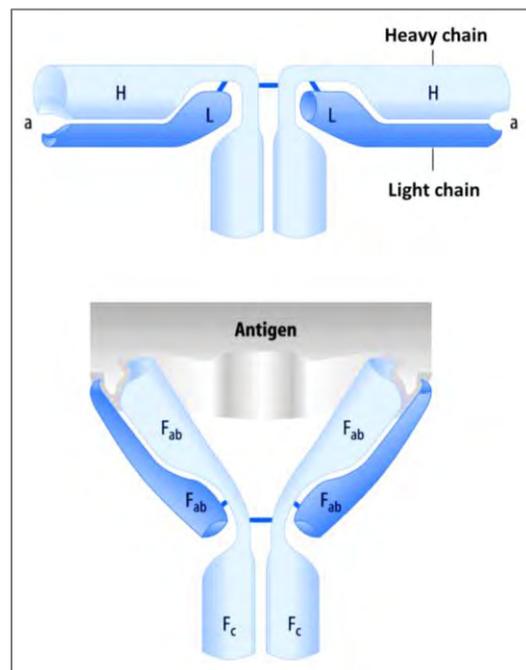


Figure 20.10 Antibody structure



3. **IgD** (immunoglobulin D): Found attached to the surface of B lymphocytes it functions as a cell receptor.
4. **IgG** (immunoglobulin G): Secreted in the late stages of a primary and throughout a secondary immune response, IgG makes up 75–85% of antibodies in the plasma. IgG crosses the placental barrier and gives the baby a passive immunity for the first months of its life.
5. **IgE** (immunoglobulin E): Found in some allergies and parasitic infections. It causes mast cells and basophils to release histamine (see also hypersensitivities below).

#### **Antibodies inactivate and tag antigens and form antigen-antibody (immune) complexes.**

- **Neutralization of antigens** is the simplest defense mechanism. Antibodies block specific sites on viruses or bacterial exotoxins, which prevents these antigens from binding to receptors on tissue cells. **Antigen-antibody complexes** undergo phagocytosis.
- **Agglutination of cells**, e.g., red blood cells of a different blood group, is accomplished by antibodies binding to the same determinant on more than one cell-bound antigen. The cross-linked antigen-antibody complexes agglutinate. IgM is a potent agglutinating agent.
- **Precipitation of soluble molecule** is also accomplished through cross-linkages. The complexes precipitate and are subject to phagocytosis.
- **Complement fixation and activation** is the main antibody defense against cellular antigens. Several antibodies bind in close proximity on a cellular antigen. Their complement-binding sites trigger complement fixation on the cell's surface and the membrane attack complex causes cell lysis. C3a and C3b also amplify the inflammatory response and encourage phagocytosis via opsonization.

**Monoclonal antibodies (MAB)** are commercially prepared pure antibodies. They are produced using hybridomas (tumors consisting of fused tumor cells and B lymphocytes). MABs are used in research, clinical testing, and cancer treatment. **Trastuzumab** (Herceptin<sup>®</sup>), for example, interferes with the HER2/neu receptor of certain breast cancers. **Adalimumab** (HUMIRA<sup>®</sup>) is used for the treatment of rheumatoid arthritis (**human monoclonal antibody in rheumatoid arthritis**) and other autoimmune disorders.

#### **Cell-Mediated Immune Response**

In a cell-mediated immune response, **T cells provide defense against intracellular antigens**. Their targets are body cells infected by viruses or bacteria, abnormal or cancerous cells, and cells of infused or transplanted foreign tissue.

There are two major types of T lymphocytes based on the cell differentiation (CD) glycoproteins that play a role in T cell interactions with other cells:

- **CD4 cells** turn into **helper T cells (TH)** when activated.
- **CD8 cells** turn into **cytotoxic T cells (TC)** that destroy cells harboring non-self-antigens.

Other types of T cells are **regulatory T cells (TREG)** and **memory T cells**. Regulatory T cells dampen the immune response by direct contact or by inhibitory cytokines.

Unlike B lymphocytes, **mature T lymphocytes cannot identify non-self-antigens**. They need **antigen-presenting cells (APCs)** to help them with this step. Immunocompetent **T cells are activated** when their surface receptors bind to a **recognized antigen** (nonself). For this to happen, the **T cells must simultaneously recognize nonself**, i.e., the antigen, **and self**, i.e., a self-antigen of the body.

**APCs**, most often dendritic cells, migrate to lymph nodes and other lymphoid tissues to present their antigens to T cells. **T cell activation** is a two-step process of antigen binding and costimulation. Because of **MHC restriction**, CD4 cells bind to antigen linked to class II MHC proteins, and CD8 cells are activated by antigen fragments linked to class I MHC proteins.

**Cytokines** (interleukin 1 and 2 from APCs or T cells) trigger proliferation and differentiation of activated T cell.

T lymphocytes that are activated enlarge, proliferate, and form clones of helper T cells (TH) and cytotoxic T cells (TC).

The **primary T cell response** peaks within a week and then gradually wanes as T cell apoptosis occurs between days 7 and 30. However, memory T cells remain and are able to start a secondary T cell response.

**Helper T cells** play a central role in the adaptive immune response. They **help activate T and B cells, induce T and B cell proliferation, and activate macrophages** as well as recruit other immune cells. **There is no adaptive immune response without helper T cells!**

**Cytotoxic T cells** directly attack and kill other cells. They can destroy any infected or abnormal cell that displays a non-self-antigen. Their targets are virus-infected cells, cells with intracellular bacteria or parasites, cancer cells, and foreign cells (transfusions or transplants). Once they have identified and attached to a target, they release perforins and granzymes by exocytosis. The perforins create pores in the cell wall through which granzymes enter the target cell. The granzymes stimulate apoptosis (cell death). In some cases, the cytotoxic T cell binds with a receptor on the target cell and stimulates apoptosis.

**Natural killer cells** also destroy cells, but they recognize other signs of abnormality, such as a lack of class I MHC, antibody coating (opsonization) of target cells, or different surface marker on stressed cells.

## Immunity

Immunity is defined as **resistance to a disease**; the body can resist a particular infection or toxin by the action of specific antibodies or sensitized white blood cells. However, immunity is **also the ability to fight foreign cells**, for example, in organ transplants and blood transfusions.

In **active immunity**, the body has memory cells that allow the immune system to react swiftly and strongly against a threat it encountered previously (see secondary immune response above). In **passive immunity**, our body receives outside help to defeat a threat it has either never encountered before or for which it does not possess memory cells.

**Active humoral immunity** occurs when B cells encounter antigens and produce specific antibodies against them. There are two types:

- **Naturally acquired immunity** is a response to a bacterial or viral infection.
- **Artificially acquired immunity** is response to a vaccine of dead or attenuated pathogens. **Vaccines** spare us most of the clinical symptoms of the primary response. They provide antigenic determinants that are immunogenic and reactive. However, they fail to fully establish cellular immunological memory.

In **passive humoral immunity**, antibodies produced outside the body are used to fight a pathogen. Because our B lymphocytes are not challenged by non-self-antigens, immunological memory is not created. Therefore, the protection is immediate but ends when the antibodies naturally degrade in the body. The two types of passive humoral immunity are:

- **Naturally acquired immunity** is based on antibodies delivered to a fetus via the placenta or to an infant through breast milk.
- **Artificially acquired immunity** is achieved through injection of a serum, such as gamma globulin to Rh<sup>-</sup> mothers.

## Organ Transplants

Depending on the origin of the tissue transplanted, four varieties of transplants can be defined:

1. **Autografts** (*auto-* self) are transferred from one body site to another site in the same person.
2. **Isografts** (*iso-* equal) are transferred between identical twins.
3. **Allografts** (*allo-* other) are transferred between individuals who are not identical twins.
4. **Xenografts** (*xeno-* foreign) are transferred from another animal species.

**Allografts and xenografts will be attacked by cytotoxic T cells because they carry non-self-antigens.** The strength of this **rejection reaction** depends on the similarity of the tissues. The closer the tissue match, the less ferocious the rejection reaction will be. Transplant recipients are treated with immunosuppressive drugs to minimize rejection. However, the rejection reaction will never cease and anti-rejection therapy must be continued for as long as the allograft or xenograft remains in the body.

## 20.6 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	lymph	_____	splen(o)-
2.	lymph node	_____	immun(o)-
3.	spleen	_____	lymph(o)-
4.	tonsil	_____	lymphangi(o)-
5.	immune system	_____	tonsill(o)-
6.	lymph vessel	_____	lymphaden(o)-

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- The thymus produces hormones that promote maturation of T cells. \_\_\_\_\_
- Fluid enters the lymphatic system directly from the blood. \_\_\_\_\_
- Lacteals are highly specialized lymph capillaries found in the intestinal mucosa. \_\_\_\_\_
- T lymphocytes populate the germinal centers of lymphoid follicles. \_\_\_\_\_
- Complement proteins promote cytolysis, phagocytosis, and inflammation. \_\_\_\_\_
- Haptens are complete antigens. \_\_\_\_\_
- Opsonization makes microbes more susceptible to phagocytosis. \_\_\_\_\_
- Natural killer (NK) cells can fight cancer and virus-infected cells. \_\_\_\_\_
- The adaptive defense depends upon the ability of its cells to recognize self and non-self-antigens. \_\_\_\_\_
- Plasma cells release antigens in response to foreign antibodies. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                         |  |          |
|-------------------------|--|----------|
| 1. Active immunity      | a) transplant between identical twins            | 1. _____ |
| 2. Nonspecific immunity | b) antigen presenting cells                      | 2. _____ |
| 3. Lymphocytes          | c) play active role in filtering lymph           | 3. _____ |
| 4. Helper T cells       | d) largest lymphoid organ in the human body      | 4. _____ |
| 5. Dendritic cells      | e) after natural exposure to an infectious agent | 5. _____ |

- |     |                   |    |  |     |       |
|-----|-------------------|----|--|-----|-------|
| 6.  | Thoracic duct     | f) | defends against any type of invader    | 6.  | _____ |
| 7.  | Spleen            | g) | can recognize foreign cells            | 7.  | _____ |
| 8.  | Macrophages       | h) | targets body cells infected by viruses | 8.  | _____ |
| 9.  | Isograft          | i) | display CD 4 in their membrane         | 9.  | _____ |
| 10. | Cytotoxic T cells | j) | arises from the cisterna chyli         | 10. | _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- Which of the following is **not** a function of the lymphatic and immune system?
  - Draining excess interstitial fluid
  - Maintaining water balance in the body
  - Transporting dietary lipids
  - Carrying out immune responses
- What is the major difference between lymph and interstitial fluid?
  - The composition of electrolytes
  - White blood cells are present in lymph
  - The location
  - The number of red blood cells
- A lymphoid organ that does **not** directly fight antigens is the \_\_\_\_\_.
  - spleen
  - thymus
  - tonsil
  - liver
- The left subclavian vein receives lymph from the \_\_\_\_\_.
  - left axillary vein
  - lumbar trunk
  - jugular trunk
  - thoracic duct
- Which of these provides a non-specific cellular disease resistance mechanism?
  - Macrophages
  - T lymphocytes
  - B lymphocytes
  - Memory B cell
- This class of antibodies is mainly found in sweat, tears, breast milk, and GI secretions.
  - IgG
  - IgA
  - IgM
  - IgE
- Which of the following statements is **not** true?
  - An autograft is transferred from one body site to another in the same person.
  - A xenograft is transferred from another animal species.
  - Naturally acquired immunity develops as a response to a bacterial or viral infection.
  - Vaccines give us passive immunity only.

8. Which of the following statements is **incorrect**?
- a. IgM is the first antibody released.
  - b. IgG makes up 75–85% of antibodies in plasma.
  - c. Monoclonal antibodies are used for the treatment of autoimmune disorders.
  - d. In cell-mediated immune response B cells provide defense against bacteria.
9. The response to the first exposure to a specific antigen is called the \_\_\_\_.
- a. immediate response
  - b. humoral response
  - c. primary immune response
  - d. active immune response
10. Antibodies (immunoglobulins) are produced by \_\_\_\_.
- a. plasma cells
  - b. cytotoxic T cells
  - c. memory cells
  - d. antigen presenting cells



## Chapter 21 Respiratory System

### 21.1 Chapter Outline

The respiratory system works together with the cardiovascular system to deliver oxygen from the atmosphere to the tissues. Simultaneously, carbon dioxide is removed from the tissues and put back into the atmosphere.

### 21.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Identify and describe the location, structure, and function of the organs forming the respiratory tract in descending order.
- Distinguish between conducting and respiratory zone structures.
- Explain the makeup of the respiratory membrane.
- Describe the structure of the lungs and pleurae.
- Relate Boyle's law to the events of inspiration and expiration.
- Explain the relative roles of the respiratory muscles and lung elasticity in producing the volume changes that cause air to flow into and out of the lungs.
- Define and compare the lung volumes and capacities.
- Define dead space.
- Explain the differences in composition of atmospheric air and alveolar gas.
- Describe how oxygen is transported in the blood, and how oxygen loading and unloading is affected by  $P_{O_2}$ , temperature, pH, and  $P_{CO_2}$ .
- Explain carbon dioxide transport in the blood.
- Describe the neural controls of respiration.
- Compare and contrast the influences of arterial pH, arterial  $P_{O_2}$  and  $P_{CO_2}$ , and emotions on respiratory rate and depth.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 21.3 Combining Forms

Table 21.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 21.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
alveol(o)-	alveolus	<i>alveoli</i> = small, grape-like clusters found at the end of each bronchiole
bronch(o)-, bronchi(o)-	bronchus or bronchiole	<i>bronchopneumonia</i> = form of pneumonia that affects patches of the bronchioles throughout both lungs
laryng(o)-	larynx	<i>laryngitis</i> = inflammation of the larynx
nas(o)-, rhin(o)-	nose	<i>nasal</i> = relating to the nose
ox(i)-, ox(y)-	oxygen	<i>anoxia</i> = absence of oxygen in body
pharyng(o)-	pharynx	<i>pharyngitis</i> = inflammation of the pharynx
pleur(o)-	pleura	<i>pleurisy</i> = inflammation of the pleura

pneum(o)-	lung, air	<i>pneumothorax</i> = air in the pleural space
pulmon(o)-	lung	<i>pulmonary</i> = relating to the lung(s)
spir(o)-	to breath	<i>spirometry</i> = breathing test to measure a patient's airflow
thorac(o)-, -thorax	thorax, chest	<i>thoracocentesis</i> = surgical puncture of the chest wall with a needle to obtain fluid from the pleural cavity
trache(o)-	trachea	<i>tracheostomy</i> = surgical creation of an opening and insertion of a tube into the trachea

## 21.4 Introduction

**Respiration** involves two systems, the **respiratory system** and the **cardiovascular system**. Its task is to supply the body with oxygen and to dispose of carbon dioxide. There are four processes working together:

1. **Pulmonary ventilation** or **breathing**: Moving air into and out of the lungs is accomplished by the respiratory system.
2. **External respiration**: The exchange of O<sub>2</sub> and CO<sub>2</sub> between the lungs and the blood is accomplished by the respiratory system.
3. **Transport of O<sub>2</sub> and CO<sub>2</sub> in the blood** to organs and tissues is a function of the cardiovascular system.
4. **Internal respiration**: The exchange of O<sub>2</sub> and CO<sub>2</sub> between the blood and the tissues is accomplished by the cardiovascular system.

## 21.5 Anatomy of the Respiratory Tract

The organs of the respiratory system include the **upper respiratory tract organs** (the nose, pharynx, and larynx) and the **lower respiratory tract organs** (the trachea, bronchi, and the alveoli of the lungs). Air passes from the upper respiratory organs to the lower respiratory organs. In the lungs, gas exchange occurs at the level of the alveoli. Oxygen is delivered to the lungs from the atmosphere, and carbon dioxide is expelled back into the atmosphere.

The airways can be subdivided into two zones, a conducting zone and a respiratory zone.

- The **conducting zone** carries air to the gas exchange sites. It consists of the nose, pharynx, larynx, trachea, and bronchi. The last structures are the terminal bronchioles.
- The **respiratory zone** is the site of gas exchange. It consists of the respiratory bronchioles, alveolar ducts, and alveoli.

The terms **upper airways** and **lower airways** are clinical terms. Usually, the term **upper airways** refers to all structures up to and including the larynx; the **lower airways** are made up of all the structures below the larynx.

### Nose

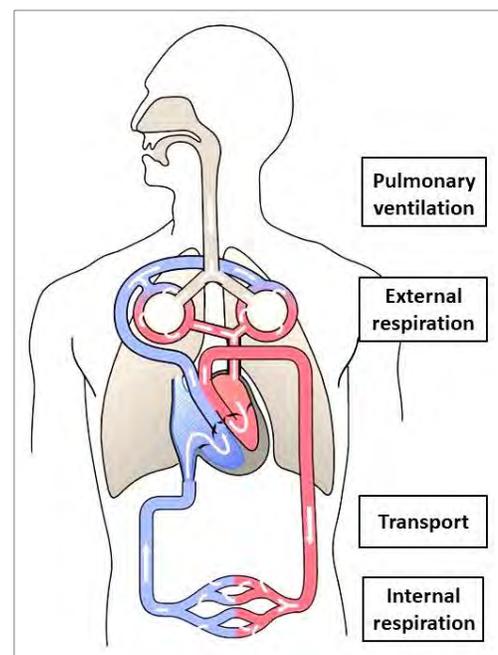
The nose provides a patent airway for respiration. It also filters, heats, and moistens air, serves as a resonating chamber for speech, reclaims heat and moisture during exhalation, and houses olfactory receptors.

The **external nose** consists of the root, bridge, dorsum nasi, and apex. The **philtrum** is a shallow vertical groove inferior to the apex.

The **nostrils** or **nares** are the entry into the nasal cavity. They are bounded laterally by the alae of the nose. The **nasal cavity** is divided by the **nasal septum**. The roof of the cavity is formed by the ethmoid and sphenoid bones. Its floor consists of the **hard** and **soft palate**. The nasal cavity superior to the nostrils is called the **vestibule**. Hairs growing in the vestibule, the so-called **vibrissae**, filter coarse particles from the inspired air.

Three shell-like structures, the **conchae**, protrude from the lateral walls of the nasal cavity. The **inferior concha** is a distinct bone, while the **superior and middle conchae** are part of the ethmoid bone. The nasal cavity opens into the

Figure 21.1 The four stages of respiration

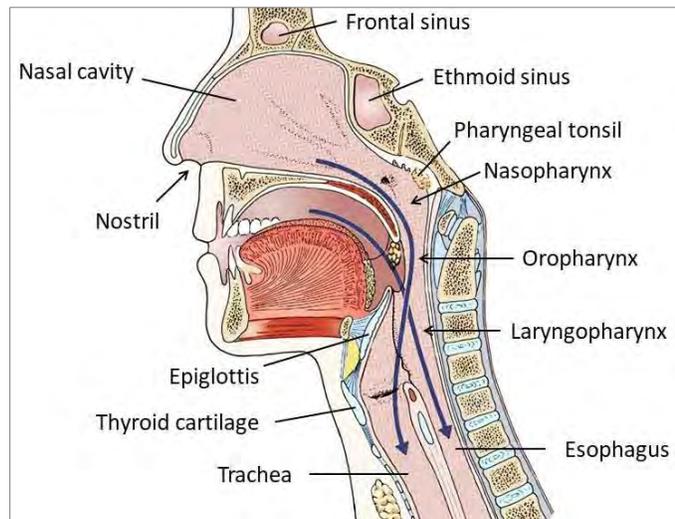


upper part of the pharynx, the **nasopharynx**, via the **posterior nasal apertures** or **choanae**.

Because the nasal cavity is a body cavity open to the outside, its surface is covered by a mucous membrane. The **olfactory mucosa** lines the superior nasal cavity and contains olfactory receptors for the sense of smell (see **Chapter 14 General & Special Senses**). The **respiratory mucosa** is ciliated and has plexuses of capillaries and veins that help warm inspired air. The **nasal conchae** increase the surface area of the mucosa and enhance turbulent airflow, which helps to clean, heat, and moisten the air during inhalation and to reclaim heat and moisture during exhalation.

The **paranasal sinuses** (sinus = cavity) are air-filled spaces within the bones of the skull. They are similarly lined with a mucous membrane. In addition to producing mucus, the sinuses make the bones of the skull lighter and produce sound by giving resonance to the voice. There are four paired sinuses around the nasal cavity. They are named the **frontal, ethmoid, maxillary, and sphenoid sinus** for the bones in which they are found.

Figure 21.2 Upper airways



### Pharynx

The pharynx, commonly known as the **throat**, receives the air after it passes through the nose. The pharynx is a muscular tube at the back of the nose and mouth that leads down to **larynx** and **esophagus**. It has three parts:

1. The first part, the **nasopharynx**, is located posterior to the nasal cavity. It is a passageway for air only. The **pharyngeal tonsil** (adenoids) is located on the posterior wall; the **pharyngotympanic tubes** open into the lateral walls. The **soft palate and uvula close the nasopharynx during swallowing**.
2. The **oropharynx** is the second division of the pharynx; it is visible when the mouth is open. The oropharynx is a passageway for both air and food. Hence, the oropharynx is shared by both the respiratory and digestive systems. The **isthmus of the fauces** is the opening to the oral cavity. The **palatine tonsils** are located in the lateral walls of the fauces. The **lingual tonsil** is situated on the posterior surface of the tongue.
3. The **laryngopharynx** is the third division of the pharynx; it is also a passageway for both the respiratory and digestive systems. Air, fluid, and food continue through this tube to either the trachea (part of the respiratory system) or the esophagus (part of the digestive system). The laryngopharynx is located posterior to the upright epiglottis; it is continuous with the esophagus.

### Larynx

Air passes from the laryngopharynx to the larynx. The larynx is not just a passageway for air but also the major organ for voice production, which is why it is also known as the **voice box**.

The larynx has a **cartilage skeleton** mostly made of hyaline cartilage. There are two big cartilages, the shield-shaped **thyroid cartilage** with the **laryngeal prominence** that forms the so-called **Adam's apple**, and the ring-shaped **cricoid cartilage**. These cartilages are complemented by three pairs of smaller cartilages (**arytenoid, cuneiform, corniculate cartilage**). All laryngeal cartilages are connected by ligaments and membranes, such as the **thyrohyoid membrane** between hyoid bone and thyroid cartilage, and the **cricothyroid ligament** between thyroid and cricoid cartilage.

The **epiglottis** (*epi-* above, *-glottis* glottis) is made of elastic cartilage. It protects the larynx when we eat or drink because it acts as a lid to cover the larynx and trachea in order to prevent food and drinks from entering the lungs.

The **vocal ligaments** run from the arytenoid cartilages to the thyroid cartilage. They form the core of the **vocal folds** or **true vocal cords**. The opening between the folds, the **glottis**, can be opened or closed to regulate airflow for voice production. During speech, the vocal cords are close together and sound is produced as air passes over them, causing vibration.

The **vestibular folds** superior to the vocal folds are often mistaken for the vocal cords and, thus, are also called **false vocal cords**. However, they only help close the glottis during swallowing and play no role in voice production.

Figure 21.3 Larynx, anterior view

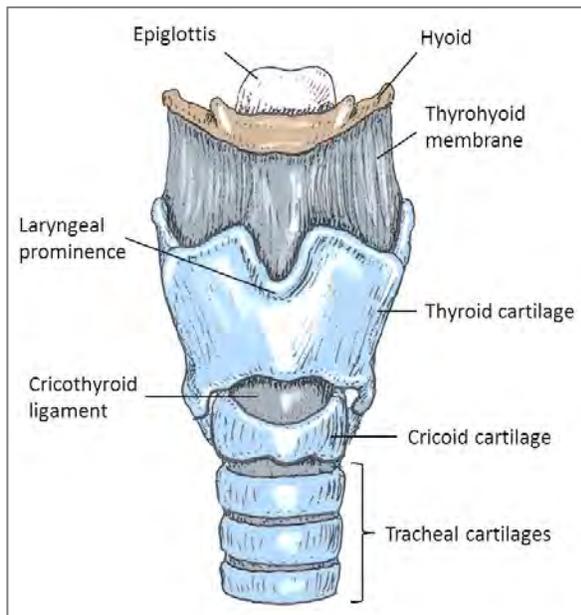
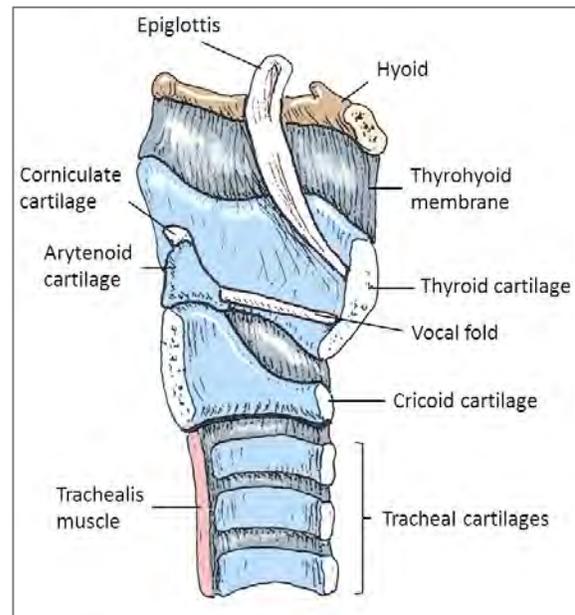


Figure 21.4 Larynx, sagittal view



### Trachea

The next part, the trachea, is commonly known as the **windpipe**. It is a tube that extends directly from the larynx to the bronchi of the lungs. The trachea's primary function is to transport air to and from the lungs. It is made of **horse-shoe-shaped cartilage rings** that are connected by membranes. The **trachealis muscle** connects the posterior parts of the cartilage rings. It contracts during coughing to expel air.

The last tracheal cartilage is called the **carina**. This is the point where the trachea branches into the **right** and **left main bronchus** for the right and left lung.

Within each lung, the **bronchi** undergo 23 orders of branching and form smaller and smaller branches, eventually becoming **bronchioles**.

The lower part of the trachea and the bronchi form a structure that resembles the branching structures of an inverted tree, appropriately called the **bronchial** or **respiratory tree**.

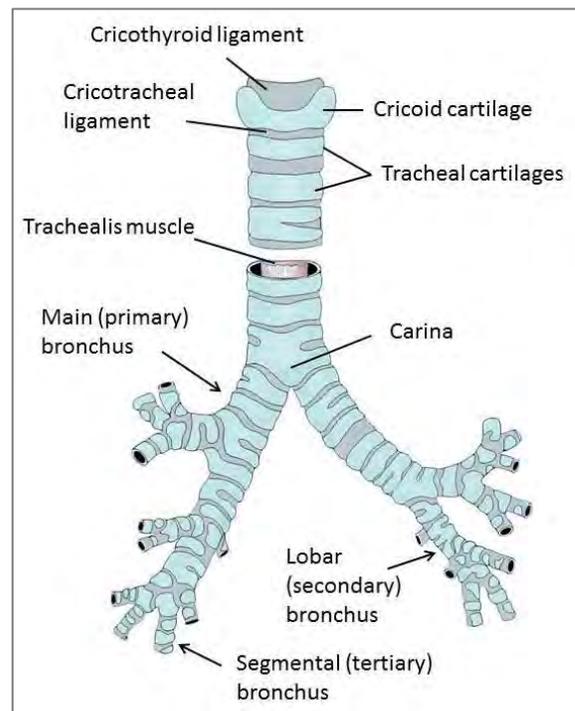
The branching starts with two **main** or **primary bronchi**, one for the right and one for the left lung. Each main bronchus divides into smaller bronchi for the lobes of each lung, which are called **lobar** or **secondary bronchi**. There are three of them for the right lung and two for the left lung.

These lobar bronchi subdivide into **segmental bronchi** for the individual segments of each lobe. Further branching leads to smaller bronchi, which are called **bronchioles**, once the diameter is less than 1 mm.

The **terminal bronchioles** with a diameter of less than 0.5 mm are the last part of the conducting zone. They do not have cartilage in their walls anymore but have **smooth muscle cells** that allow them to constrict or dilate to regulate airflow.

The **respiratory bronchioles** are the **first part of the respiratory zone**, although, no gas exchange will take place here. The bronchioles lead to **alveolar ducts** and finally to clusters of **alveoli** that are called **alveolar sacs**. Alveoli

Figure 21.5 Trachea and major bronchi

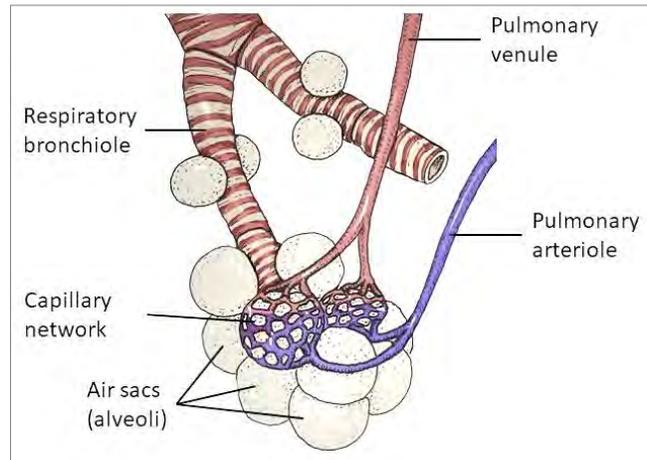


resemble grapes and respiratory bronchioles resemble the stems from which they hang. A healthy lung contains approximately 300 million air-filled alveoli that are the **site of the gas exchange**. Surrounding the alveolar sacs are small blood vessels called **pulmonary capillaries**.

The microscopic structure allowing the diffusion of gases is the **respiratory membrane**. It is an approximately 0.5- $\mu\text{m}$ -thick air-blood barrier that consists of alveolar and capillary walls and their fused basement membranes.

The **alveolar wall** is made of a single layer of **type I alveolar cells** as well as scattered **type II alveolar cells**. There are also **alveolar macrophages** that phagocytize foreign material, such as dust particles, which lead to them also being called **dust cells**. Neighboring alveoli are connected by **alveolar pores** that allow air pressure throughout the lung to be equalized. Alveoli are surrounded by **elastic fibers** that **resist expansion and encourage recoil during expiration** (see below).

Figure 21.6 Alveoli-capillary relationship



### Lungs

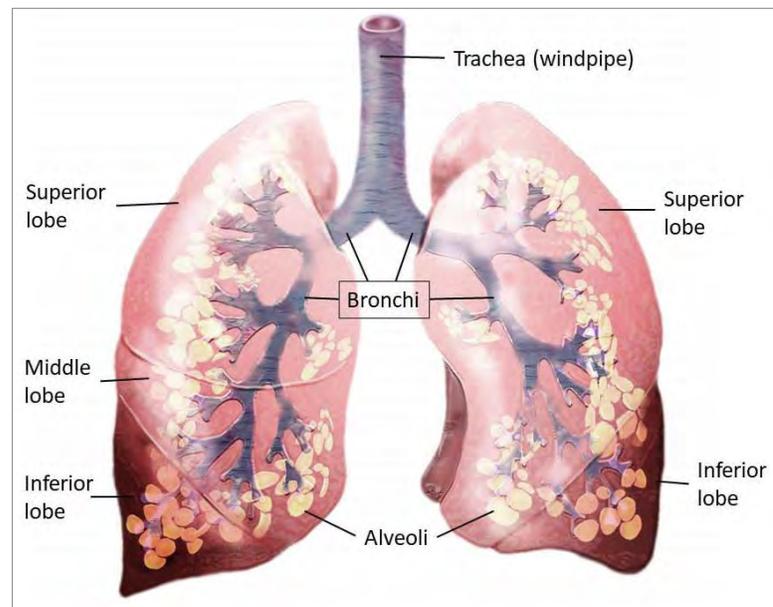
The lungs are the **organs of respiration**. They are made of a soft, spongy tissue with many blood vessels. Both lungs have the task to surround and protect the bronchi and alveoli and to lead blood vessels to them so that gases can be exchanged. The **right lung** is larger; it has **three lobes (superior, middle, inferior)** that are separated by **oblique** and **horizontal fissures**. The **left lung** is smaller, because it has to mold around the heart. It is separated into **two lobes (superior, inferior)** by an **oblique fissure**.

Each lung has an **apex** as their superior tip and a **base** that sits on and is attached to the diaphragm. The **hilum** on the mediastinal surface is the site where blood and lymphatic vessels, bronchi, and nerves enter or leave the lungs. The **cardiac notch of left lung** is a concavity that accommodates the heart.

The lungs receive blood from the pulmonary and the systemic circulation. **Pulmonary arteries** coming from the right ventricle of the heart carry oxygen-depleted blood towards the lungs, while **pulmonary veins** convey oxygen-rich blood back to the left atrium.

The systemic circulation delivers oxygen-rich blood to the lung tissue via **bronchial arteries** that arise from the aorta. **Bronchial veins** anastomoses with pulmonary veins, which is why most venous blood from the lungs is carried back to the left atrium of the heart via the pulmonary veins.

Figure 21.7 Lungs, overview



### Pleural Cavity

The cavity surrounding the lungs is covered by a serosa called **pleura**. The pleura is a thin, double-layered lining that covers the outer surface of the lung (**visceral pleura**) as well as the inner surface of the rib cage (**parietal pleura**). The **pleural cavity**, also known as the **pleural space**, is the space between the two membranes. This space contains a thin layer of **pleural fluid** that allows the membranes to slide easily during breathing.

The pleural cavity helps to protect the lungs within the thorax. The pleura further helps to create the vacuum needed for inspiration and expiration (see below).

### Check Your Understanding

1. Which of the following is not a part of the upper respiratory airways?
  - a) Bronchi
  - b) Nose
  - c) Pharynx
  - d) Larynx
2. Which of the following statements is incorrect?
  - a) The oropharynx is the second part of the pharynx.
  - b) The laryngopharynx is the third part of the pharynx.
  - c) The nasopharynx is the last part of the pharynx.
  - d) The pharynx receives the air after it passes through the nose.
3. The \_\_\_ is the space in between the vocal cords.
  - a) larynx
  - b) trachea
  - c) glottis
  - d) epiglottis
4. The \_\_\_ prevents food from entering the lower airways.
  - a) pharynx
  - b) Adam's apple
  - c) nasopharynx
  - d) epiglottis

1.A.2.C.3.C.4.D

## 21.6 Pulmonary Ventilation

**Breathing** or pulmonary ventilation consists of **inhalation** (or **inspiration**) and **exhalation** (or **expiration**). Inhalation allows oxygen-rich air to enter the lungs from the atmosphere, whereas exhalation is the process of breathing out carbon dioxide-rich air. The **movement of air** into or out of the lungs is a **passive process caused by a pressure gradient**. Air moves from an area of higher pressure to an area of lower pressure.

**Atmospheric pressure** is the pressure exerted by the air surrounding the body. It is approximately 760 mm Hg at sea level. The pressure inside the airways, the **respiratory pressure**, is **described relative to the atmospheric pressure**.

- If the respiratory pressure is higher than the atmospheric pressure, it is called positive, and air will move out of the lungs.
- If the respiratory pressure is negative, i.e., the respiratory pressure is lower than the atmospheric pressure, air will move into the lungs.
- If the pressures are equal, no air will move in either direction.

The pressure inside the lungs or alveoli, the **intrapulmonary** or **intra-alveolar pressure**, fluctuates with breathing. It is negative when we start breathing in and positive when we start breathing out. But, because of the airflow caused by the pressure difference, the intrapulmonary pressure will always eventually equal the atmospheric pressure.

**The lungs have a tendency to collapse** because of the **recoil of the elastic fibers** surrounding the alveoli and the **surface tension of the alveolar fluid** (see below). However, the fluid inside the pleural cavity connects the lungs to the parietal pleura and, thus, prevents a collapse. However, **the inward pull of the lungs creates the intrapleural pressure**, which is **always negative**. If the intrapleural pressure becomes zero, the lungs collapse in a process called **atelectasis**.

The **transpulmonary pressure** is the difference between the intrapulmonary pressure and the intrapleural pressure. It **has to be positive**, i.e., the pressure in the lung has to be greater than the pressure in the pleural cavity, to keep the airways open. The greater the transpulmonary pressure, the larger the lungs.

According to **Boyle's law**, in a closed container any change in either volume or pressure of a gas has an inverse effect on the other parameter. In other words, if the pressure goes up, the volume will go down and vice versa.

**Pulmonary ventilation is based on volume changes leading to pressure changes** that lead to gases flowing to equalize pressure. The volume inside the thoracic cavity changes depending on contraction and relaxation of muscles that attach to the inside or outside of ribs.

Muscles that assist with breathing are called **respiratory muscles**. At rest, we only use the **diaphragm**. If we want to take a deeper breath, we use muscles that can lift the ribs (the **external intercostal muscles**) or the thorax as a whole (the **sternocleidomastoid and scalene muscles**) as **accessory inspiratory muscles**. This lifting of the rib cage creates more suction and more air streams into our lungs.

To breathe out, all we have to do is to relax our inspiratory muscles. This allows the lungs to recoil and the air is pushed out. In order to breathe out faster or more forcefully, we use **expiratory muscles** that can lower the ribs (the **internal intercostal muscles**) as well as muscles that can increase the pressure inside the abdominal cavity and push the diaphragm up into the thoracic cavity (the **abdominal wall muscles**). By using these muscles, we increase the pressure inside the lungs and push the air out.

**Inspiration**, i.e., the act of breathing in, **is always an active process**. When inspiratory muscles contract, they cause an **increase in the thoracic volume**. This increase stretches the lungs, which leads to an **increased intrapulmonary volume** and a **decrease in intrapulmonary pressure** to approximately -1 mm Hg. As long as the glottis is open, the difference between intrapulmonary pressure and atmospheric pressure leads to air flowing into the lungs until the pressure is equalized.

**Quiet expiration is a passive process**. Once the **diaphragm or the other inspiratory muscles relax**, elastic recoil of the lungs and the alveolar surface tension lead to an **increase in intrapulmonary pressure** to approximately +1 mm Hg, which **pushes the air out of the lungs**. **Forced expiration**, however, **is an active process** that uses muscles such as the internal intercostal muscles and the muscles of the abdominal wall (see above).

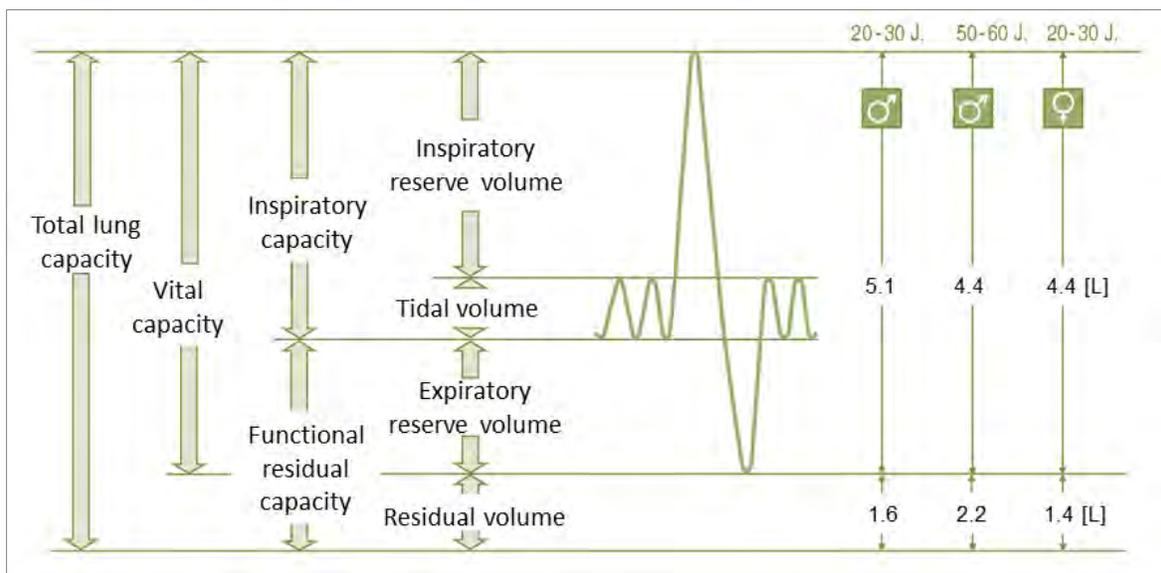
Inspiratory muscles have to overcome three factors: airway resistance, alveolar surface tension, and lung compliance.

- **Airway resistance** is usually very low, unless the flow is restricted by a narrowing of the air passages. This low resistance is due to the large airway diameters in the first part of the conducting zone and progressive branching of airways as they get smaller, increasing the total cross-sectional area.
- **Alveolar surface tension** is caused by liquid molecules attracting each other at a gas-liquid interface. The tension resists any force that tends to increase the surface area of the liquid. The overall alveolar surface of our lungs is considerable and the surface tension of the water covering it would prevent the lungs from expanding. The alveolar surface tension is lowered just enough by **surfactant** secreted by **type II alveolar cells** to allow for expansion, but kept high enough to assist with recoil during expiration. Lack of surfactant in premature newborn is the cause of **infant respiratory distress syndrome (IRDS)**.
- **Lung compliance** is a measure of how easily the lung volume can be changed by a change in transpulmonary pressure. The **higher the compliance** (i.e., the more elastic the lung tissue), **the easier the lungs expand during inspiration**. Lung compliance is normally high due to the elasticity (distensibility) of the lung tissue. It is reduced by nonelastic scar tissue, lack of surfactant, and decreased flexibility of the thoracic (deformities, such as hunchback, ossification of costal cartilage, paralysis of intercostal nerves).

### Lung Volumes and Capacities

There are a number of lung volumes and capacities that can be determined directly or indirectly using a spirometer. **Volumes** can be **measured directly**, while **capacities** are **made up of two or more volumes**.

Figure 21.8 Lung volumes and capacities



Some inhaled air never reaches the alveoli (**anatomical dead space**) or flows into alveoli that do not contribute to gas exchange for one reason or other (**alveolar dead space**). The sum of these nonuseful volumes is called **total dead space**. In a healthy young patient, all alveoli contribute to gas exchange and the total dead space equals the anatomical dead space, which is approximately 150 ml.

**Minute ventilation (MV)** or the total amount of **gas flow into or out of the respiratory tract** in one minute is calculated by multiplying the **respiratory rate** with the **tidal volume** ( $MV = RR \times TV$ ). At rest, the respiratory rate (RR) is 12-15/minute and the tidal volume is 500 ml. Therefore, the **minute ventilation at rest** is between 6,000 ml (6 L) and 7,500 ml (7.5 L).

**Alveolar ventilation rate (AVR)** is the **flow of gases into and out of the alveoli** in one minute. The alveolar ventilation rate is different from the minute ventilation because it depends on the depth of the breathing much more than on the respiratory or breathing rate. Because the anatomical dead space is 150 ml, only 350 ml of the tidal volume reaches the alveoli. Thus, the **AVR at rest** is between 4200 ml (4.2 L) and 5250 ml (5.25 L).

**Table 21.2 Lung Volumes and Capacities**

Parameter	Definition	Average value adult male	Average value adult female
Tidal volume (TV)	Amount of air inhaled or exhaled with each breath under resting conditions	500 ml = 0.5 l	500 ml = 0.5 l
Inspiratory reserve volume (IRV)	Amount of air that can be forcefully inhaled after a normal tidal volume inhalation	3100 ml = 3.1 l	1900 ml = 1.9 l
Expiratory reserve volume (ERV)	Amount of air that can be forcefully exhaled after a normal tidal volume exhalation	1200 ml = 1.2 l	700 ml = 0.7 l
Residual volume (RV)	Amount of air remaining in the lungs after forced exhalation	1200 ml = 1.2 l	1100 ml = 1.1 l
Inspiratory capacity (IC)	Maximum amount of air that can be inspired after a normal expiration: $IC = TV + IRV$	3600 ml = 3.6 l	2400 ml = 2.4 l
Functional residual capacity (FRC)	Volume of air remaining in the lungs after a normal tidal volume expiration: $FRC = ERV + RV$	2400 ml = 2.4 l	1800 ml = 1.8 l
Vital capacity (VC)	Maximum amount of air that can be expired after a maximum inspiratory effort: $VC = TV + IRV + ERV$	4800 ml = 4.8 l	3100 ml = 3.1 l
Total lung capacity (TLC)	Maximum amount of air contained in lungs after a maximum inspiratory effort: $TLC = TV + IRV + ERV + RV$	6000 ml = 6.0 l	4200 ml = 4.2 l

## 21.7 External & Internal Respiration

Ventilating the airways by removing used, carbon dioxide-rich air and replacing it with fresh, oxygen-rich air is important; still, **breathing is only the first step of respiration**. The next steps are the gas exchange between the lungs and the blood (**external respiration**) and between the blood and the tissues (**internal respiration**). Both processes are based on the diffusion of gases along a concentration gradient from an area with a higher concentration to an area with a lower concentration.

The best way to measure the concentration of gases in mixtures is by measuring their partial pressure. According to **Dalton's law of partial pressure**, the total pressure exerted by a mixture of gases is the sum of the pressures exerted by each gas. The **partial pressure of each gas is directly proportional to its percentage in the mixture**. For example, if the atmospheric pressure is 760 mm Hg and oxygen makes up 20% of the air, then the partial pressure of oxygen ( $P_{O_2}$ ) is 20% of 760 mm Hg or 152 mm Hg.

According to **Henry's law**, if a mixture of gases is in contact with a liquid, each gas will dissolve in the liquid in proportion to its partial pressure. At equilibrium, the partial pressures in the two phases will be equal.

The **amount of gas that will dissolve in a liquid also depends upon its solubility**. **Carbon dioxide ( $CO_2$ ) is 20 times more soluble in water than oxygen ( $O_2$ )**. Because of that, we drink carbonated drinks, such as sodas, instead of oxygenated drinks.

**Alveolar gas has a different composition than atmospheric air**. Because of the ongoing gas exchange, the  $P_{O_2}$  is lower in the alveolar gas than the inspired air (104 mm Hg vs. 159 mm Hg). However, the  $P_{CO_2}$  is higher (40 mm Hg vs. 0.3 mm Hg), as is the  $P_{H_2O}$  (47 mm Hg vs. 3.7 mm Hg) due to the humidification of the air in the upper airways.

The composition also reflects the fact that only a smaller portion of the air in the lungs is replaced with fresh air during each breathing cycle (see tidal volume above).

### External Respiration

External respiration is the exchange of  $O_2$  and  $CO_2$  across the respiratory membrane. It is a passive process driven by a concentration gradient between alveolar space and blood. Efficient external respiration depends on three main factors:

#### 1. Partial pressure gradients and gas solubilities:

The partial pressure gradient for oxygen between alveoli and blood is approximately 64 mm Hg because the  $P_{O_2}$  in the alveoli is 104 mm Hg and the  $P_{O_2}$  in the blood is 40 mm Hg. This gradient causes  $O_2$  to move across the respiratory membrane from the alveoli into the blood.

The **pressure gradient for  $CO_2$  is much lower** (5 mm Hg) because the  $P_{CO_2}$  in the blood is 45 mm Hg and the  $P_{CO_2}$  in the alveoli is 40 mm Hg. Yet, this gradient **is sufficient to cause a diffusion of  $CO_2$  from the blood to the alveolus**.

**Blood entering the alveolar capillaries** has a  $P_{O_2}$  of 40 mm Hg and a  $P_{CO_2}$  of 45 mm Hg. Within 0.25 seconds, the blood loads up on oxygen and increases its  $P_{O_2}$  up to 104 mm Hg. At the same time, it loses carbon dioxide leading to the  $P_{CO_2}$  dropping to 40 mm Hg. Normally, the blood spends about 0.75 seconds in the capillary and, therefore, has plenty of time for the gas exchange.

Most of the oxygen-depleted blood in the bronchial veins enters the pulmonary veins. Because of that, the **blood flowing back to the heart has a  $P_{O_2}$  of 100 mm Hg and a  $P_{CO_2}$  of 40 mm Hg**.

2. **Ventilation-perfusion coupling:** Blood flow (**perfusion**) through the alveolar capillaries and air flow (**ventilation**) into the alveolar cavity have to be matched for an efficient gas exchange. The blood flowing into the lungs in pulmonary arteries and arterioles is oxygen-depleted and, thus, needs to get to areas with a high alveolar  $P_{O_2}$ . Therefore, **arterioles dilate where alveolar  $P_{O_2}$  is high** to get the blood to the oxygen and **constrict where alveolar  $P_{O_2}$  is low**.

Bronchioles have to carry incoming oxygen to alveoli with a low  $P_{O_2}$ . Thus, **bronchioles dilate where the alveolar  $CO_2$  is high** to get the alveolus ventilated and **constrict where the alveolar  $CO_2$  is low**.

3. **Structural characteristics of the respiratory membrane:** The respiratory membrane **has to be very thin** (0.5 to 1  $\mu m$  thick) for **gases to move across via diffusion only**. Any thickening or fluid collection in the alveoli will impair gas exchange.

The same can be said about the **overall surface area**. The larger it is, the more gas can be exchanged in a given time. Any reduction of the surface area will impair gas exchange, too.

Figure 21.9 Respiratory membrane

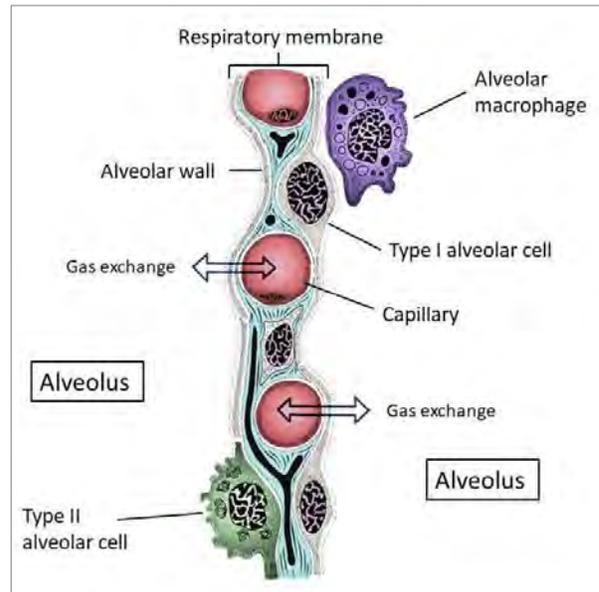
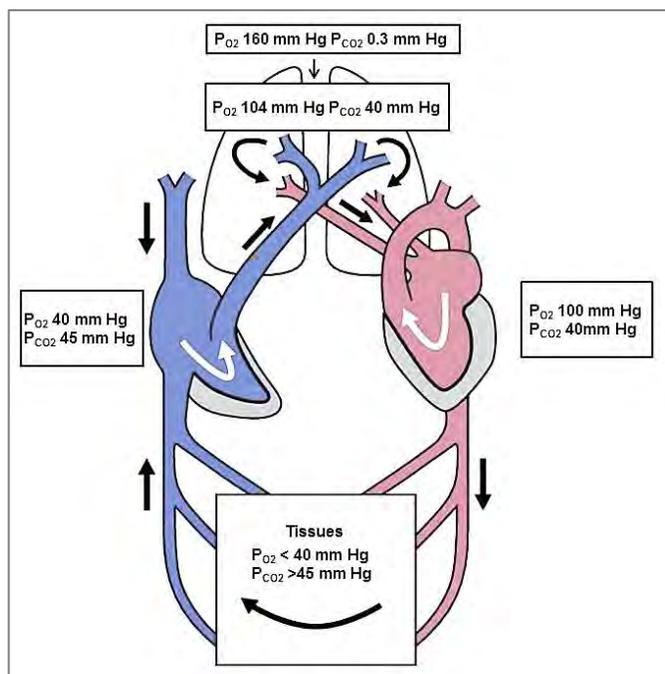


Figure 21.10 External and internal respiration



### Internal Respiration

Internal respiration, i.e., the gas exchange between capillaries and tissues, also depends on partial pressures and diffusion gradients. However, they are reversed compared to external respiration and, therefore, O<sub>2</sub> and CO<sub>2</sub> move in opposite directions.

**The P<sub>O<sub>2</sub></sub> in the tissue is always lower than the P<sub>O<sub>2</sub></sub> in the blood.** On average, tissue P<sub>O<sub>2</sub></sub> is 40 mm Hg or less, compared to a blood P<sub>O<sub>2</sub></sub> of 100 mm Hg. Because of this gradient of 60 mm Hg, **O<sub>2</sub> moves from the blood into the tissue.**

**CO<sub>2</sub> has a higher partial pressure in the tissue (>45 mm Hg) than the blood (40 mm Hg) and, thus, moves from the tissue to the blood.**

#### Check Your Understanding

- Which of the following statements is *incorrect*?
  - The diaphragm is the main muscle for inhalation.
  - At rest, we only use the diaphragm.
  - The more we expand the thorax, the less air is sucked into the airways.
  - The P<sub>O<sub>2</sub></sub> in the tissue is always lower than the P<sub>O<sub>2</sub></sub> in the blood.
- During inspiration \_\_\_\_\_.
  - the diaphragm contracts and pulls downwards
  - air moves out of the lung
  - the diaphragm relaxes and oxygen-rich air flows out
  - 4-5 l of air are exchanged
- External respiration is the \_\_\_\_\_.
  - gas transport in the blood
  - gas exchange between the blood and the tissue
  - ventilation of the lungs
  - gas exchange between the alveoli and the blood
- How much air do we exchange during a normal cycle of breathing in and out?
  - 4000 ml
  - 3000 ml
  - 150 ml
  - 500 ml

1.C.2.A.3.D.4.D

### 21.8 Gas Transport in the Blood

Gas transport is a function of the cardiovascular system. Erythrocytes and blood plasma work to together in the transport of oxygen and carbon dioxide in the blood. **Oxygen is** carried in molecular form (O<sub>2</sub>) in the blood. Only a small percentage of oxygen (1.5%) is dissolved in the plasma, the rest is **carried bound to the iron in hemoglobin** (Hb). However, this bond is not a chemical bond, but a loose bond based on weak attraction forces and oxygen can be released from it easily.

**Hemoglobin** consists of four chains, **two alpha chains and two beta chains** (see **Chapter 18 Blood, Hemostasis, and Blood Groups**). They make up the protein part (**globin**) of the molecule. The *hemo-* part comes from a pigment (**heme**) that contains one atom of iron at its core. **Each molecule of hemoglobin can transport four molecules of O<sub>2</sub>.**

- Loading** of hemoglobin with O<sub>2</sub> is called **oxygenation** and leads to the formation of bright red **oxygenated hemoglobin** or **oxyhemoglobin**.
- Unloading** of oxygen is called **deoxygenation** and produces dark red **deoxygenated hemoglobin** or **deoxyhemoglobin**.

Loading and unloading are facilitated by a **change in the three-dimensional shape of hemoglobin** that **affects the affinity of hemoglobin for O<sub>2</sub>**. When O<sub>2</sub> binds to hemoglobin, the affinity of hemoglobin for O<sub>2</sub> increases; release of O<sub>2</sub> decreases the affinity of hemoglobin for O<sub>2</sub>.

- Oxygen-free hemoglobin has a rather weak affinity to O<sub>2</sub>. However, once the first O<sub>2</sub> has been bound, the affinity increases with binding of each subsequent O<sub>2</sub>.
- Fully loaded or **saturated hemoglobin carries 4 molecules of O<sub>2</sub> per hemoglobin molecule**. Hemoglobin is partially saturated when it carries between 1 and 3 O<sub>2</sub>. In **systemic arterial** (oxygen-rich) **blood**, the P<sub>O<sub>2</sub></sub> is 100 mm Hg and **hemoglobin is 98% saturated**. In **venous blood**, the P<sub>O<sub>2</sub></sub> drops to 40 mm Hg and the **oxygen saturation to 75%**.

- Once fully saturated **hemoglobin gives up its first O<sub>2</sub>** in the tissue, its **affinity to the three remaining O<sub>2</sub> declines** and it is more likely to give up another one. Loss of the second O<sub>2</sub> further weakens the affinity and the third O<sub>2</sub> is released even more easily as is the last one.

The **rate of loading and unloading** of O<sub>2</sub> is regulated by P<sub>O<sub>2</sub></sub>, temperature, blood pH, and P<sub>CO<sub>2</sub></sub>. A graph plotting hemoglobin saturation against P<sub>O<sub>2</sub></sub> shows how binding and release of O<sub>2</sub> is influenced by the P<sub>O<sub>2</sub></sub>. This S-shaped curve is called the **oxygen-hemoglobin dissociation curve**.

Because of this S-shape hemoglobin is almost completely saturated at a P<sub>O<sub>2</sub></sub> of 70 mm Hg, i.e., O<sub>2</sub> loading and delivery to tissues is adequate even when P<sub>O<sub>2</sub></sub> is below normal levels. **If O<sub>2</sub> levels in active tissues drop below the average of 40 mm Hg, more oxygen dissociates** from hemoglobin and diffuses into the tissue.

**Metabolically active tissues** cause a number of changes in their environment that modify the structure of hemoglobin and decrease its affinity for O<sub>2</sub>. As they metabolize glucose, tissues use O<sub>2</sub> and the P<sub>O<sub>2</sub></sub> of the tissue **decreases**. Oxidation of glucose produces CO<sub>2</sub>, which leads to an **increased P<sub>CO<sub>2</sub></sub>** in the tissue, and heat, which **increases the local temperature**. CO<sub>2</sub> forms carbonic acid, which is a weak acid, but still **lowers the pH**.

The weakening of the Hb-oxygen bond caused by a decline in pH is called the **Bohr effect**.

Any of those changes caused by metabolic activity decrease the affinity of hemoglobin for O<sub>2</sub> and lead to an increased O<sub>2</sub> release.

In **systemic arterial blood**, the **P<sub>O<sub>2</sub></sub> is 100 mm Hg and hemoglobin is 98% saturated**, i.e., a further increase in P<sub>O<sub>2</sub></sub> can only produce a minimal increase in O<sub>2</sub> saturation. In resting or moderately active tissues, the P<sub>O<sub>2</sub></sub> decreases to 40 mm Hg. However, the O<sub>2</sub> saturation goes down to 75% only, i.e., only 20-25% of oxygen is unloaded and the blood still contains enough oxygen to satisfy the needs of more active tissues without an increase in blood flow.

**Carbon dioxide is transported** in the blood in three ways: **dissolved in plasma** (7-10%), **bound to hemoglobin** as carbaminohemoglobin (20%), and as **bicarbonate ions (HCO<sub>3</sub><sup>-</sup>) in plasma** (70%).

**Carbon dioxide** combines with **water** to form **carbonic acid** (H<sub>2</sub>CO<sub>3</sub>), which is a weak acid and has a tendency to dissociate into **hydrogen ions (H<sup>+</sup>)** and **bicarbonate ions (HCO<sub>3</sub><sup>-</sup>)**  $\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$ .

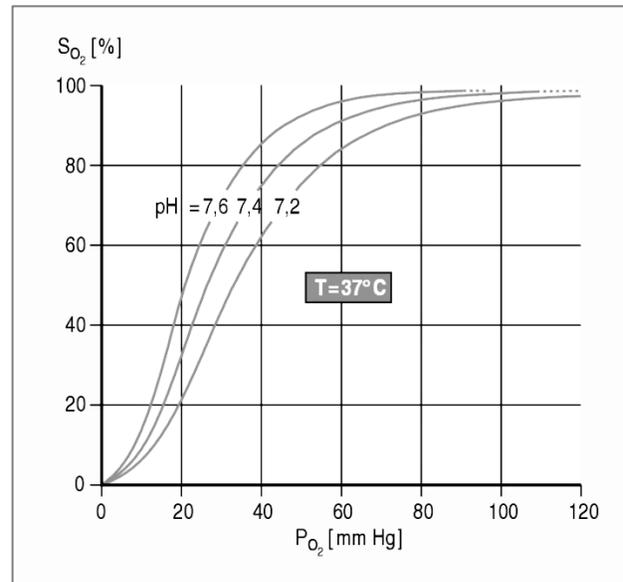
However, this reaction would be too slow on its own and, therefore, our body uses the enzyme **carbonic anhydrase** (CA) to speed it up. The enzyme is located inside the erythrocytes and catalyzes the production of most of the bicarbonate found in oxygen-depleted blood.

**Bicarbonate quickly diffuses out of the erythrocytes** into the plasma.

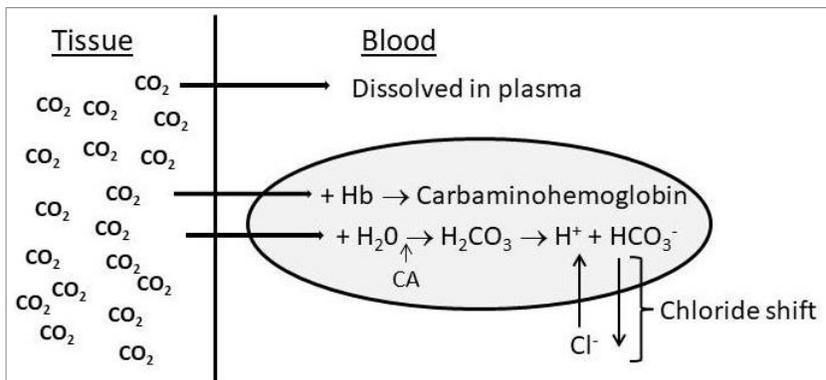
This outward shift of a negatively charged ion has to be balanced by the inflow of another ion with the same charge to keep the inside of the RBCs electrically neutral. This ion is chloride and, therefore, the process is called the **chloride shift**.

**In the pulmonary capillaries, the mechanism is reversed**. Bicarbonate moves into the erythrocytes and binds with H<sup>+</sup> to form H<sub>2</sub>CO<sub>3</sub>, which

**Figure 21.11 Oxygen-hemoglobin dissociation curve for different pH ranges at normal body temperature**



**Figure 21.12 Carbon dioxide loading in tissues**



is split by carbonic anhydrase into water and CO<sub>2</sub>. CO<sub>2</sub> diffuses out of the RBC and into the alveoli. At the same time, chloride ions move out of the RBCs in a **reverse chloride shift**.

The **Haldane effect** states that **the amount of CO<sub>2</sub> transported in blood is affected by the Po<sub>2</sub>**. The lower the Po<sub>2</sub> and hemoglobin saturation with O<sub>2</sub>, the more CO<sub>2</sub> can be carried in the blood. In the tissues, more O<sub>2</sub> dissociates from hemoglobin because of a lower pH (**Bohr effect**), which frees up Hb to combine with CO<sub>2</sub>.

The HCO<sub>3</sub><sup>-</sup> in the plasma is the **alkaline reserve** of the **carbonic acid–bicarbonate buffer system** (see **Chapter 23 Fluid, Electrolyte, and Acid-Base Balance**). If the H<sup>+</sup> concentration in blood rises and the pH goes down, excess H<sup>+</sup> is removed by combining it with HCO<sub>3</sub><sup>-</sup>; when the H<sup>+</sup> concentration begins to drop and the pH goes up, H<sub>2</sub>CO<sub>3</sub> dissociates, releasing H<sup>+</sup>.

### Control of Respiration

There are **two respiration centers** in the CNS, a **pontine respiratory center** in the pons and a **medullary respiratory center** in the medulla oblongata. Together, these centers **control the depth and rate of breathing depending on body demands**.

**Chemical factors have the most influence** on the respiratory centers. If the P<sub>CO2</sub> levels rise in the blood (**hypercapnia**), more CO<sub>2</sub> accumulates in the brain, leading to a drop in the blood pH. This drop in turn stimulates the central chemoreceptors of the brain stem and **increases the depth and rate of breathing**. A drop in the P<sub>CO2</sub> (**hypocapnia**) has the opposite effect, i.e., it **lowers the breathing rate**. If the P<sub>CO2</sub> is abnormally low, the breathing can stop completely (**apnea**).

**Oxygen has less influence on the respiratory centers** because even a drop in arterial P<sub>O2</sub> down to 70 mm Hg will not change the oxygen saturation of hemoglobin by much (see hemoglobin-dissociation curve above). Thus, a **substantial drop in arterial Po<sub>2</sub>** (down to 60 mm Hg or less) **must occur in order to stimulate increased ventilation**.

**A change in blood pH will change the respiratory rate even if CO<sub>2</sub> and O<sub>2</sub> levels are normal**. A drop in pH will increase pulmonary ventilation, while a rise in pH will slow it down (see also **Chapter 24 Fluid, Electrolyte, and Acid-Base Balance**).

**Higher brain centers**, such as the **hypothalamus** and the **limbic system**, also influence breathing depth and rate, e.g., when we are cold or frightened. The **cerebral cortex** can directly change ventilation, e.g., to blow up a balloon.

The **Hering-Breuer reflex** is a **protective response to prevent overinflation of the lungs**. It is based on stretch receptors in the pleurae and airways that send inhibitory signals to the medullary respiratory centers. When activated, they end inhalation and allow expiration to occur.

Any bodily activity, whether it is **physical work or exercise**, increases oxygen use and production of CO<sub>2</sub> and acids in the tissues. To keep P<sub>CO2</sub>, P<sub>O2</sub>, and pH constant, our minute ventilation has to go up 10 to 20 fold.

## 21.9 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	alveolus	_____	pulmon(o)-
2.	larynx	_____	pneum(o)-
3.	air	_____	rhin(o)-
4.	lung	_____	pharyng(o)-
5.	nose	_____	laryng(o)-
6.	pharynx	_____	bronch(o)-
7.	bronchus	_____	alveol(o)-

**True/False**

Write "T" on the line if the statement is true and "F" if the statement is false.

1. The larynx is located anterior to the esophagus and carries air to the trachea. \_\_\_\_\_
2. The point where the trachea divides into primary bronchi is a ridge called Adam's apple. \_\_\_\_\_
3. The smallest conducting passageways of the lungs are called bronchioles. \_\_\_\_\_
4. Air moves out of the lungs when inspiratory muscles relax. \_\_\_\_\_
5. Bronchioles are the first division of the trachea. \_\_\_\_\_
6. The larynx routes air and food into their proper channels. \_\_\_\_\_
7. The parietal pleura lines the thoracic wall. \_\_\_\_\_
8. The paranasal sinuses are air-filled spaces within the chest. \_\_\_\_\_
9. Without surfactant, the alveoli would collapse, and we would suffocate. \_\_\_\_\_
10. Muscles that assist with breathing are called respiratory muscles. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                                |  |           |
|--------------------------------|--|-----------|
| 1. Pharynx                     | a) windpipe                                      | 1. _____  |
| 2. Left lung                   | b) air that remains within the conducting zone   | 2. _____  |
| 3. Respiratory bronchioles     | c) continuation of the trachea                   | 3. _____  |
| 4. Trachea                     | d) passageway for air, food, and water           | 4. _____  |
| 5. Glottis                     | e) where the respiratory zone begins             | 5. _____  |
| 6. Main (primary) bronchi      | f) can be inhaled forcibly over the tidal volume | 6. _____  |
| 7. Vital capacity              | g) tube posterior to the trachea                 | 7. _____  |
| 8. Dead space volume           | h) opening to the trachea                        | 8. _____  |
| 9. Esophagus                   | i) has two lobes                                 | 9. _____  |
| 10. Inspiratory reserve volume | j) total amount of exchangeable air              | 10. _____ |

**Multiple Choice**

Choose the one alternative that **best** completes the statement or answers the question.

1. Which cells of the alveoli that produce surfactant?
  - a. Type I alveolar cells
  - b. Type II alveolar cells
  - c. Surface cells
  - d. Macrophages

2. The membrane that adheres to the outer surface of the lungs is the \_\_\_\_.
  - a. respiratory membrane
  - b. visceral pleura
  - c. parietal pleura
  - d. mucosa
  
3. All of the following are part of the conduction zone **except** \_\_\_\_.
  - a. main bronchi
  - b. segmental bronchioles
  - c. respiratory bronchioles
  - d. terminal bronchioles
  
4. The relationship between the pressure and volume of gases is given by \_\_\_\_\_ law.
  - a. Henry's
  - b. Boyle's
  - c. Adam's
  - d. Dalton's
  
5. Which is the direction of diffusion of gases at capillaries in the tissues?
  - a. Oxygen into blood, carbon dioxide into blood
  - b. Oxygen into blood, carbon dioxide out of blood
  - c. Oxygen out of blood, carbon dioxide out of blood
  - d. Oxygen out of blood, carbon dioxide into blood
  
6. Which is the dominant method of carbon dioxide transport?
  - a. Bound to hemoglobin
  - b. Bound to oxygen
  - c. Dissolved in plasma as a gas
  - d. Dissolved in plasma as bicarbonate ions
  
7. Which of the following that does **not** affect hemoglobin's affinity for oxygen?
  - a. pH of blood
  - b. Partial pressure of the oxygen
  - c. Temperature
  - d. Respiratory rate
  
8. Which of the following has the greatest effect on respiration rate?
  - a. Low  $P_{O_2}$
  - b. High  $P_{CO_2}$
  - c. Low  $P_{N_2}$
  - b. Both a and b have an equal effect
  
9. Voluntary apnea (breath-holding) for 60 seconds will \_\_\_\_.
  - a. decrease alveolar  $pCO_2$
  - b. increase arterial  $pO_2$
  - c. inhibit the arterial chemoreceptors
  - d. increase alveolar  $pCO_2$
  
10. The partial pressure for  $CO_2$  is higher than the partial pressure for  $O_2$  in the \_\_\_\_.
  - a. alveoli
  - b. blood leaving the lungs
  - c. blood entering the capillary bed
  - d. blood leaving the right ventricle

## Chapter 22 Digestive System

### 22.1 Chapter Outline

The digestive system consists of the organs of the gastrointestinal tract and accessory organs. Together these structures have to coordinate food intake, digestion of food, absorption of nutrients into the body, and excretion of food content that cannot be broken down and absorbed.

### 22.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the function of the digestive system, and differentiate between organs of the alimentary canal and accessory digestive organs.
- List and define the major processes occurring during digestive system activity.
- Describe stimuli and controls of digestive activity.
- List the basic functions of the organs of the alimentary canal and accessory digestive organs.
- Describe the composition and the general function of each of the four layers of the alimentary canal.
- Explain how gastric secretion and stomach motility are regulated.
- Name the cell types responsible for secreting the various components of gastric juice.
- Discuss the function of gastrointestinal hormones and paracrines.
- Compare mechanical and chemical digestion.
- List the enzymes involved in chemical digestion and name the foodstuffs on which they act.
- State the role of bile in digestion and describe how its release and entry into the small intestine is regulated.
- Describe the process of absorption of breakdown products of foodstuffs.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 22.3 Combining Forms

Table 22.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 22.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
aliment(o)-	nourishment or food	<i>alimentary</i> = relating to nourishment or sustenance
bil(i)-	bile	<i>biliary</i> = relating to bile
chol(e)-	bile	<i>cholelithiasis</i> = the presence of stones in the gallbladder or bile ducts
cholecyst(o)-	gallbladder	<i>cholecystalgia</i> = pain in the gallbladder
col(o)-	colon	<i>colonoscopy</i> = the visual examination of the colon
duoden(o)-	duodenum	<i>duodenal</i> = relating to the duodenum
enter(o)-	intestine	<i>enteritis</i> = inflammation of the small intestine
esophag(o)-	esophagus	<i>esophageal</i> = relating to the esophagus
gastr(o)-	stomach	<i>gastrointestinal</i> = relating to stomach and (small) intestine
hepat(o)-	liver	<i>hepatectomy</i> = surgical removal of all or part of the liver

ile(o)-	ileum	<i>ileitis</i> = inflammation of the ileum
intest(o)-	intestine	<i>intestinal</i> = relating to the intestine(s)
jejun(o)-	jejunum	<i>jejunal</i> = relating to the jejunum
lapar(o)-	abdomen	<i>laparoscopy</i> = the visualization of the interior of the abdomen with a small camera
pancreat(o)-	pancreas	<i>pancreatotomy</i> = a surgical incision into the pancreas
peritone(o)-	peritoneum	<i>retroperitoneal</i> = located behind the peritoneal cavity
proct(o)-	rectum	<i>proctoscopy</i> = the visual examination of the rectum
rect(o)-	rectum	<i>rectal</i> = relating to the rectum
sigmoid(o)-	sigmoid colon	<i>sigmoidectomy</i> = surgical removal of all or part of the sigmoid colon
stomat(o)-	mouth	<i>stomatitis</i> = inflammation of the mouth

## 22.4 Overview

Supplying our cells with nutrients is one of the survival needs of our body (see **Chapter 3 Introduction into Anatomy & Physiology**). The digestive system takes in food and moves it through the gastrointestinal tract. Along the way, it breaks the food down into absorbable units that enter the blood for distribution to body cells. Indigestible foodstuffs are eliminated as feces.

The digestive system consists of two groups of organs:

1. The **alimentary canal (gastrointestinal or GI tract)** digests and absorbs food. It consists of the mouth, pharynx, esophagus, stomach, small intestine, and large intestine.
2. **Accessory digestive organs** assist mainly in the mechanical (teeth, tongue) and chemical breakdown (gallbladder, digestive glands, salivary glands, liver, pancreas) of the ingested food.

Together, these structures have to manage **six essential activities**:

1. **Ingestion:** Eating or drinking nutrients.

**Propulsion:** Movement of the ingested material from the mouth through the GI tract to the anus. In order to change the shape of the organ, smooth muscle in the walls of digestive organs is usually arranged in two layers: an **outer longitudinal layer** and an **inner circular layer**. Where necessary, the muscle layers form **sphincters** that control the movement of GI tract content.

**Peristalsis** is the alternate contraction and relaxation of the two smooth muscle layers. For example, contraction of the longitudinal layer and relaxation of the circular layer of a segment of the small intestine will lead to shortening and dilation of the segment, whereas contraction of the circular layer combined with relaxation of the longitudinal layer leads to constriction and elongation of the segment. Together, they lead to a mixing of the content and a slow forward movement.

2. **Mechanical digestion:** Breaking down the food by physical means, such as chewing.
3. **Chemical digestion:** Breaking down the nutrients in basic units that can be absorbed using strong acid in the stomach and enzymes.
4. **Absorption:** Moving nutrients across the basement membrane of the mucous membrane into the blood or lymph by active or passive transport processes.
5. **Defecation:** Excretion of food content that cannot be broken down and absorbed in the GI tract.

Most digestive organs are located inside the **peritoneal cavity**. As a body cavity not open to the outside, it is lined by a serous membrane called **peritoneum**. The **parietal peritoneum** lines the wall, while the **visceral peritoneum** covers the outer surface of most digestive organs. The peritoneal cavity between the two layers contains lubricating fluid to allow the mobile parts of the digestive tract to move against each other without friction.

Not all organs of the abdominopelvic cavity are located inside the peritoneal cavity. Organs that are surrounded by the peritoneum are called **intraperitoneal** or **peritoneal organs**, while **retroperitoneal organs** are located posterior to the peritoneum. The kidneys, for example, are situated behind the peritoneal cavity and most reproductive organs

are located below it in the pelvis.

The peritoneum also has to hold organs in place and store fat. For that purpose, it forms a double-layered structure called **mesentery** that also provides routes for blood vessels, lymphatics, and nerves.

Digestive organs in the abdominal cavity receive arterial blood from branches of the abdominal aorta. The major arteries are the **hepatic, splenic, left gastric, inferior mesenteric, and superior mesenteric artery**. Venous blood drains via the **hepatic portal circulation** to the liver (see also **Chapter 17 Blood Vessels and Circulation**).

## 22.5 Anatomy & Physiology of the GI Tract

The **alimentary canal** is a continuous and hollowed out tube that twists and turns through the body while being open at both ends — the mouth and the anus. It is also called the **gastrointestinal** or **GI tract** (*gastr(o)-* stomach, *intestin(o)-* intestine), although it does not just consist of the stomach and the intestines. The alimentary canal can be divided into an **upper** (mouth, esophagus, and stomach) and **lower GI tract** (small and large intestine, rectum, and anus).

All organs of the GI tract have **four basic layers or tunics**:

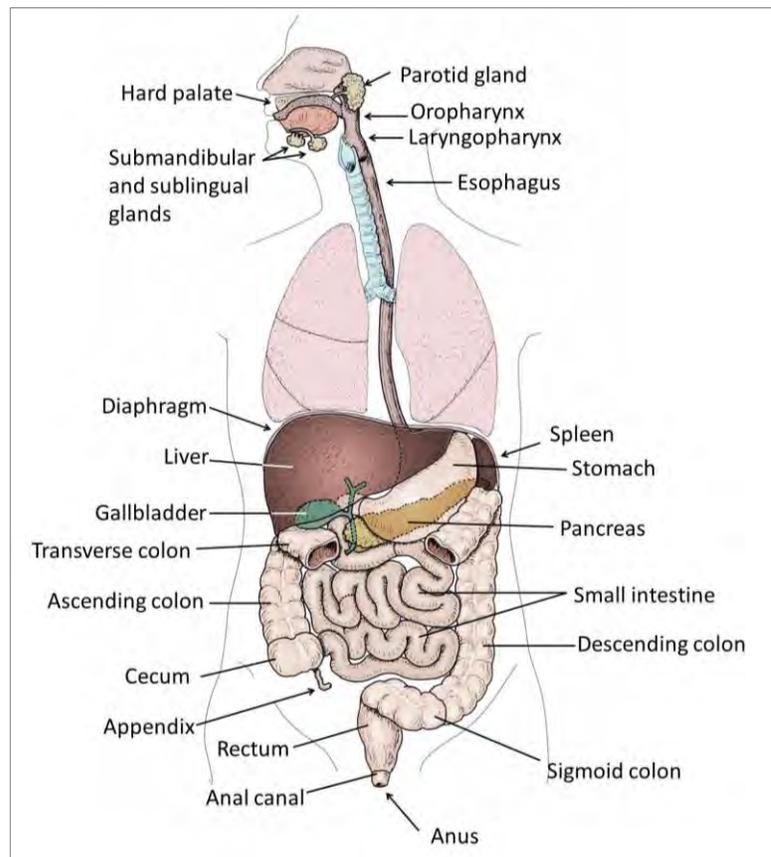
1. The innermost layer, the **mucosa**, has a variety of functions, such as secretion of mucus, digestive enzymes, and hormones, absorption of the end products of digestion, and protection against pathogens.

The mucosa has three layers: epithelium, lamina propria, and muscularis mucosae. The lamina propria consists of loose areolar connective tissue and has capillaries for nourishment and absorption as well as lymphatic follicles (MALT).

2. The second layer, called the **submucosa**, is made of dense connective tissue with blood and lymphatic vessels, lymphoid follicles, and submucosal nerve plexuses embedded.
3. The third layer, the **muscularis externa**, is responsible for segmentation and peristalsis. It has two sublayers of smooth muscle cells, an **inner circular** and an **outer longitudinal layer**. Both layers are regulated by **myenteric nerve plexuses**.

4. The outermost layer, the **serosa**, is identical with the **visceral peritoneum**.

Figure 22.1 Gastrointestinal tract and accessory digestive organs



### Regulatory Mechanism of the GI Tract

As one of the oldest systems of the human body, the digestive system relies heavily on hormones for autoregulation. Chemical messengers from **enteroendocrine cells** in the stomach and small intestine stimulate target cells in the same organ (paracrines) or different organs (hormones).

Table 22.2 Major Hormones of the Digestive System

Hormone	Production site	Release stimulus	Target organ(s)	Effect(s)
Gastrin	G cells of gastric glands	Food in stomach (esp. proteins); ACh	Parietal cells of stomach	Increased HCl secretion

		release by vagus nerve	Stomach	Stimulates gastric emptying
			Small intestine	Contraction of smooth muscles
			Ileocecal valve	Relaxation
			Large intestine	Mass movement
<b>Histamine</b>	Enteroendocrine cells of gastric mucosa	Food in stomach	Parietal cells of stomach	Increased HCl secretion
<b>Serotonin</b>	Enteroendocrine cells of gastric mucosa	Food in stomach	Stomach	Contraction of smooth muscles
<b>Somatostatin</b>	Enteroendocrine cells of gastric and duodenal mucosa	Food in stomach; stimulation by sympathetic fibers	Stomach	Inhibits secretion
			Pancreas	Inhibits secretion
			Small intestine	Inhibits blood flow and nutrient absorption
			Liver and gallbladder	Inhibits bile secretion and contraction
<b>Cholecystokinin [CCK]</b>	Enteroendocrine cells of duodenal mucosa	Fatty chyme; partially digested proteins	Liver	Increased bile secretion
			Pancreas	Increased secretion of enzyme-rich juice
			Gallbladder	Contraction
			Hepatopancreatic sphincter	Relaxation
<b>Secretin</b>	Enteroendocrine cells of duodenal mucosa	Acidic chyme; partially digested proteins and fats; hypotonic or hypertonic chyme	Stomach	Inhibits gastric glands and motility
			Pancreas	Increases production of bicarbonate-rich juice by duct cells; increases CCK action
			Liver	Increases bile production and release
<b>Gastric inhibitory peptide [GIP]</b>	Enteroendocrine cells of duodenal mucosa	Glucose, fatty acids, amino acids in small intestine	Stomach	Inhibits HCl production
			Pancreas, $\beta$ cells	Stimulates insulin release
<b>Vasoactive intestinal peptide [VIP]</b>	Enteric neurons	Chyme with partially digested food	Small intestine	Stimulates buffer secretion; dilates capillaries increasing absorption
			Pancreas	Stimulates secretion of enzymes
			Stomach	Inhibits HCl secretion
<b>Motilin</b>	Enteroendocrine cells of duodenal mucosa	Fasting; also periodically released by neural stimuli	Proximal duodenum	Stimulates migrating motility complex

Signals from the autonomic nervous system modify gastrointestinal activity, depending on our needs. **Parasympathetic impulses stimulate** the activity of the GI tract, whereas **sympathetic impulses inhibit** its activity.

**Parasympathetic fibers** travel via the **vagus nerve fibers** along the esophagus down into the peritoneal cavity. They innervate most digestive organs apart from the second part of the large intestine, which receives fibers from the sacral division. Almost 80% of the parasympathetic nerve fibers are sensory fibers. The postganglionic neurons of the **sympathetic fibers** innervate all digestive organs inside and outside the peritoneal cavity. The nerves contain up to 50% sensory fibers.

The GI tract has **mechanoreceptors** that respond to stretch and **chemoreceptors** that respond to changes in osmo-

larity and pH and the presence of food and end products of digestion. These receptors initiate **reflexes** that **activate or inhibit digestive glands** and **stimulate smooth muscle** to mix and move lumen contents. The GI tract also has **intrinsic and extrinsic controls**, such as:

- **Short reflexes** initiated by **enteric nerve plexuses** (so-called **gut brain**) in response to stimuli in the GI tract.
- **Long reflexes** in response to stimuli inside or outside the GI tract involve CNS centers and autonomic nerves.

Among the reflexes that are part of the autoregulation are **vagovagal reflexes** that control gastric motor and secretory activity, an **enterogastric reflex** that regulates gastric emptying into the duodenum, a **gastroileal reflex** that causes the ileocecal sphincter to relax when the stomach fills up with food or liquids, and a **gastrocolic reflex** that initiates mass movement toward the rectum when the stomach fills up with food or liquids.

The **intrinsic nerve supply** of the GI tract can be regarded as its own **enteric nervous system (ENS)**. It consists of the **submucosal nerve plexuses** that **regulate glands and smooth muscle in the mucosa** and **myenteric nerve plexuses** that **control GI tract motility**. These plexuses are linked to the CNS via **afferent visceral fibers**.

**Myenteric nerve plexuses** are found from the esophagus to the anus between the longitudinal and circular smooth muscle layers. They can stimulate tonic contraction and the frequency and intensity of contraction, while also causing the pyloric, gastroesophageal, and ileocecal sphincters to relax.

**Submucosal nerve plexuses** are located below the mucosa from esophagus to anus. They control secretion, absorption, and contraction of the muscularis mucosae on a local level.

## Mouth

Food enters the digestive tract through the **mouth**. The major part of the mouth is the **oral** or **buccal cavity**, which is surrounded by the **lips**, **cheeks**, **palate** (forms the roof), and **tongue** (forms the floor).

The **hard palate** helps with chewing food, while the **soft palate** has to close off the nasopharynx during swallowing. The **uvula** hangs off of the free edge **at the back end of the palate**. During swallowing, the uvula moves upward and **closes off the nasal passage** so that the food is not pushed up into the nasal cavity.

The **tongue** plays a principal role in repositioning and mixing food during chewing, formation of the so-called **bolus** (food that has been chewed and broken down), and swallowing, speech, and taste. It is attached to the floor of the mouth by the **lingual frenulum**. **Intrinsic muscles** change the shape of the tongue, while **extrinsic muscles**, such as the genioglossus, hyoglossus, and styloglossus, alter the tongue's position.

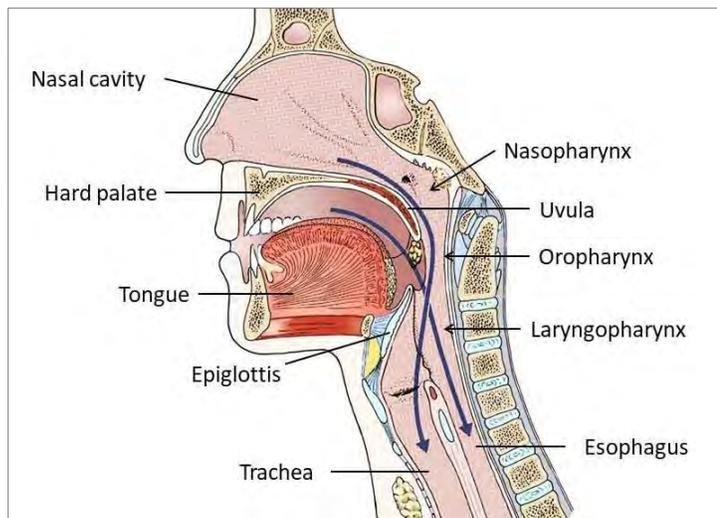
The surface of the tongue bears four kinds of raised projections called papillae (**filiform**, **fungiform**, **(circum)vallate**, and **foliate papillae**). However, only filiform papillae aid in mechanical digestion. The other three house **taste buds** (see **Chapter 14 General & Special Senses**).

We have two sets of **teeth** - 20 **deciduous** or **baby teeth** and 32 **permanent teeth**. All of our teeth, except the third molars or **wisdom teeth**, erupt by the end of adolescence. They can be subdivided into **incisors** for cutting food, **canines** that tear or pierce food, and **premolars** and **molars** with broad crowns and rounded cusps for grinding or crushing food.

The exposed part of a tooth above the **gingiva** or **gum** is called the **crown**. It is covered by the hardest substance in the body, **enamel**. The invisible part below the gum line is the **root**, which is connected to the crown by the **neck**. Teeth are held in place by the **periodontal ligament** in a fibrous joint (**gomphosis**).

The teeth help with mechanical digestion by breaking food down into pieces. This process is called **chewing** or **mastication**. It breaks down food into smaller pieces, mixing it with saliva and preparing it to be swallowed.

Figure 22.2 Mouth and pharynx



**Saliva** is a colorless liquid that moistens the mouth and begins the digestion process. It wets and dissolves food for tasting. Saliva also contains bicarbonate ions (which buffer acidic foods), salivary amylase (which begins chemical digestion of carbohydrates), and lysozyme (which destroys bacteria).

**Intrinsic salivary glands** keep the mouth moist continuously, while **extrinsic salivary glands** produce secretions when ingested food stimulates chemoreceptors and mechanoreceptors in the mouth. The three pairs of extrinsic salivary glands - the **parotid glands**, the **sublingual glands**, and the **submandibular glands** - are located outside the oral cavity proper and use ducts to secrete saliva into the oral cavity.

### Pharynx

From the oral cavity, the food bolus passes posteriorly into the **pharynx**. The pharynx is the part of the throat that is behind the mouth (**oropharynx**) and nasal cavity (**nasopharynx**) and above the esophagus and the larynx (**laryngopharynx**). The nasopharynx is part of the respiratory system only; the oropharynx and laryngopharynx are used as passageways for both air and food. The **epiglottis** serves as a lid to close off the respiratory system (larynx and below) to prevent swallowed food from entering the lungs.

**Swallowing** (or **deglutition**) is a complex process that involves the tongue, soft palate, pharynx, and esophagus. Overall, 22 muscles groups have to be coordinated via control centers in the brain stem. The first phase, called **buccal phase**, starts with voluntary contraction of the tongue. This pushes the bolus into the middle part of the pharynx and the second, involuntary phase, called **pharyngeal-esophageal phase**, is initiated.

### Esophagus

The food bolus continues moving down the GI tract through a muscular tube called the **esophagus** or **gullet**. The esophagus begins at the lower end of the pharynx, passes through the diaphragm via a hole called the **esophageal hiatus**, and connects to the upper portion of the stomach. Food is pushed down the esophagus by peristalsis.

The esophagus has to get the swallowed bolus down to the stomach fast so that the pharynx is empty again and can function as part of the respiratory system. Its muscular layer consists of **voluntary skeletal muscle in the upper 1/3** and **involuntary smooth muscle below**.

The esophagus has two sphincters, an **upper esophageal sphincter** made of **skeletal muscle** and a **lower esophageal** or **gastroesophageal sphincter** (*gastro-* stomach, *esophag(o)-* esophagus) consisting of **smooth muscle**. The lower esophageal sphincter controls the amount of food that can be pushed into the stomach at one time. It also prevents stomach contents from regurgitating back up into the mouth.

Figure 22.3 Parts of the stomach

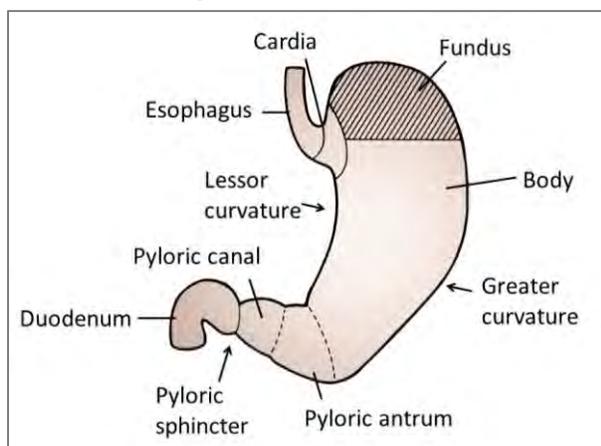
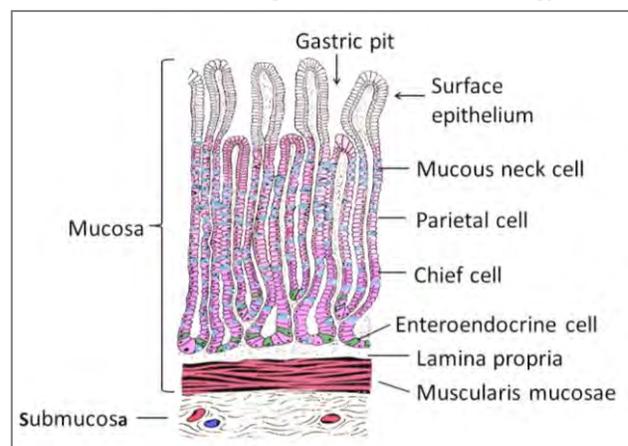


Figure 22.4 Stomach histology



### Stomach

The **stomach** is the size of a small sausage when it is empty; at its fullest it can contain a gallon of food or drink. The **major stomach regions** are:

- **Cardiac region** or **cardia**: The first region just behind the sphincter.
- **Fundus**: A dome-shaped region beneath the diaphragm.
- **Body**: The mid-portion forming most of the stomach.

- **Pyloric region:** Consists of **antrum**, **pyloric canal**, and **pylorus**, which is continuous with the duodenum through the **pyloric sphincter**.

Microscopically, two adaptations to the basic plan of the GI tract can be seen:

1. The **muscularis externa** has an additional **inner oblique layer**, which gives it three layers of smooth muscle.
2. The mucosa has **gastric pits** leading into **gastric glands**. Glands in the fundus and body produce most of the gastric juice, while glands in the pyloric region are more active as endocrine glands.

Gastric glands possess four types of secretory cells:

1. **Mucous neck cells** produce a thin, acidic mucus.
2. **Enteroendocrine cells** secrete paracrines, e.g., **serotonin** and **histamine**, and hormones, e.g., **somatostatin** and **gastrin**.
3. **Chief cells** are also called **peptic cells** because they produce and release the inactive enzyme **pepsinogen** into the stomach lumen. This protein-digesting enzyme (protease) is activated to **pepsin** by hydrochloric acid and by pepsin itself in a positive feedback mechanism.
4. The **parietal cells** produce two secretions – hydrochloric acid and intrinsic factor. **Hydrochloric acid (HCl)** lowers the **stomach pH** down to **1.5-3.5**, which helps denature protein in food, activate pepsin, and kills most bacteria. The hydrogen ion concentration in parietal cell secretions is about one million fold higher compared to blood. The **H<sup>+</sup>-K<sup>+</sup>-ATPase** or **proton pump** is the key player for gastric acid production.

**Intrinsic factor** is a glycoprotein required for absorption of **vitamin B<sub>12</sub>** in the small intestine. **Lack** of it leads to **pernicious anemia**. Intrinsic factor is the only essential substance produced by the stomach.

Secretion of the **gastric glands is regulated by neural and hormonal mechanisms** that occur in three phases:

1. **Cephalic phase:** Sight and thoughts of food and stimulation of smell and taste receptors initiate secretion via the parasympathetic fibers in cranial nerve X.
2. **Gastric phase:** Starts when food or fluid enters the stomach and lasts 3-4 hours on average.
3. **Intestinal phase:** Consists of a brief stimulatory effect as partially digested food enters the duodenum, followed by inhibitory effects (enterogastric reflex and enterogastrones).

**Parietal cells** can be stimulated by three chemical messengers to increase their rate of HCl secretion: **acetylcholine** (ACh, released by vagus nerve fibers), **histamine**, and **gastrin**. All three substances are necessary for maximum HCl secretion. HCl secretion is lowered when enteroendocrine cells in the antrum stop releasing **gastrin** in response to a low pH or when enteroendocrine cells in the duodenum release the hormone **secretin** in response to acid stomach content entering the small intestine.

The stomach must protect itself from the low pH of the acid and the protein-digesting enzymes with a **mucosal barrier** consisting of a layer of **bicarbonate-rich mucus** and tight junctions between epithelial cells. Anything that breaches the mucosal barrier can cause an inflammation of the mucosa (**gastritis**) or lead to erosion of the stomach wall (**ulcer**).

**Rennin** (or **chymosin**) is a proteolytic enzyme that is secreted in early infancy with a maximum secretion during the first few days after birth. It causes milk to curdle in the stomach, which causes the milk to stay longer in the stomach and to be released into the duodenum more slowly.

In response to filling, the stomach stretches to accommodate food and fluid via:

- **Reflex-mediated receptive relaxation** coordinated by the swallowing center of the brain stem.
- **Gastric accommodation**, i.e., stress-relaxation response of smooth muscle.

The stomach smooth muscle has the ability to generate its own **basic electrical rhythm (BER)** of three contractions per minute initiated by **pacemaker cells (cells of Cajal)**. Distension by food and gastrin increases the force of contraction, which is most vigorous near the pylorus. Once the food has been broken down sufficiently, the so-called **chyme** is delivered in ~30 ml spurts into the duodenum.

**Gastric emptying is regulated by enterogastric reflexes** and chemical messengers (**enterogastrones**) that originate in the duodenum. **If the chyme is rich in carbohydrates** it will move quickly through the duodenum and gastric emptying can continue at a normal pace. However, **if the chyme contains fat/lipids** than it will spend more time in the duodenum and gastric emptying must be slowed down.

## Small Intestine

The small intestine is the **major organ of digestion and absorption**. It **stretches 7-14 feet** from the **pyloric sphincter** to the **ileocecal valve** and has three subdivisions called **duodenum**, **jejunum**, and **ileum**.

The **duodenum** is the first portion and can be considered to be the “brain of the small intestine”. It has chemoreceptors that analyze the chemical composition of the chyme and releases chemical messengers to regulate further chemical digestion as well as absorption of nutrients. **Duodenal glands (Brunner glands)** secrete **alkaline mucus** to neutralize the low pH of the chyme.

In the duodenum, secretions from liver and pancreas are mixed with the chyme. The **bile duct**, coming from the liver and gallbladder, joins the **main pancreatic duct** at the **hepatopancreatic ampulla**. Their combined opening into the duodenum at the **major duodenal papilla** is controlled by the **hepatopancreatic sphincter**. If there is a **minor pancreatic duct**, it will create a **minor duodenal papilla**.

The **jejunum** is the middle portion of the small intestine. Its main jobs are digestion of food and absorption of nutrients. The primary function of the third and final portion of the small intestine, the **ileum**, is to complete absorption of the various nutrients from digested food.

Further along the small intestine past the duodenum, absorption of nutrients and water is the main function of the small intestine. There are three **structural modifications** to increase the surface area to increase absorption. **Circular folds** force the chyme to slowly spiral through the lumen. **Villi** are motile finger-like extensions (~1 mm high) of the mucosa. Their epithelium contains absorptive **enterocytes** with **microvilli** that form the so-called **brush border**. They carry digestive enzymes on their surfaces (**brush border enzymes**).

The small intestinal **crypt epithelium** has secretory cells that produce a **slightly alkaline intestinal juice**. It is largely water, enzyme-poor, but contains mucus and aids transport and absorption of nutrients. There are also cells that play a role in defense against pathogens, such as **Paneth cells** and **intraepithelial lymphocytes**. The **Peyer's patches** of the mucosa are part of **mucosa-associated lymphatic tissue (MALT)**.

The small intestine has **intrinsic pacemaker cells** that initiate smooth muscle contractions that mix and move contents slowly and steadily toward the ileocecal valve as long as there is something left in the small intestine. Once the small intestine becomes almost empty, the hormone **motilin** starts **peristaltic waves** that move meal remnants, bacteria, and debris to the large intestine.

**Local enteric neurons** coordinate intestinal motility. Cholinergic sensory neurons may activate the myenteric plexus, which causes contraction of the circular muscle proximally and of longitudinal muscle distally and forces chyme along the tract. The **ileocecal sphincter** relaxes to allow the chyme into the **large intestine**, while the **gastroileal reflex** enhances the force of segmentation in the ileum. **Gastrin** increases the motility of the ileum. Backflow into the ileum is prevented by the **ileocecal valve**.

Figure 22.5 Large intestine

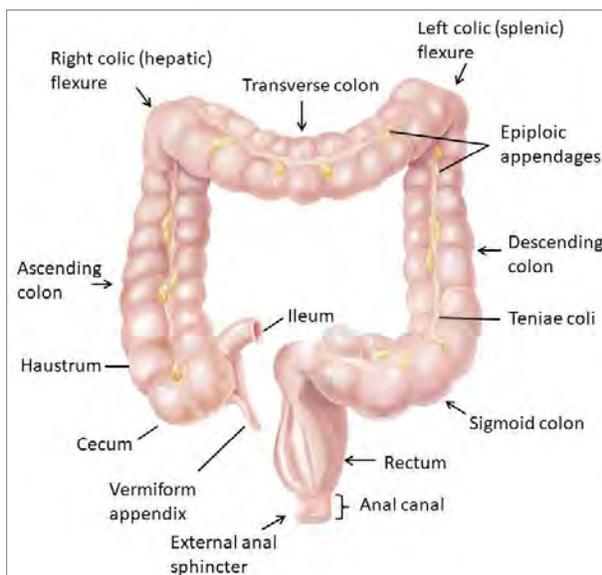
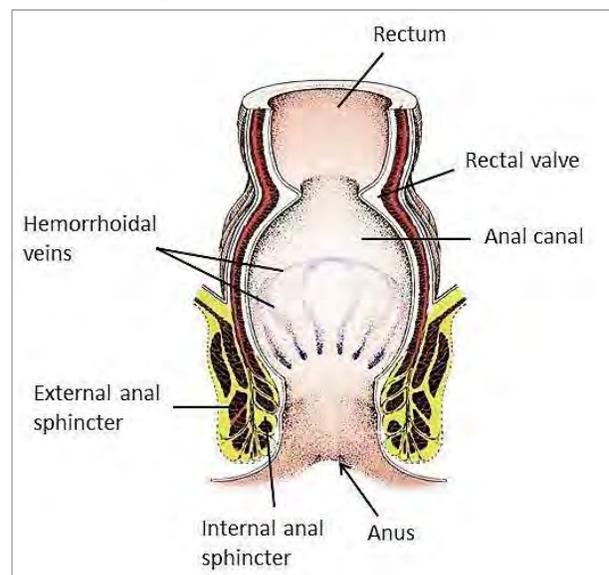


Figure 22.6 Rectum and anal canal



## Large Intestine

The share of food that cannot be digested or absorbed is passed on to the large intestine for final processing. The **large intestine** extends from the end of the small intestine to the anus. It is about twice as wide but only about one-fourth (3–4 feet) as long as the small intestine. Although most of the remaining water and electrolytes will be absorbed in the large intestine, its main function is to move chyme toward the anus, turn it into formed feces, and assist in defecation. Because the absorption of water and electrolytes is not essential to life, parts or all of the large intestine can be removed.

The **cecum** is the blind ending first part of the large intestine (*cecum* = blind). The **vermiform appendix** (*vermiform* = worm-like) is a remnant from earlier evolutionary stages when we lived mainly on plants. The three parts of the **colon** (**ascending**, **transverse**, and **descending colon**) extend from the lower right abdomen to the left lower abdomen. The descending colon is followed by the S-shaped **sigmoid colon**. The **rectum** is about four inches long and straight (*rectum* = straight). It has three **rectal valves** that stop feces from being passed with gas. However, in diarrhea, the liquid stool can fool our body leading into involuntary defecation.

The last segment of the large intestine, the **anal canal**, has two sphincters that have to work together for defecation. The **involuntary internal anal sphincter** is made of smooth muscle, while the **voluntary external anal sphincter** consists of skeletal muscle. The **anus** is the terminus of the intestine after the rectum.

The large intestine has three unique features:

1. **Teniae coli**: Three bands of longitudinal smooth muscle in the muscularis.
2. **Haustra**: Pocket-like sacs caused by the tone of the teniae coli.
3. **Epiplioic appendages**: Fat-filled pouches of visceral peritoneum

**Movement of feces** along the large intestine is accomplished by haustral contractions in response to distension by chyme entering from the ileum and by **3–4 peristaltic waves per day (mass movements)** caused by a **gastrocolic reflex**.

The large intestine is filled with a **bacterial flora** that **ferments indigestible carbohydrates** and **synthesizes vitamin B complex and vitamin K**, which can be absorbed into the body. It has been estimated that for each cell in our whole body, we have 10 bacteria colonizing our large intestine. Researchers have found that there are many different bacteria that together form a so-called **microbiome**. Which bacteria are dominant in a person's microbiome is of great importance for how their body processes food, how many calories they extract from the food they eat, and how their body weight develops, for example.

## Defecation

Defecation is the evacuation or emptying of the large intestine. The process starts with feces being pushed into the rectum by mass movement, which initiates a **spinal defecation reflex**. **Parasympathetic signals** stimulate contraction of the sigmoid colon and rectum and **relax the internal anal sphincter**. However, the **external anal sphincter is under conscious control and allows for controlled defecation**. We learn to control the external sphincter at around two years of age. As long as we have control of this sphincter, we are continent; loss of control leads to incontinence, for example, in spinal cord damage.

## 22.6 Accessory Digestive Organs

The accessory organs of the digestive system assist in digestion. They play a key role in the digestive process but are not actually a part of the tube through which food travels.

### Liver

The liver is a large organ located in the right upper quadrant of the abdomen. It is the largest gland of the human body. Its only direct contribution to digestion is the production and release of bile. However, it is the most important organ for processing absorbed nutrients.

Liver cells (**hepatocytes**) can process nearly every class of nutrients, metabolize alcohol, drugs, hormones, and bilirubin, and produce bile. They play a major role in regulating plasma cholesterol levels (see below) and for the central organ for protein metabolism. Only the liver cells can deaminate amino acids and create urea from ammonia and carbon dioxide. The liver also produces most plasma proteins, such as albumin and blood clotting factors.

The liver **receives blood from two circulations**, oxygen-rich blood via the **hepatic artery** and oxygen-depleted but nutrient-rich blood via the **hepatic portal vein**.

Microscopically, the liver consists of **hexagonal liver lobules**, which are structural and functional units that filter and process nutrient-rich blood. They are composed of plates of liver cells (**hepatocytes**) that are surrounded by leaky capillaries called **liver sinusoids**. **Kupffer cells** are fixed macrophages in these sinusoids. The sinusoids empty into a longitudinal **central vein** that carries the blood towards the **hepatic vein** and finally to the inferior vena cava.

At each corner of the liver lobule is a so-called **portal triad** consisting of three vessels:

- **Bile duct** - receives bile from bile canaliculi.
- **Portal arteriole** - a branch of the hepatic artery.
- **Portal venule** - a branch of the hepatic portal vein.

The **bile ducts** carrying bile down to the duodenum start as **right** and **left hepatic duct** in the **right** and **left lobes** of the liver. They combine to form the **common hepatic duct**, which unites with the **cystic duct** from the **gallbladder** to form the **common bile duct**.

The liver produces approx. 0.9 l of bile a day. **Bile** is a **yellow-green, alkaline solution** containing:

- **Bile salts**: Cholesterol derivatives that function in fat emulsification and absorption.
- **Bilirubin**: A pigment formed from heme during hemoglobin breakdown.
- **Cholesterol, neutral fats, phospholipids, and electrolytes**.

Bile salts go through an **enterohepatic circulation**, i.e., they are released with bile into the duodenum, reabsorbed from the ileum, travel in the hepatic portal blood to the liver and are secreted into the bile again.

Without bile, most fat/lipids end up in the large intestine, where bacteria break down the fat and can cause a foul smelling diarrhea called **steatorrhea** (*steat(o)- fat, -rrhea* discharge).

### Gallbladder

The gallbladder is a thin-walled muscular sac about the size of an egg. It is embedded into the underneath side of the liver. The gallbladder receives preliminary bile from the liver via the **cystic duct**. It stores and concentrates the bile by absorbing its water and ions. When bile is needed in the small intestine, the gallbladder contracts and secretes the bile into the duodenum via the **common bile duct**.

**Bile secretion is stimulated by the secretin**, which is released by duodenal enteroendocrine cells in response to exposure to HCl and fatty chyme.

**Contraction of the gallbladder** is stimulated by **cholecystokinin (CCK)**, which is released by enteroendocrine duodenal cells in response to exposure to proteins and fat in chyme. CCK also causes the hepatopancreatic sphincter to relax.

### Pancreas

The pancreas resembles a feather; it is about six inches long and located behind the stomach. The pancreas is a mixed exocrine-endocrine gland with **mainly exocrine functions**. But, it also has endocrine cells (**islets of Langerhans**) that produce hormones such as **insulin** and **glucagon** (see also **Chapter 15 Endocrine System**).

Figure 22.7 Liver histology

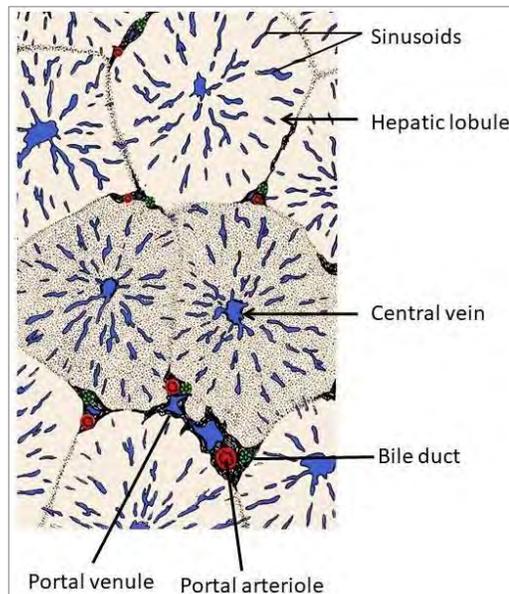
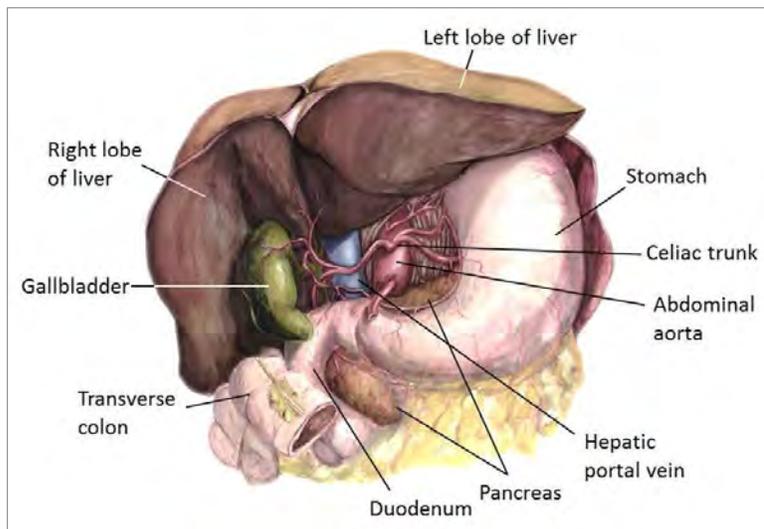


Figure 22.8 Relationship of upper abdominal organs



The **exocrine pancreas** is very important to our digestive system. It secretes a watery, **alkaline pancreatic juice** that contains **electrolytes** (primarily  $\text{HCO}_3^-$  to neutralize acidic chyme) and **enzymes** for chemical digestion of starch (**amylase**), fats (**lipases**), nucleic acids (**nucleases**), and proteins (inactive **proteases** that are activated inside the intestinal lumen).

This digestive juice enters smaller ducts that merge to form the **main pancreatic duct**, which empties into the duodenum along with bile via the **common bile duct**.

The digestive enzymes are critical in digestion of proteins, carbohydrates, and fats; without pancreatic enzymes entering the small intestine, food would be indigestible. The bicarbonate secretion is essential for neutralizing gastric acid in the chyme exiting the stomach.

**Secretion from the exocrine pancreas** is regulated by **cholecystokinin** and **secretin**. CCK induces the secretion of enzyme-rich juice by acini, whereas secretin causes secretion of bicarbonate-rich juice by duct cells. **Vagal stimulation** during the cephalic phase of digestion is a minor stimulus only.

### Check Your Understanding

- Which of the following statements is *incorrect*?
  - We have two sets of teeth - 20 deciduous or baby teeth and 32 permanent teeth.
  - The major part of the mouth is the oral cavity.
  - The stomach is the size of a one-gallon milk carton when it is empty.
  - The epiglottis prevents swallowed food from entering the lungs.
- Which of the following statements is correct?
  - The duodenum is the final portion of the small intestine.
  - The cecum is the blind ending first part of the small intestine.
  - The rectum is about four feet long and s-shaped.
  - The rectum has three valves that stop feces from being passed with gas.
- Which of the following is the primary function of the large intestine?
  - Mechanical digestion
  - Chemical digestion
  - Absorption
  - Feces formation
- Which of the following accessory organs produces a fluid to soften food?
  - Salivary glands
  - Liver
  - Gallbladder
  - Pharynx
- Bile is produced in the \_\_\_\_ and stored in the \_\_\_\_\_.
  - liver, duodenum
  - liver, gallbladder
  - gallbladder, liver
  - stomach, liver
- The teeth used to tear and pierce food are the \_\_\_\_\_.
  - incisors
  - molars
  - canines
  - premolars

1.C 2.D 3.D 4.A 5.B 6.C

## 22.7 Digestion & Absorption

Breaking down the nutrients in the ingested food or fluids to smaller building blocks is essential as this is the only way nutrients can be taken in (absorbed). Malabsorption usually is caused by insufficient chemical digestion.

### Mechanical digestion

Mechanical digestion is the process of breaking down the food by physical means, such as chewing, and happens in three parts of the GI tract:

- Mouth:** The teeth, tongue (keeps food between teeth), and cheek muscles (keep food between teeth) work together to breakdown food. Mechanical digestion is more important for the digestion of vegetables and, especially, for grain and nuts than meat. Chewing (**mastication**) is a partly voluntary, partly reflexive process.
- Stomach:** Most of the mechanical digestion of meat and softer vegetables and fruit happens here. The low pH created by hydrochloric acid denatures proteins, which helps to break down collagen fibers and cell walls. The strong stomach muscle layer with the added inner oblique layer churns the food for hours until it has a thick creamy consistency known as chyme. However, grains and nuts cannot be broken down. Lipids, especially animal fat, are also hardly broken down, but mixed with the protein paste.

- 3. Small intestine:** The small intestinal muscle layer isn't strong enough to create enough force to crush food. It works together with the bile produced and secreted by the liver to break down fat/lipid drops into tiny droplets (**micelles**) in a process called **emulsification**. Emulsification increases the overall surface area of the fat/lipid droop and, thus, the interface between the lipid medium and watery medium manifold. The increased interface makes it possible for lipases to chemically digest lipids; without emulsification, most fat/lipids would end up undigested in the large intestine.

### Chemical digestion

The digestive system uses strong acid in the stomach and enzymes (see Table 22.3) to break down the nutrients into basic units that can be taken into our body (absorbed).

**Table 22.3 Digestive Enzymes**

Enzyme(s)	Origin	Action
Salivary amylase	Salivary glands	Starch → oligosaccharides and disaccharides
Pancreatic amylase	Exocrine pancreas	Starch → oligosaccharides and disaccharides
Pepsin	Chief cells of gastric glands; released as inactive pepsinogen; activated by HCl and pepsin	Protein → large polypeptides
Proteases (trypsin, chymotrypsin, carboxypeptidase)	Exocrine pancreas; all released in inactive form into small intestinal lumen	Large polypeptides → small peptides
Lipases	Exocrine pancreas	Triglycerides → glycerol, short-chain fatty acids, long-chain fatty acids, monoglycerides
Ribonuclease and deoxyribonuclease	Exocrine pancreas	Nucleic acids → pentose sugars, N-containing bases, phosphate ions
Brush border enzymes	Brush border cells in small intestinal mucosa	
Disaccharidases (dextrinase, glucoamylase, lactase, maltase, sucrose)		Disaccharides → monosaccharides Lactose → glucose & galactose Sucrose → glucose & fructose Maltose → glucose
Proteases (aminopeptidase, carboxypeptidase, dipeptidase)		Small peptides → amino acids and some dipeptides and tripeptides
Nucleosidases, phosphatases		Nucleic acids → pentose sugars, N-containing bases, phosphate ions

Chemical digestion also happens in three parts of the GI tract:

- 1. Mouth:** Saliva contains **amylase**, an enzyme that breaks down starch (flour) to sugars (disaccharides). The longer the food stays in the mouth, the more starch will be broken down. Amylase does not act on cellulose (cell walls of lettuce, for example) and similar complex structural carbohydrates. **Salivary amylase** is inactivated by the low pH in stomach fluid. However, during a bigger meal, the food coming into the stomach absorbs the acid initially and the pH will go up. This rise in pH reactivates amylase, and it continues to break down starch. Over time, the pH goes down again, because of the gastric phase of secretion, and amylase will be inactivated.
- 2. Stomach:** **Hydrochloric acid** denatures functional and structural proteins in the food, including bacterial proteins. It also activates **pepsinogen** to **pepsin**, which then starts enzymatic digestion of proteins down to smaller units (peptides). The predigested food released from the stomach into the small intestine is called **chyme**.
- 3. Small intestine:** The small intestine is **the main area for chemical digestion**. The chyme is mixed with **enzyme-rich pancreatic juice**, which contains enzymes to break down all major nutrients, and **bile from the liver and gallbladder** to aid in the emulsification of lipids. The cells of the small intestinal lining (enterocytes) produce **brush-border enzymes** that complete the catabolic processes by breaking down disaccharides to monosaccharide, peptides to amino acids and dipeptides and so on.

## Absorption

Moving nutrients and water from the lumen of the alimentary canal through the mucous membrane into the body involves specific active and passive transport processes. **Only nutrients that make it into our body have a nutritional value.** As long as they are in the lumen of the, GI tract they are still outside of the body.

### Chemical Digestion and Absorption of Carbohydrates

Carbohydrates are **digested** by enzymes **starting in the mouth with salivary amylase**. This process continues until the amylase is inactivated by the low pH in the stomach. During an average meal, approximately half the starch is digested by salivary amylase. The digestive process is continued in the **small intestine** by **pancreatic amylase**. **Brush border enzymes** finally create monosaccharides (mostly glucose) that can be absorbed.

**Absorption** happens via **secondary active transport** (cotransport with  $\text{Na}^+$ ) or **facilitated diffusion** (fructose). Monosaccharides are **transported to the liver via the hepatic portal vein**.

### Chemical Digestion and Absorption of Proteins

Protein **digestion starts in the stomach (pepsin)** and continues in the **small intestine**. **Pancreatic proteases** do most of the work, while **brush-border enzymes** catalyze the final step to **absorbable amino acids** as well as a few dipeptides.

**Absorption** happens via **secondary active transport** (cotransport with  $\text{Na}^+$ ). The amino acids and dipeptides are **transported to the liver via the hepatic portal vein**.

### Chemical Digestion and Absorption of Lipids

Chemical **digestion of lipids is challenging** because they are not water-soluble. Therefore, **emulsification** by bile salts is an **essential pre-treatment**. Without it, most lipids will not be digested and have no nutritional value for the body.

**Neutral fats (triglycerides)** are split by **pancreatic lipases** into **glycerol** and three **fatty acids** or into **monoglycerides** and two **fatty acids**. **Glycerol and short-chain fatty acids are water-soluble** and are **transported to the liver via the hepatic portal vein**.

**Absorption of monoglycerides** and (long-chain) **fatty acids is more complex**. In the first step, they cluster with bile salts and lecithin to form **micelles**. They are released from these micelles and enter **enterocytes**. There they are **recombined to triglycerides** and combine with apolipoproteins to form **chylomicrons**, which enter lymph vessels (**lacteals**) and are transported via the **cisterna chyli** and the **thoracic duct** to the **systemic circulation**.

**Cholesterol** does not undergo enzymatic breakdown but is integrated into micelles and the chylomicrons.

### Chemical Digestion and Absorption of Nucleic Acids

Nucleic acids are broken down by **pancreatic ribonuclease and deoxyribonuclease**. Absorption is via **active transport**. They are water-soluble and are **transported to the liver via the hepatic portal vein**.

### Vitamin Absorption

**Fat-soluble vitamins** (A, D, E, and K) are absorbed together with fat in the small intestine, enter **lacteals**, and are transported to the systemic circulation.

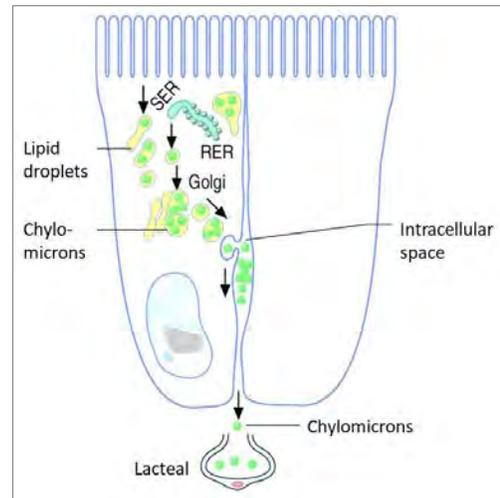
**Water-soluble vitamins** (B complex, C) are absorbed by diffusion or by passive or active transporters. **Vitamin B<sub>12</sub>** binds with **intrinsic factor** and is absorbed by endocytosis.

### Electrolyte and Water Absorption

Electrolyte and water absorption happens **mostly along the length of the small intestine**. **Iron** and  **$\text{Ca}^{2+}$**  are absorbed in the duodenum.  $\text{Ca}^{2+}$  absorption is regulated by vitamin D and parathyroid hormone.

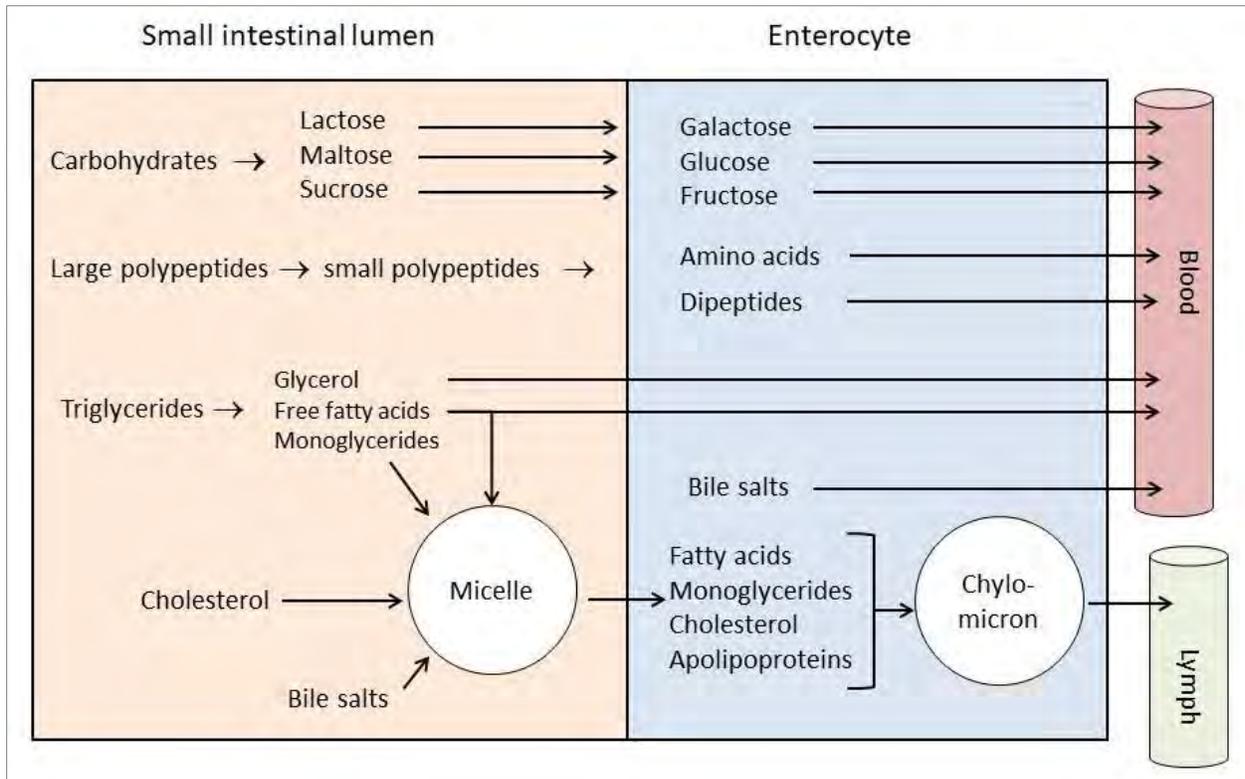
**$\text{Na}^+$**  absorption is coupled with the active transport of glucose and amino acids.  **$\text{K}^+$**  diffuses passively in response to a concentration gradient.

Figure 22.9 Chylomicron formation and release



Most of the **water** (95%) is absorbed in the small intestine by osmosis; the rest is absorbed almost completely in the large intestine. The **total fluid turnover in the digestive system is approximately 9 l/day**, of which only 1.5 l is water taken in with the food or as liquid. The rest is produced by the glands of the digestive system. On average **only 0.1 l (100 ml) are lost each day via the feces**.

Figure 22.10 Digestion and absorption of major nutrients



## 22.8 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	bile	_____	hepat(o)-
2.	liver	_____	cholecyst(o)-
3.	abdomen	_____	proct(o)-
4.	rectum	_____	col(o)-
5.	colon	_____	gastr(o)-
6.	gallbladder	_____	chol(e)-
7.	intestine	_____	enter(o)-
8.	stomach	_____	lapar(o)-

**True/False**

Write "T" on the line if the statement is true and "F" if the statement is false.

1. Cholecystokinin functions to counteract the effect of gastric acid in the small intestine. \_\_\_\_\_
2. The transverse colon is the third part of the large intestine. \_\_\_\_\_
3. The small intestine runs from the pyloric sphincter to the gastroesophageal sphincter. \_\_\_\_\_
4. Bile enters the duodenum through the pancreatic duct. \_\_\_\_\_
5. The gallbladder produces and stores bile. \_\_\_\_\_
6. All organs of the abdominopelvic cavity are located inside the peritoneal cavity. \_\_\_\_\_
7. The small intestine is quite long (approximately 20 feet) and narrow. \_\_\_\_\_
8. The large intestine extends from the mouth to the small intestine. \_\_\_\_\_
9. The liver is an accessory digestive organ. \_\_\_\_\_
10. Vagal stimulation slows down digestive processes. \_\_\_\_\_

**Matching**

Choose the item in column 2 that best matches each item in column 1.

- |                            |  |           |
|----------------------------|--|-----------|
| 1. Enteroendocrine cells   | a) only digestive structure with three muscle layers               | 1. _____  |
| 2. Peristalsis             | b) increases gastric acid secretion                                | 2. _____  |
| 3. Stomach                 | c) produces enzymes for all categories of nutrients                | 3. _____  |
| 4. Parietal cells          | d) causes gallbladder to contract                                  | 4. _____  |
| 5. Pancreas                | e) pocket-like sacks of the colon                                  | 5. _____  |
| 6. Ileum                   | f) controls GI tract motility                                      | 6. _____  |
| 7. Cholecystokinin         | g) release histamine, serotonin and cholecystokinin                | 7. _____  |
| 8. Haustra                 | h) last part of small intestine                                    | 8. _____  |
| 9. Gastrin                 | i) produce intrinsic factor  | 9. _____  |
| 10. Myenteric nerve plexus | j) rhythmic, wavelike propelling mechanism of the alimentary canal | 10. _____ |

**Multiple Choice**

Choose the one alternative that best completes the statement or answers the question.

1. Which of following processes is the function of the smooth muscle layer of the digestive system?
  - a. Ingestion
  - b. Secretion
  - c. Mixing and propulsion
  - d. Absorption

2. Which of the following cells secrete gastric acid?
  - a. Mucous cells
  - b. Parietal cells
  - c. Chief cells
  - d. Serosa cells
  
3. Release of which hormone is stimulated by high levels of dietary fat in the small intestine?
  - a. Pepsin
  - b. Secretin
  - c. Gastrin
  - d. Cholecystokinin
  
4. Which structure regulates the flow of material into the colon?
  - a. Ileocecal sphincter
  - b. Pyloric sphincter
  - c. Appendix
  - d. Sigmoid colon
  
5. The function of the hepatic portal circulation is to \_\_\_\_\_.
  - a. return glucose to the general circulation when blood sugar is low
  - b. carry toxins to the venous system for disposal through the urinary tract
  - c. distribute hormones
  - d. carry absorbed nutrients to the liver for metabolic processing or storage
  
6. Which of the following statements is **not** correct?
  - a. Mechanical digestion is more important for vegetables and especially for grain and nuts than meat.
  - b. Amylase doesn't act on cellulose.
  - c. The large intestine is the main area for chemical digestion.
  - d. Enterocytes release chylomicrons into the lacteals.
  
7. Digestion of which of the following would be affected the most if the liver were severely damaged?
  - a. Lipids
  - b. Proteins
  - c. Carbohydrates
  - d. Starches
  
8. How are most nutrients absorbed through the mucosa of the intestinal villa?
  - a. Simple diffusion
  - b. Bulk flow
  - c. Active transport
  - d. Facilitated diffusion
  
9. Dietary lipids are transported by \_\_\_\_\_.
  - a. low density lipoproteins
  - b. chylomicrons
  - c. very low density lipoproteins
  - d. high density lipoproteins
  
10. Liver cells convert \_\_\_\_\_.
  - a. ammonia into lactic acid
  - b. pyruvic acid into lactic acid
  - c. pyruvic acid into urea
  - d. ammonia into urea

## Chapter 23 Urinary System

### 23.1 Chapter Outline

The urinary system, sometimes referred to as the urinary tract, performs essential functions in order to maintain our body's homeostasis by excreting liquid waste in the form of urine. It removes toxins, metabolic wastes, and excess ions from the blood and regulates blood volume, chemical composition, and pH.

### 23.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- Describe the macroscopic and microscopic anatomy of the kidney.
- Explain the anatomy and physiology of a nephron.
- Describe the location, structure, and function of the ureters, urinary bladder, and urethra.
- Compare the course, length, and functions of the male urethra with those of the female.
- Define micturition and describe its neural control.
- Describe the forces (pressures) that promote or counteract glomerular filtration.
- Compare the intrinsic and extrinsic controls of the glomerular filtration rate.
- Describe the mechanisms underlying water and solute reabsorption.
- Explain how sodium and water reabsorption is regulated in the distal tubule and collecting duct.
- Describe the mechanisms responsible for the medullary osmotic gradient.
- Explain formation of dilute urine versus concentrated urine.
- Describe the normal physical and chemical properties of urine.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 23.3 Combining Forms

Table 23.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 23.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
cyst(o)-	urinary bladder	<i>cystocele</i> = hernia of the bladder through the vaginal wall
glomerul(o)-	glomerulus	<i>glomerulonephritis</i> = inflammation of the glomeruli of the kidneys
lith(o)-	stone	<i>nephrolithiasis</i> = presence of kidney stones
nephr(o)-	kidney	<i>hydronephrosis</i> = swelling of the kidney due to an obstruction of urine flow
pyel(o)-	renal pelvis	<i>pyelolithotomy</i> = surgical removal of stones from the renal pelvis
ren(o)-	kidney	<i>renography</i> = radiography of the kidney
ur(o)-, urin(o)-	urine	<i>urinalysis</i> = analysis of urine
ureter(o)-	ureter	<i>ureterectasis</i> = distention of a ureter
urethr(o)-	urethra	<i>urethrorrhagia</i> = bleeding from the urethra
-uria	urine	<i>nocturia</i> = excessive urination during the night

### 23.4 Anatomy of the Urinary Tract

The **kidneys, ureters, bladder, and urethra** are the organs that make up the urinary system. The adrenal glands sit on top of the kidneys but are not a part of the urinary system.

Almost all physiologic functions of the urinary tract are taken over by the kidneys. They remove **toxins, metabolic wastes, and excess ions** from the blood; regulate **blood volume, chemical composition and pH**; and produce **glucose** via **gluconeogenesis** during prolonged fasting. The kidneys also have **endocrine** functions; they produce **renin** and **erythropoietin** and activate **vitamin D**.

The **ureters** transport urine from the kidneys to the **urinary bladder**, which is just a temporary storage reservoir for urine. The **urethra** transports the urine out of the body.

The **kidneys are located retroperitoneally** at the back of the abdominal cavity in the superior lumbar region. The **right kidney is lower than the left** because of the liver's size. The kidneys are **bean-shaped** organs with a **medial hilum** where ureters, blood vessels, lymphatics, and nerves enter and exit.

Each kidney is supported and protected by **three layers of supportive tissue**:

1. The **renal fascia** forms an anchoring outer layer of dense fibrous connective tissue.
2. The **perirenal fat capsule** is a fatty cushion.
3. The **fibrous capsule** surrounds and protects the kidney itself.

A longitudinal cross-section of the kidney shows an outer **cortex** and an inner **medulla**. The medulla consists of cone-shaped **medullary or renal pyramids** that are separated by **renal columns**.

The tips of the pyramids are called **papillae**. This is the area where urine drips out into smaller cup-shaped structures, the so-called **minor calyces** (singular calyx). Two or more minor calyces combine to form the **major calyces**, which then form the **renal pelvis**.

**Renal arteries** deliver approximately  $\frac{1}{4}$  of the cardiac output to the kidneys each minute. Arterial blood flowing into and venous blood flowing out of the kidneys follow similar paths. Nerve supply is via **sympathetic fibers** from the **renal plexus**.

#### Nephron

The microscopically small nephrons are the **structural and functional units that form the urine**. They have **two main parts**: a tuft of capillaries called the **glomerulus** and a long **tubule**.

The first part of the tubule forms the **glomerular or Bowman capsule** around the glomerulus. The glomerulus together with the capsule forms a so-called **renal corpuscle**. The **glomerular capsule has two layers**, an outer **parietal layer** and an inner **visceral layer**. The visceral layer is made of branching epithelial **podocytes** (*podo-* foot) that cover the outside of the glomerular capillaries. The foot-like extensions of these podocytes form the **filtration slits** that allow filtrate to pass into the **capsular space**.

Figure 23.1 Urinary system

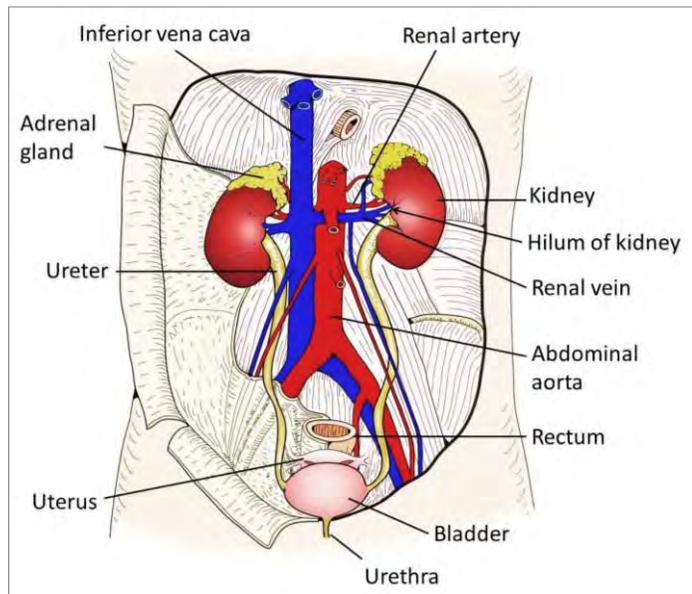
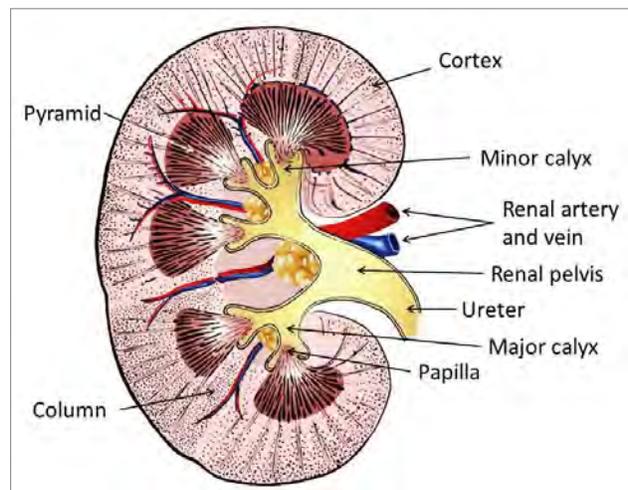


Figure 23.2 Kidney, frontal section



The capsule is followed by the **proximal convoluted tubule (PCT)**, which is **confined to the cortex** and **functions in reabsorption and secretion**.

The next part of the tubule, the **loop of Henle**, has a **descending** and an **ascending limb**. The loop can lead deep into the **medullary pyramids**. The last segment, the **distal convoluted tubule (DCT)**, is again **confined to the cortex**. The DCT **functions more in secretion** than reabsorption.

**Collecting ducts** receive filtrate from many nephrons. The ducts fuse together to deliver urine through the papillae into minor calyces. Collecting ducts have two cell types:

1. **Intercalated cells** function in maintaining the acid-base balance of the body.
2. **Principal cells** help maintain the body's water and salt balance.

**Each kidney has approx. 1 million nephrons.** We lose many of them over our lifetime and, thus, impaired kidney function is common in older people.

Nephron that can be subdivided into two types, depending on their location. **Cortical nephrons** (85% of nephrons) are almost entirely located in the cortex; **juxtamedullary nephrons** have long loops of Henle with extensive thin segments that deeply invade the medulla. They are important in the production of concentrated urine.

Each nephron has three capillary beds. The glomerulus receives blood via an **afferent arteriole** and drains into an **efferent arteriole**. This unique setup allows for **efficient control of filtration**.

**Peritubular capillaries** are low-pressure, porous capillaries **adapted for absorption** that arise from efferent arterioles. They cling to adjacent renal tubules in the cortex and empty into venules.

**Vasa recta** are long, straight vessels that run parallel to the long loops of Henle. They **function in the formation of concentrated urine**.

Nephrons possess a so-called **juxtaglomerular apparatus (JGA)** that is **important in the regulation of filtrate formation and blood pressure**. The JGA has three parts:

1. **Granular** or **juxtaglomerular** or **JG cells** are **mechanoreceptors** that **react to changes in blood pressure**. They contain granules containing the hormone **renin**.
2. A so-called **macula densa** of closely packed cells at the end of the **ascending limb**. These cells are **chemoreceptors** that sense the **NaCl content of the filtrate**.
3. **Extraglomerular mesangial cells** that are interconnected with **gap junctions** and, thus, can **pass signals between macula densa and granular cells**.

Figure 23.3 Nephron and collecting duct

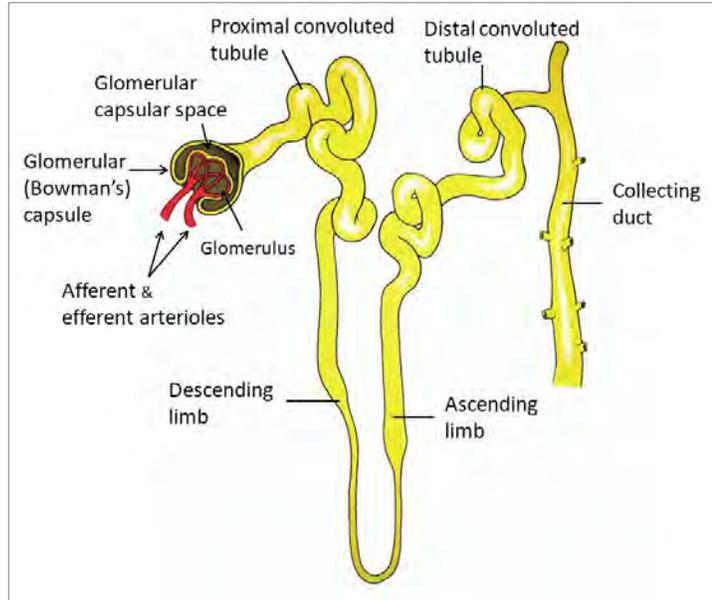
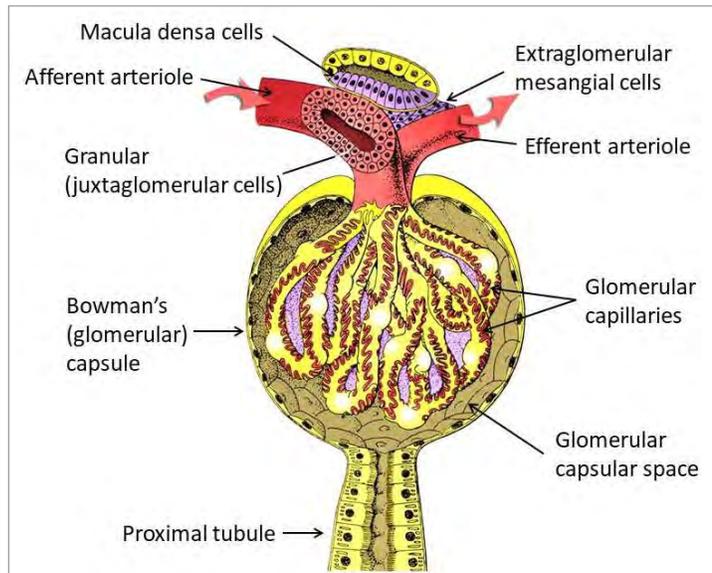


Figure 23.4 Renal corpuscle



The porous **filtration membrane** between the blood and the capsular space **allows for passage of water and solutes but not for large molecules** such as proteins or cells. The membrane consists of the fenestrated endothelium of the glomerular capillaries, a gel-like basement membrane, and the visceral membrane of the glomerular capsule.

Special cells in between the capillary loops of the glomerulus, the so-called **glomerular mesangial cells**, degrade macromolecules that make it through the filtration membrane. The cells can contract in order to change the total surface area available for filtration.

### Ureters, Bladder, and Urethra

The two **ureters** transport urine from the kidneys to the urinary bladder. They are long and narrow tubes, each about 10-12 inches in length. Their walls contain smooth muscle cells that push the urine toward the bladder via peristalsis.

The ureters enter the **base of the bladder** through the posterior wall. There are no valves or sphincters to prevent backflow of urine from the bladder but when the bladder pressure increases, it closes the distal end of the ureters thereby preventing backflow.

The **urinary bladder** is a muscular sac for the temporary storage of urine. Its inside lining consists of a **transitional epithelial mucosa** that collapses when empty and **rugae** appear. The thick wall has three layers of smooth muscle that are collectively called **detrusor muscle**.

The smooth triangular area outlined by the openings for the ureters and the urethra is called the **trigone**. It frequently is the site of bladder infections that can be persistent or become chronic.

The bladder can store about one pint (or close to two beer bottles) of urine before it needs to be emptied. The male bladder is larger than the female bladder, which is why women usually have to go to the bathroom more often.

The **urethra** is a muscular tube with two sphincters:

1. The **involuntary internal urethral sphincter** sits at the bladder-urethra junction. It contracts to open.
2. The **voluntary external urethral sphincter** surrounds the urethra as it passes through the pelvic floor.

The **female urethra is much shorter** (1-1.5 inches) than the male urethra. Its **external urethral orifice** is located superior to the vaginal opening and inferior to the clitoris.

The **male urethra** carries urine and semen at different times. It has three regions: a **prostatic urethra** (1 inch) **within the prostate gland**, a **membranous urethra** (.8 inch) that passes through the **urogenital diaphragm**, and a **spongy or penile urethra** (6 inches) that passes through the penis and opens via the external urethral orifice on the tip of the penis.

The **prostate gland** surrounds the male urethra prior to its entry into the penis. Hence, diseases of the prostate may affect a man's ability to urinate. The outermost opening of the urethra is known as the **urethral meatus**.

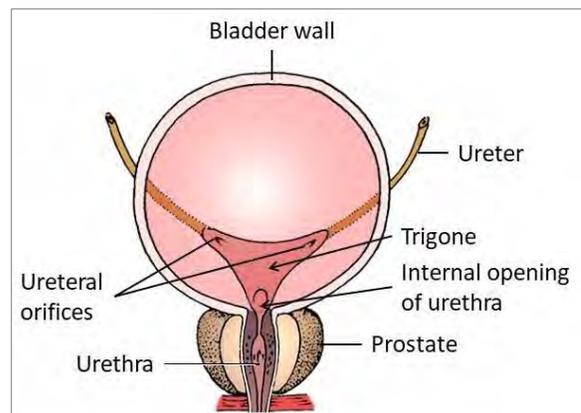
### Urination

Urination or **micturition** is a complicated process. There are two sphincters involved: an **involuntary internal urethral sphincter** at the top of the urethra at the bladder-urethral junction and a **voluntary external urethral sphincter** at the base of the urethra.

In the first step, the **parasympathetic nervous system** sends signals to the bladder wall (detrusor muscle) to contract. This increases the pressure in the bladder and leads to the opening of the involuntary urethral sphincter muscle. But, the outer (external) urethral sphincter muscle is still closed until we allow the muscle to relax. This clears the pathway and urine flows out of the urethra as long as the detrusor muscle maintains the pressure.

Infants have no control over their external urethral sphincter muscle and pass urine whenever the nervous system senses that the bladder is filled. The control centers in the brain that give us control over the external urethral sphincter mature between the ages of two and three. Before this time, potty training will be unsuccessful.

Figure 23.5 Male bladder



### Check Your Understanding

1. Which of the following statements is not correct?
  - a) The urethra extends from the bladder to the outside of the body.
  - b) The female urethra is much shorter.
  - c) The outermost opening of the urethra is known as the trigone.
  - d) At the base of the urethra, is a voluntary external urethral sphincter.
2. Which part of the bladder is frequently the site of bladder infections?
  - a) Trigone
  - b) Detrusor muscle
  - c) Meatus
  - d) Urethra
3. Which structures are the functional units of the kidney?
  - a) Collecting ducts
  - b) Pelvis
  - c) Ureters
  - d) Nephrons
4. Which of the following is not a function of the kidney?
  - a) Temporary storage of urine
  - b) Removal of toxins and excess ions from the blood
  - c) Regulation of blood volume and blood pressure
  - d) Hormone production, e.g., erythropoietin

1.C 2.A 3.D 4.A

### 23.5 Renal Physiology

The kidneys filter the body's entire plasma volume **60 times each day**, i.e., they produce approximately **180 l** or 47.5 gallons of **filtrate per day**. The final product, however, amounts to less than 1% of the filtrate or approximately **1.5 l of urine per day**.

**Urine formation** happens in three steps:

1. **Filtration** is a passive movement of a solute or solution through a porous membrane caused by a pressure difference. If the pores are extremely small, only the solvent (water) will move through. In our glomeruli, the pores are bigger and allow for ions and small molecules to move across, as well. The **filtrate** originally **has the same composition as the blood plasma**, minus the proteins that cannot pass through the filtration slits.
2. **Tubular reabsorption** returns all nutrients (glucose, amino acids), 99% of water, salt, and other components to the blood.
3. **Tubular secretion** selectively adds substances to the filtrate.

#### Glomerular filtration

Glomerular filtration is a **passive mechanical process driven by a net filtration pressure (NFP)**. The main force is the **glomerular hydrostatic pressure**, which is higher (55 mm Hg) than in the other capillaries of the systemic circulation (35 mm Hg). This outward pressure is opposed by two forces, the **colloid osmotic pressure** of the glomerular blood and the **capsular hydrostatic pressure**. Under normal conditions the NFP is approximately 10 mm Hg.

The **glomerular filtration rate (GFR)** is the **volume of filtrate formed per minute** by the kidneys (approximately **120-125 ml/min**). The GFR is directly proportional to:

1. The **total surface area** available for filtration - the more surface area, the higher the GFR.
2. The **permeability** of the filtration membrane - the higher the permeability, the higher the GFR.
3. The **net filtration pressure (NFP)** - the higher the NFP, the higher the GFR.

The **glomerular filtration rate is tightly controlled** by intrinsic and extrinsic mechanisms. **Intrinsic controls**, i.e., **renal autoregulation**, maintain a nearly constant GFR when the MAP is in the range of 80–180 mm Hg. **Myogenic mechanisms react to changes in the blood pressure**. Increased BP leads to constriction of afferent arterioles, which helps maintain normal GFR and protects the glomeruli from a damaging high BP. Decreased BP causes a dilation of afferent arterioles to keep the GFR steady.

The **tubuloglomerular feedback mechanism is a flow-dependent mechanism** directed by the macula densa cells that sense the **NaCl concentration in the filtrate**. If the NaCl concentration is high, then the macula densa cells cause constriction of the afferent arteriole and a reduction in GFR. The opposite occurs if the NaCl content is low.

**Extrinsic controls take over under extreme stress**. Norepinephrine is released by the sympathetic nervous system

and epinephrine by the adrenal medulla. Both cause constriction of afferent arterioles, inhibit filtration, and trigger the release of renin.

Another major **factor that triggers** renin release from the granular cells of the JGA and, thus, starts the **renin-angiotensin mechanism**, is reduced stretch of the cells in **hypotension** (MAP below 80 mm Hg). Renin converts angiotensinogen to angiotensin I, which is then activated to **angiotensin II** by **angiotensin converting enzyme (ACE)**. Angiotensin II has the task of increasing blood pressure back to normal levels. It does this directly by constricting arteriolar smooth muscle, causing the MAP to rise, and indirectly by increasing the blood volume via:

- **Stimulating the reabsorption of Na<sup>+</sup>** by acting directly on the renal tubules and by triggering the **release of aldosterone** from the adrenal cortex.
- Stimulating the hypothalamus to **release antidiuretic hormone (ADH)** and **activating the thirst center** in the hypothalamus to increase fluid input.
- Constricting efferent arterioles, decreasing peritubular capillary hydrostatic pressure, and **increasing fluid reabsorption**.
- Causing glomerular mesangial cells to contract, thus **decreasing the surface area available for filtration**.

### Tubular reabsorption

Tubular reabsorption is a **selective transepithelial process that includes active and passive processes**. It can happen via two routes: a **transcellular route** through the tubule cells and a **paracellular route** through leaky tight junctions between cells. This latter route is limited to water movement and reabsorption of Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, and some Na<sup>+</sup> in the PCT.

**Sodium reabsorption** is a **primary active process using Na<sup>+</sup>-K<sup>+</sup> ATPases** (sodium-potassium pumps) in the basolateral membrane of tubule cells. This reabsorption creates a **concentration gradient** that leads to an **inflow of Na<sup>+</sup>** from the tubule through the luminal membrane by secondary active transport or facilitated diffusion mechanisms.

The concentration gradient for Na<sup>+</sup> also **provides the energy and the means for reabsorbing organic nutrients**, such as glucose and amino acids, **via secondary active transport**.

The number of carriers available for secondary active transport determines the **transport maximum (T<sub>m</sub>)** for a specific substance. When the carriers are saturated, i.e., the transport maximum has been reached, not all of the substance can be reabsorbed and the excess substance is excreted in the urine.

The **threshold** for a substance to turn up in the urine is not the same as the transport maximum. It is the tubular concentration at which the transport maximum is exceeded in some nephrons (not all nephrons have the exact same T<sub>m</sub>) and small amount of a specific substance may show up in the urine.

For example, if a substance has a concentration of 180 mg/ml in the filtrate and the T<sub>m</sub> for this substance is 100 mg/ml, not all of the substance can be reabsorbed and some of it will be excreted in the urine. Examples for substances with a T<sub>m</sub> are glucose and amino acids.

**Water is reabsorbed via osmosis**, aided by water-filled pores called aquaporins. **Cations and lipid-soluble substances follow by simple diffusion** because the flow of water creates a concentration gradient.

The **proximal convoluted tubule (PCT)** is the site of **most obligatory reabsorption** - 65% of water and sodium, all nutrients, most ions and small proteins.

Figure 23.6 Active and passive reabsorption

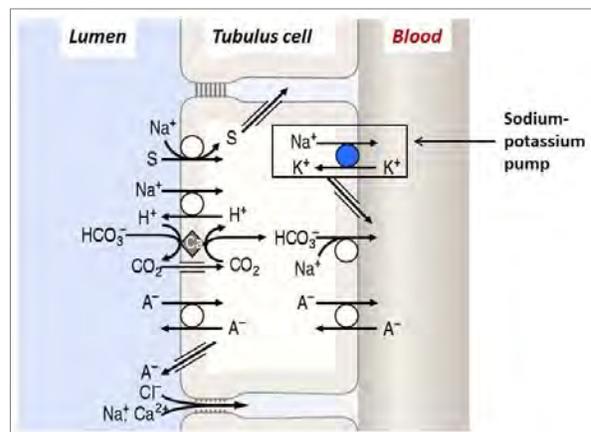
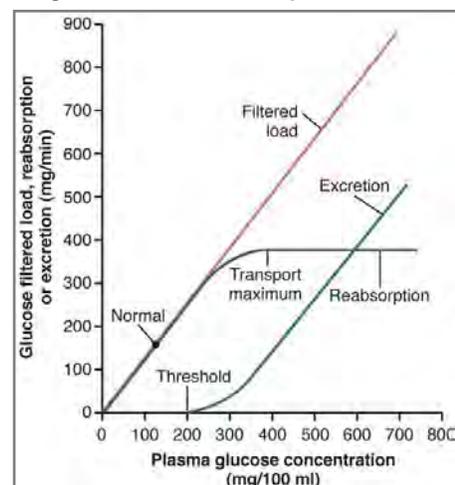


Figure 23.7 Glucose transport maximum



The **loop of Henle** performs the second step of obligatory reabsorption of water in the **descending loop** as well as of sodium, potassium, and chloride ions in the **ascending loop**.

By the time the filtrate enters the **distal convoluted tubule (DCT)**, 90% of the water and most ions have been reabsorbed.

**Further reabsorption** in the DCT and collecting ducts **is facultative and controlled by four hormones**:

- **Parathyroid hormone (PTH)** for  $\text{Ca}^{2+}$ .
- **Aldosterone** and **atrial natriuretic hormone (ANP)** for  $\text{Na}^+$ .
- **Antidiuretic hormone (ADH)** for water.

### Tubular secretion

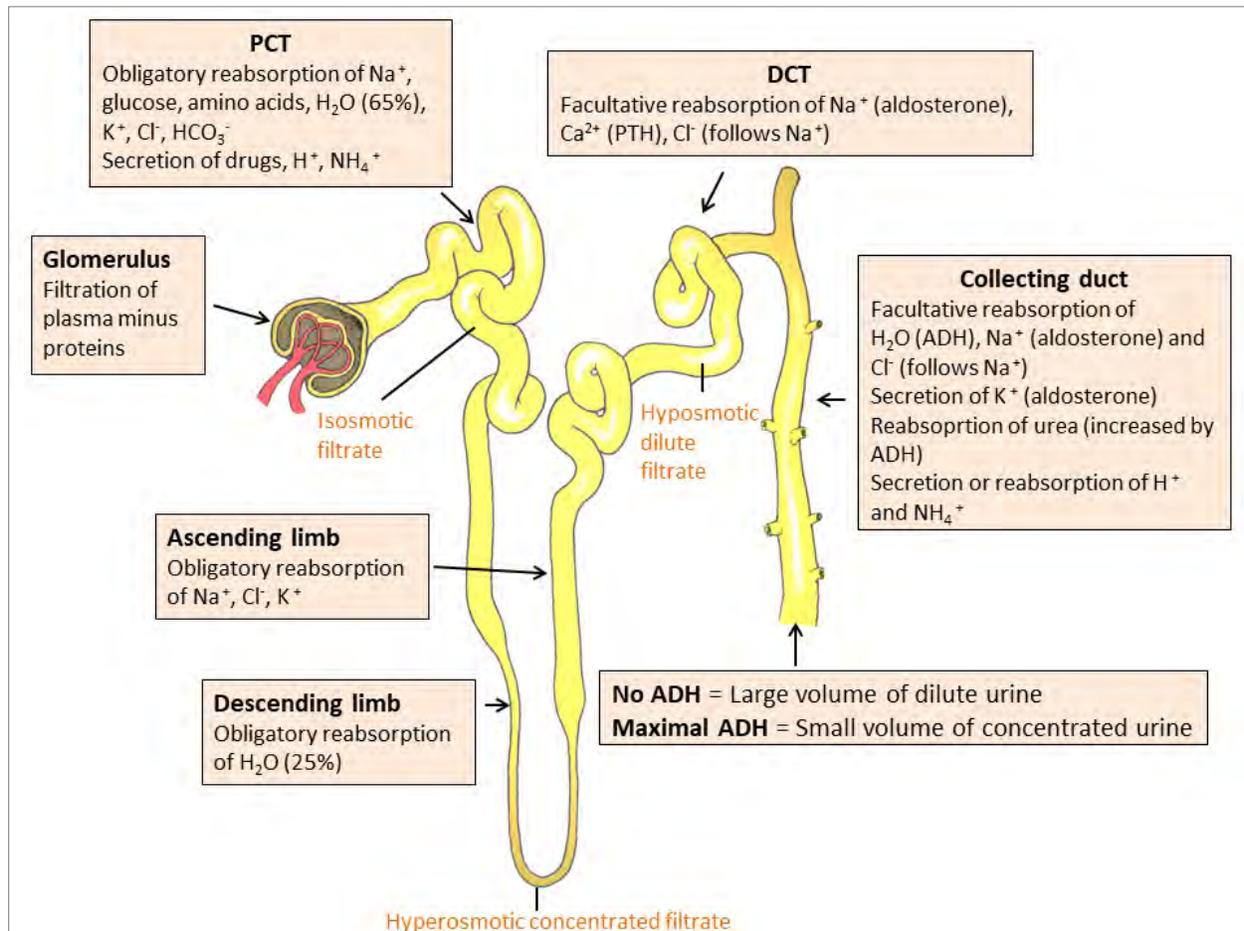
The purpose of tubular secretion is to dispose of substances that are bound to plasma proteins and, thus, will not be in the filtrate, to eliminate undesirable substances that have been passively reabsorbed (e.g., urea and uric acid), to rid the body of excess  $\text{K}^+$ , and to control blood pH by altering amounts of  $\text{H}^+$  or  $\text{HCO}_3^-$  in urine.

### Maintaining plasma osmolality

The kidneys have to **maintain the plasma osmolality at the normal level of ~300 mOsm**. The most important mechanism for this task is the **countercurrent mechanism**, which is **based on an opposite flow of the filtrate in the loop of Henle and the blood in the vasa recta**. This countercurrent establishes and maintains an **osmotic gradient** from the renal cortex through the medulla that allows the kidneys to vary urine concentration.

The **descending limb is freely permeable to water**, which passes out of the filtrate into the hyperosmotic medullary interstitial fluid. The filtrate osmolality increases to ~1200 mOsm. The **longer the loop, the more concentrated the filtrate becomes and the more the urine can be concentrated**. Because of that, the juxtaglomerular nephrons are important for water preservation.

Figure 23.8 Urine formation



The **ascending limb** is impermeable to water but selectively permeable to solutes.  $\text{Na}^+$  and  $\text{Cl}^-$  are passively reabsorbed in the **thin segment** (lower part of ascending limb) but actively reabsorbed in the **thick segment**. The filtrate osmolality decreases to 100 mOsm or less, i.e., the **filtrate osmolality at the end of the loop of Henle is below the plasma osmolality**.

**Urea** moves between the collecting ducts and the loop of Henle. This urea recycling contributes to the high osmolality in the medulla.

When **plasma osmolality is low**, ADH secretion from the hypothalamus ceases, and **in the absence of ADH**, dilute filtrate continues into the renal pelvis as **dilute urine**. When osmolality is high, ADH is released by the hypothalamus, and triggers reabsorption of  $\text{H}_2\text{O}$  in the collecting ducts. This **facultative water reabsorption** of up to 99% of water creates small amounts of **concentrated urine**.

### Renal Clearance

Renal clearance (RC) is **the volume of plasma cleared of a particular substance in a given time**. It is used to determine glomerular filtration rate, to help detect glomerular damage, and to follow the progress of renal disease.

For any substance that is:

- Freely filtered and neither reabsorbed nor secreted by the kidneys, the renal clearance equals GFR and, thus, is 120-125 ml/min.
- Completely reabsorbed, the renal clearance is 0 ml/min.
- Is only partially reabsorbed, the renal clearance is between 0 and 120-125 ml/min.
- Is secreted into the filtrate, the renal clearance is greater than 120-125 ml/min.

**Table 23.2 Renal clearance for different substances**

Substance	Clearance (ml/min)
Glucose	0
Albumin	0
Sodium	0.9
Urea	70
Inulin	125 (= GFR)
Creatinine	140 (used to estimate GFR)

For example, **glucose** is filtered into the filtrate but is completely reabsorbed in the proximal convoluted tubule. Therefore, the plasma has not been cleared of any glucose and the renal clearance of glucose is zero.

**Creatinine**, on the other hand, is filtered but not reabsorbed, which clears 125 ml of plasma (the amount of filtrate produced per minute) of creatinine because the filtrated water will be reabsorbed. However, creatinine is also secreted in addition to being filtered, which is why its renal clearance of 140 ml/min is higher than the glomerular filtration rate.

The renal clearance for **albumin** has to be zero, because it is a protein and, thus, cannot cross the filtration membrane and be excreted in the urine.

### Physical and Chemical Characteristics of Urine

**Fresh urine should be clear** with a **pale to deep yellow color** depending on its concentration. Cloudy urine may indicate a urinary tract infection.

The **odor** of urine should be **slightly aromatic** and the pH is usually slightly acidic (pH 6) with a normal range from 4.5 to 8. Urine develops ammonia upon standing, which will change the smell and the pH. Diet and drugs can change the color and pH of urine without these changes being pathologic.

**Urine consists of 95% water and 5% solutes** such as nitrogenous wastes (urea, creatinine, uric acid) and ions ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{PO}_4^{3-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{HCO}_3^-$ ). Abnormally high concentrations of any constituent or the presence of red or white blood cells or protein in the urine may indicate a pathologic condition.

### 23.6 Test Your Knowledge

#### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	urine	_____	cyst(o)-
2.	urethra	_____	neph(r)o-
3.	ureter	_____	lith(o)-
4.	kidney	_____	urethr(o)-
5.	urinary bladder	_____	pyel(o)-
6.	renal pelvis	_____	-uria
7.	stone	_____	ureter(o)-

#### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Regulation of blood volume and pressure is a major function of the kidney. \_\_\_\_\_
- Glucose is a waste product normally excreted by the kidneys. \_\_\_\_\_
- The proximal convoluted tubules reabsorb 65% of filtered water. \_\_\_\_\_
- The ascending loop of Henle is impermeable to water. \_\_\_\_\_
- The collecting duct is impermeable to water in the presence of ADH. \_\_\_\_\_
- Tubular reabsorption begins in the glomerulus. \_\_\_\_\_
- Proteins are too big to pass through the filtration membrane and should not be found in filtrate. \_\_\_\_\_
- The two ureters transport urine out of the body. \_\_\_\_\_
- Diet and drugs can alter the color of urine. \_\_\_\_\_
- Almost all physiologic functions of the urinary system are performed by the kidneys. \_\_\_\_\_

#### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                   |                                   |          |
|-------------------|-----------------------------------|----------|
| 1. Renal cortex   | a) facultative water reabsorption | 1. _____ |
| 2. Renal pyramids | b) site of filtrate formation     | 2. _____ |
| 3. Bladder        | c) increase urine output          | 3. _____ |
| 4. Urethra        | d) release renin                  | 4. _____ |

- |                          |   |           |
|--------------------------|---|-----------|
| 5. Collecting duct       | e) outer, lighter region of the kidney          | 5. _____  |
| 6. Glomerulus            | f) glomerulus and Bowman's capsule              | 6. _____  |
| 7. Diuretics             | g) triangular regions with a striped appearance | 7. _____  |
| 8. Juxtaglomerular cells | h) bladder inflammation                         | 8. _____  |
| 9. Renal corpuscle       | i) muscular sac for temporary urine storage     | 9. _____  |
| 10. Cystitis             | j) transports urine and sperm in males          | 10. _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- The portion of the kidneys that extends between the renal pyramids is called \_\_\_\_.
  - renal columns
  - renal medulla
  - renal pelvis
  - calyces
- Which is the correct order of filtrate flow?
  - Glomerular capsule, PCT, Loop of Henle, DCT, Collecting duct
  - Loop of Henle, glomerular capsule, PCT, DCT, Collecting duct
  - Ascending limb of Loop, PCT, DCT, Collecting duct
  - Collecting duct, DCT, PCT, Collecting duct, glomerular capsule
- Which structure of the nephron reabsorbs the most substances?
  - Loop of Henle
  - Ascending limb
  - Collecting duct
  - Proximal convoluted tubule
- Which is a process that results in a substance in blood entering the already formed filtrate?
  - Reabsorption
  - Filtration
  - Secretion
  - Excretion
- Increased secretion of aldosterone would result in a \_\_\_\_\_ of blood \_\_\_\_\_?
  - increase, potassium
  - decrease, volume
  - decrease, pH
  - increase, sodium
- Which structure transports urine from the kidney to the bladder?
  - Urethra
  - Ureter
  - Collecting duct
  - Renal pelvis
- Nephrons are found mostly in the \_\_\_\_.
  - renal medulla
  - renal cortex
  - renal capsule
  - renal sinus

8. Which of the following substances would **not** be found in normal filtrate?
- a. Albumin
  - b. Glucose
  - c. Potassium
  - d. Urea
9. Which part of the nephron employs a countercurrent mechanism?
- a. Glomerulus
  - b. Loop of Henle
  - c. Distal convoluted tubule
  - d. Juxtaglomerular apparatus
10. Which of the following would be an abnormal pH for urine?
- a. 5.0
  - b. 6.0
  - c. 8.0
  - d. 11.0



## Chapter 24 Fluid, Electrolyte, and Acid-Base Balance

### 24.1 Chapter Outline

Balancing water intake and output is one of the five survival needs of the human body and, thus, needs to be regulated at all times. Equally important for normal functioning of our body tissues and cells are electrolytes, such as sodium and potassium, and maintaining a normal pH or acid-base balance.

### 24.2 Learning Outcomes

Upon completion of this chapter, students will be able to:

- List the factors that determine body water content and describe the effect of each factor.
- Indicate the relative fluid volume and solute composition of the fluid compartments of the body.
- Describe factors that determine fluid shifts in the body.
- Explain feedback mechanisms that regulate water intake and hormonal controls of water loss in the urine.
- Explain the importance of ionic sodium in the fluid and electrolyte balance of the body, and indicate its relationship to normal cardiovascular system functioning.
- Name mechanisms involved in regulating sodium balance, blood volume, and blood pressure.
- Explain how potassium and calcium balances in plasma are regulated.
- List important sources of acids in the body.
- Name the three major chemical buffer systems of the body and describe how they resist pH changes.
- Describe the influence of the respiratory and urinary systems on acid-base balance.
- Distinguish between acidosis and alkalosis resulting from respiratory and metabolic factors.
- Describe the importance of respiratory and renal compensations to acid-base balance.
- Demonstrate understanding of the content of this chapter by completing the Test Your Knowledge section at the end of the chapter.

### 24.3 Combining Forms

Table 24.1 lists combining forms related to this chapter. For a more complete list, check Commonly Used Adjectives, Prefixes, and Suffixes in the Appendix.

**Table 24.1 Overview of Major Combining Forms**

Combining Form	Meaning	Example(s)
acid(o)-	acid	<i>acidotic</i> = relating to, affected with, or characterized or caused by acidosis
alkal(o)-	alkali	<i>alkalotic</i> = relating to, affected with, or characterized or caused by alkalosis
calc(i)-	calcium	<i>calcipenia</i> = lack of calcium in the body
-capnia	carbon dioxide level (in the blood)	<i>hypercapnia</i> = elevated carbon dioxide level in the blood
-emia	blood condition	<i>hypercalcemia</i> = increased blood calcium level
hyp(o)-	beneath, under, below or less than normal	<i>hypokalemia</i> = lower than normal levels of potassium in the blood
hyper-	above, beyond, more than normal, or excessive	<i>hyperkalemia</i> = higher than normal levels of potassium in the blood
kal(i)-	potassium ( <i>Latin</i> kalium)	<i>hyperkalemic</i> = relating to, affected with, or characterized or caused by hyperkalemia

natr(i)-	sodium ( <i>Latin</i> natrium)	<i>natriuresis</i> = excretion of sodium in the urine
-osis	abnormal condition	<i>acidosis</i> = a condition in which there is too much acid in the body fluids

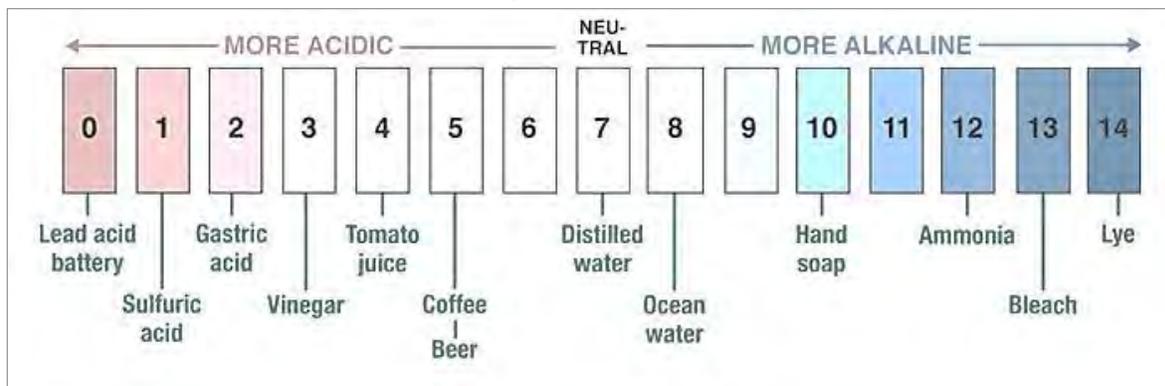
## 24.4 Acids, Bases, and Electrolytes

**Acids are proton donors**, i.e., substances that can give off (donate) protons or hydrogen ions ( $H^+$ ); **bases are proton acceptors**. For example, HCl splits (dissociates) in water into protons ( $H^+$ ) and chloride ions ( $Cl^-$ ), thereby creating **hydrochloric acid**. **Sodium hydroxide** (NaOH) splits into sodium ions ( $Na^+$ ) and hydroxide ions ( $OH^-$ ). It is a base, because the hydroxide ions can accept protons to form water:  $H^+ + OH^- \rightarrow H_2O$ .

**Strong acids and bases** dissociate (split up) completely in water; **weak acids and bases** only partially dissociate. The concentration of hydrogen and hydroxide ions in water is the basis for defining its **acidity** or **alkalinity**. When the concentration of hydrogen and hydroxide ions is the same, the solution is **neutral**; when there are more hydrogen ions than hydroxide ions, the solution is **acidic**; when there are fewer hydrogen ions than hydroxide ions, the solution is **alkaline** or **basic**.

In order to quantify acidity and alkalinity better, the **pH scale** was developed. The scale is based on the  $H^+$  concentration in the solution and **ranges from 0 (highest acidity) to 14 (highest alkalinity)**. A **pH of 7 indicates a neutral solution**. As the pH scale is a logarithmic scale, a change in one unit for the pH represents a 10-fold increase or decrease in the  $H^+$  concentration. For example, a solution with a pH of 5 has 10-times ( $10^1$ ) as many  $H^+$  as a solution with a pH of 6 and 100-times ( $10^2$ ) as many  $H^+$  as a solution with a pH of 7.

Figure 24.1 pH scale



**Electrolytes** are substances that dissociate into positive and negative ions in water. Because they create ions, the watery solution will conduct electricity; hence, the name electrolytes. Positively charged ions are called **cations**; negatively charged ions, **anions**.

**Salts** are electrolytes that contain cations other than  $H^+$ , such as  $Na^+$  (sodium) or  $K^+$  (potassium). They are formed from the reaction between an acid and a base. For example, mixing hydrochloric acid (HCl) with sodium hydroxide (NaOH) generates **sodium chloride** (aka **table salt**) and water:  $HCl + NaOH \rightarrow NaCl + H_2O$ .

Salts enter the human body by ingestion of food and drinks and are lost via perspiration, feces, and urine. They are important for:

- Controlling fluid movements
- Excitability of muscle and nerve cells (see resting membrane potential below)
- Secretory activity
- Membrane permeability

## 24.5 Fluid Balance

Our **body water content depends on our age and gender**. **Infants** have a total body water content of **approx. 75%** and **adults** of **55%**. That percentage goes even further down to **45% in old age**. **Men** have a higher water content (**60%**) than **women** (50%) because they have a higher muscle mass.

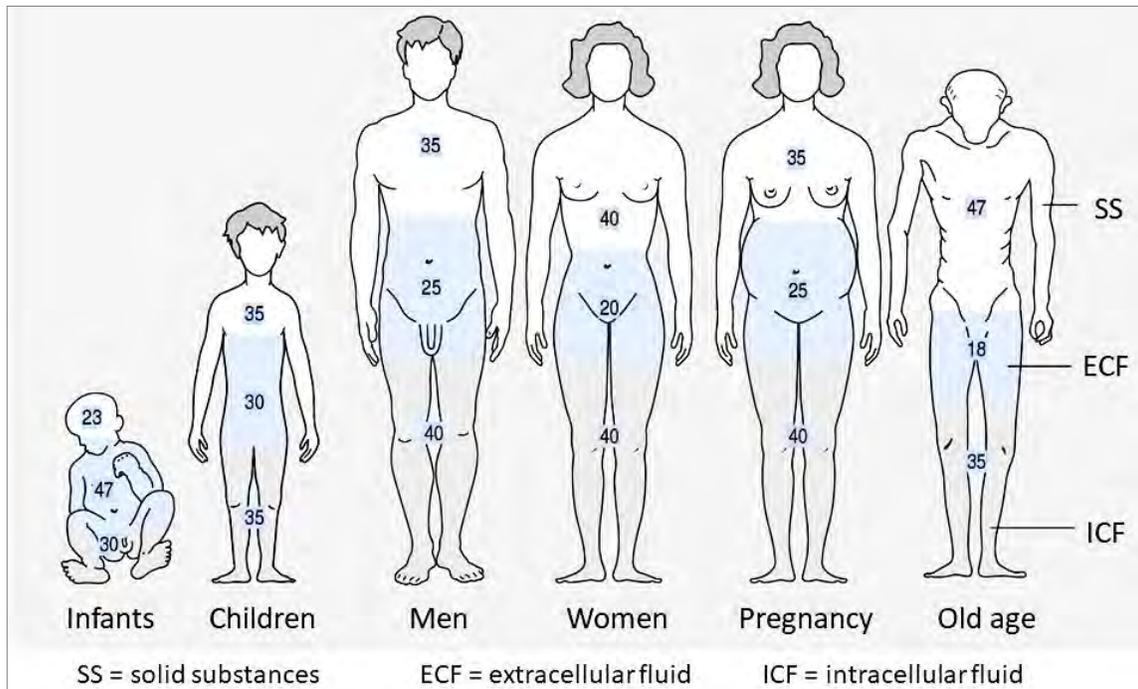
Based on these percentages, the total body water for a male weighing 150 lbs. is **90 lbs.** or **40 l** (10.5 gallons) and a

woman with a body weight of 120 lbs. has **60 lbs.** or **27 l** (7 gallons) of total body water.

There are **two main fluid compartments** in our body:

1. The **intracellular fluid (ICF) compartment** makes up 2/3 of the total body water.
2. The **extracellular fluid (ECF)** compartment makes up 1/3 of the total body water. The ECF is further subdivided into **plasma** (20% of the ECF) and **interstitial fluid (IF, 80% of the ECF)**.

**Figure 24.2 Body water content [%] throughout life**



**All body fluids consist mainly of water.** The substances dissolved in the water, the so-called **solutes**, can be subdivided into **electrolytes** (see above) and **nonelectrolytes**. Because **electrolytes** are much more numerous (see table 24.2), they **have greater osmotic power than nonelectrolytes**. They contribute to fluid shifts and determine the chemical and physical reactions of body fluids.

The **electrolyte concentration is expressed in milliequivalents per liter (mEq/l)**, which is a measure of the number of electrical charges per liter of solution. For single charges ions, such as  $\text{Na}^+$  and  $\text{K}^+$ , 1 mEq = 1 mOsm; for bivalent ions, such as  $\text{Ca}^{2+}$ , 1 mEq = 1/2 mOsm, and so on.

**Each fluid compartment has a distinctive pattern of electrolytes.** The major cation ion in the **ECF** is sodium ( $\text{Na}^+$ ), the major anion is chloride ( $\text{Cl}^-$ ). **Inside cells**, potassium ( $\text{K}^+$ ) is the major cation and hydrogen phosphate ( $\text{HPO}_4^{2-}$ ) is the major anion.

The bulk of **nonelectrolytes**, i.e. substances that do not dissociate in water, consists of proteins, phospholipids, cholesterol, and neutral fats.

**Table 24.2 Concentration of Electrolytes and Nonelectrolytes in Extracellular and Intracellular Fluids**

Substance	Plasma	Interstitial fluid	Intracellular fluid
$\text{Na}^+$	142	139	14
$\text{K}^+$	4.2	4.0	140
$\text{Ca}^{2+}$	1.3	1.2	0
$\text{Mg}^{2+}$	0.8	0.7	20
$\text{Cl}^-$	108	108	4

HCO <sub>3</sub> <sup>-</sup>	24	28.3	10
Phosphates	2	2	11
Lactate	1.2	1.2	1.5
Protein	1.2	0.2	4
Phosphocreatine	--	--	45
Carnosine	--	--	14
Urea	4	4	4
<b>Total mOsm/l</b>	<b>301.8</b>	<b>300.8</b>	<b>301.2</b>

**Fluid movement among the different compartments** is regulated by osmotic and hydrostatic pressures. The **osmolality of the body fluids is kept almost equal at all times** by substantial two-way osmotic flow of water, i.e., **a change in the solute concentration in one compartment leads to net water flow into or out of all compartments.**

Water movement across the selectively permeable cell membrane along a concentration gradient is called **osmosis**. Some water can diffuse through the plasma membrane, but the bulk uses water channels called **aquaporins**. The movement of the water is caused by a difference in the solute concentration in the water.

Water concentration is determined by solute concentration because solute particles displace water molecules; i.e., the higher the solute concentration, the lower the water concentration. Therefore, **water moves from the side of lower solute concentration to the side with higher solute concentration.**

The concentration of the solute particles in a solution can be measured as:

- **Osmolarity** = number of solutes in 1 liter of solution. Expressed as osmol/l or Osm/l.
- **Osmolality** = number of solutes in 1 kg of solvent. Expressed as osmol/kg or Osm/kg.

Because the concentration of solutes in our body fluids is rather low (~300 mOsm), there is no measurable difference between osmolarity and osmolality, and they are often used interchangeably. However, the correct term is osmolality.

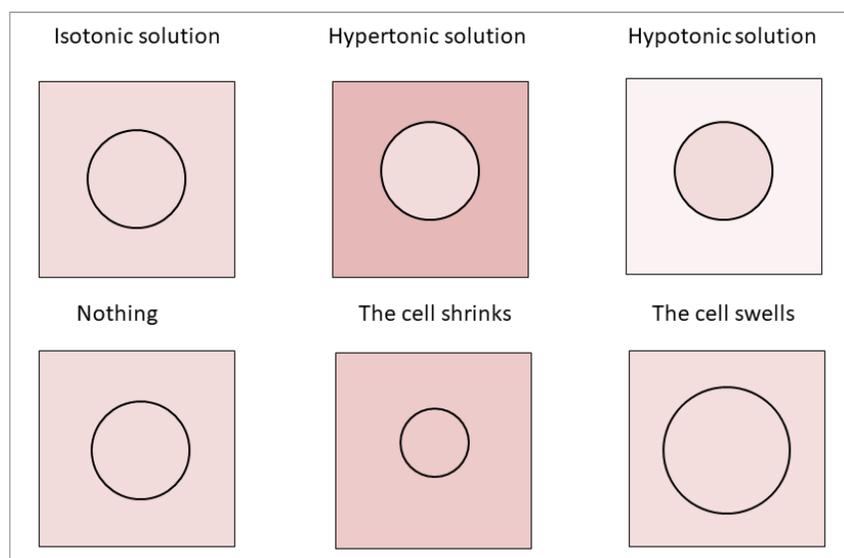
When solutions of different osmolality are separated by a semipermeable membrane that allows only water to move across, osmosis occurs until equilibrium is reached.

Inside the body, osmosis causes water to enter or leave cells. The changes in cell volume and concentration of solutes inside the cells disrupt cell function.

**Tonicity** is the ability of a solution to cause water to flow into the cell or to flow out of the cell.

- **Isotonic solutions** have the same solute concentration as that of the cytosol. Thus, no osmosis will occur.
- **Hypertonic solutions** have a greater solute concentration than the cytosol. Water will move out leading to shrinkage of the cell.
- **Hypotonic solutions** have a lower solute concentration than the cytosol. Therefore, water moves into the cell causing swelling and, eventually, cell lysis.

**Figure 24.3** What happens to the size/volume of a cell when placed in solutions of different tonicity?



**Water balance requires that water intake equals water output.** The **main sources for water** are beverages and food, but we also produce metabolic water. The **body loses water** via the urine, insensible water loss (lungs, skin), sweat, and feces. The average adult has a water turnover of about 2500 ml/day.

**Table 24.3 Average Daily Water Balance**

Intake		Output	
Source	Amount/Percentage of total	Loss	Amount/Percentage of total
Beverages	1500 ml/60%	Urine	1500 ml/60%
Food	750 ml/30%	Insensible loss via skin/lungs	700 ml/28%
Metabolism	250 ml/10%	Sensible loss via sweat	200 ml/8%
		Feces	100 ml/4%
<b>total</b>	<b>2500 ml</b>		<b>2500 ml</b>

The **hypothalamus** has **osmoreceptors** that **measure plasma osmolality**. If the measured value exceeds the norm by more than 2-3%, the **thirst center** is activated. The thirst center is also stimulated by **angiotensin II**, signals from **baroreceptors**, a **dry mouth**, and a **substantial decrease in blood volume or pressure** (see also **Chapter 18 Blood Vessels and Circulation**). Drinking water or other relief of a dry mouth, as well as activation of stomach and intestinal stretch receptors, **inhibits the thirst center**.

**Water loss** can be subdivided into **obligatory loss** via lungs, skin, feces, and urine (at least 500 ml/day), and **facultative loss** that depends on our activity, emotional state, ambient conditions, and so forth.

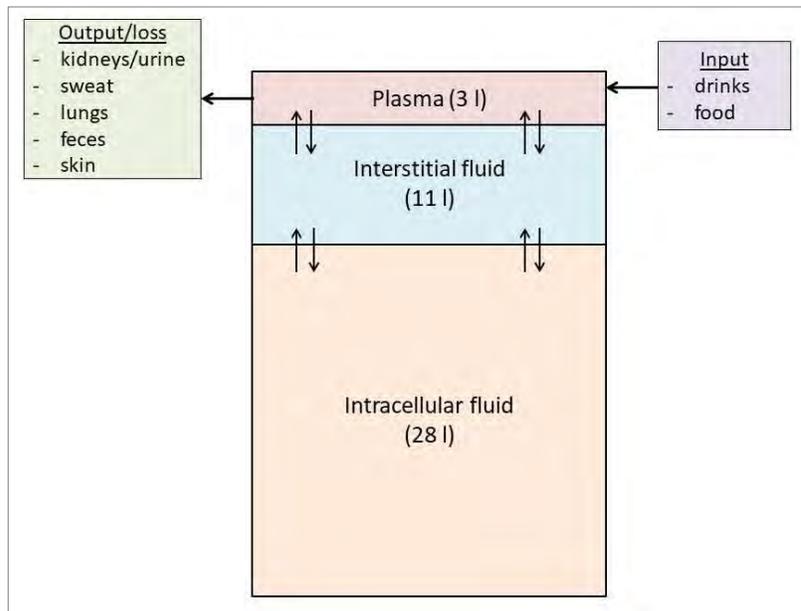
The **hormone in charge of regulating water output and conservation is the antidiuretic hormone (ADH)**. ADH is produced in the hypothalamus and stored and released by the posterior pituitary (see also **Chapter 15 Endocrine System**). ADH release is triggered by signals from hypothalamic osmoreceptors. Substantial changes in blood volume or pressure can also trigger or inhibit ADH release.

**Water reabsorption** in the collecting ducts **is proportional to ADH release**. Low levels of ADH lead to the formation of a high volume of dilute urine and our body water content decreases. High ADH release has the opposite effect (see also **Chapter 23 Urinary System**).

**A negative fluid balance**, i.e., water output exceeds water intake, **causes dehydration**. **Water loss may be** due to hemorrhage, severe burns, prolonged vomiting or diarrhea, profuse sweating, water deprivation, and diuretic abuse. Symptoms of dehydration are thirst, dry flushed skin, and oliguria. Severe dehydration may lead to weight loss, fever, mental confusion, and hypovolemic shock.

The effects of a **positive water balance** depend on the osmolality of the ingested fluid. If we **ingest water only in large quantities** with a short period of time or are in renal failure, a condition called **hypotonic hydration** develops. Dilution of the ECF leads to lower sodium levels (**hyponatremia**), which causes a net flow of water into the cells. This water influx can cause severe metabolic disturbances and even death.

**Figure 24.4 Fluid compartments and water balance**



An **accumulation of interstitial fluid with tissue swelling** is called **edema**. Any factor that increases the flow of fluid from the capillaries into the interstitial fluid or prevents the return of fluid from the interstitial fluid into the blood can cause edema. The **most common causes** of edema are high blood pressure, increased capillary permeability (e.g., in inflammation), blockage of blood vessels, incompetent venous valves, congestive heart failure, and high blood volume (see also Frank-Starling law of bulk flow in **Chapter 18 Blood Vessels and Circulation**).

A **decrease of the colloid osmotic pressure** of the plasma also leads to diminished return of fluid into the blood and edema. Blockage or surgical removal of lymph vessels disrupts lymph drainage and causes **lymph edema**. Because of the gradual accumulation of protein in the IF, more and more fluid is moving from the blood into the IF, resulting in low blood pressure and severely impaired circulation.

### Check Your Understanding

- The major physiological factors that triggers thirst is \_\_\_\_\_.
  - a rise in plasma osmolality
  - drinking caffeinated beverages
  - becoming overly agitated
  - a dry mouth from speaking in public
- Extracellular fluid in the human body is composed of all of the following *except* \_\_\_\_\_.
  - lymph and interstitial fluid
  - cytosol
  - cerebrospinal fluid
  - blood plasma
- The movement of fluids between cellular compartments \_\_\_\_\_.
  - is regulated by osmotic and hydrostatic forces
  - involves filtration
  - requires ATP for the transport to take place
  - requires carrier proteins
- The fluid link between the external and internal environment is the \_\_\_\_\_.
  - lymph
  - plasma
  - intracellular fluid
  - interstitial fluid

1.A.2.B.3.A.4.B

## 24.5 Electrolyte Balance

As already mentioned above, electrolytes are solutes that dissociate into ions in water, for example, salts, acids, and bases. However, the term electrolyte balance usually refers only to salt balance.

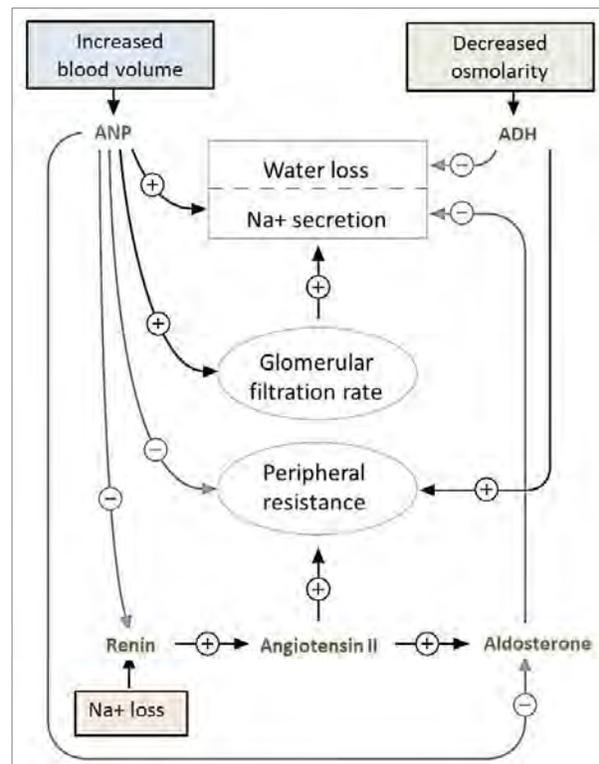
**Salts** are electrolytes that contain cations other than H<sup>+</sup>, such as Na<sup>+</sup> (sodium) or K<sup>+</sup> (potassium). Salts enter the body by ingestion in food and drinks, and are lost via perspiration, feces, and urine. Salts are important for controlling fluid movements (see above), excitability of muscle and nerve cells (see **Chapter 2 Basic Sciences Review**), secretory activity, and membrane permeability.

### Sodium

Sodium is **the most abundant cation in the ECF** with a concentration of approximately 140 mOsm/kg or 140 mEq/l (see table 24.2 above). Because its positive charge has to be balanced by an anion, such as chloride (Cl<sup>-</sup>), sodium salts (mostly NaCl) contribute 280 mOsm of the total 300 mOsm of solute concentration in the ECF. Therefore, **any change to the sodium concentration will have a marked effect on plasma osmolality as well as the water balance between the different compartments.**

Because of its high concentration in the ECF and its low concentration inside the cells (14 mEq/l), sodium leaks into the cells and is pumped out again by Na<sup>+</sup>-K<sup>+</sup> pumps.

Figure 24.5 Hormonal control of blood pressure and sodium levels



Any change in the  $\text{Na}^+$  concentration in any compartment leads to an osmotic flow of water, i.e., the  **$\text{Na}^+$  content of a compartment or the body overall may change but the  $\text{Na}^+$  concentration remains stable**. This also explains why **an increased  $\text{Na}^+$  intake increases blood volume and pressure**.

There are no receptors that monitor  $\text{Na}^+$  levels in body fluids (the chemoreceptors in the macula densa only check the tubular filtrate, which is physiologically outside of the body!). Thus,  **$\text{Na}^+$  levels are controlled together with fluid levels linked to blood pressure and blood volume control mechanisms**. If one or both of those two parameters goes down,  $\text{Na}^+$  reabsorption goes up.

The sodium in the renal filtrate is reabsorbed by **obligatory reabsorption** in the proximal convoluted tubule (65%) and the ascending limb of the loop of Henle. Reabsorption of the remaining  $\text{Na}^+$  is controlled by two hormones, **aldosterone** from the adrenal cortex and **atrial natriuretic peptide (ANP)** from the heart.

The main trigger for aldosterone release is the **renin-angiotensin mechanism**. **Renin is released from granules of the granular cells** of the juxtaglomerular apparatus (JGA) in response to decreased stretch in low blood pressure, stimulation by the sympathetic nervous system, and decreased filtrate osmolality.

Renin indirectly catalyzes the formation of **angiotensin II**, which prompts **aldosterone release** from the adrenal cortex. Because of this connection, the mechanism is also called the **renin-angiotensin-aldosterone system (RAAS)**. Aldosterone release is also triggered by elevated  $\text{K}^+$  levels in the ECF (see below).

**Aldosterone targets** the collecting ducts (**principal cells**) and the **distal convoluted tubule** of the nephron. It promotes synthesis of luminal  $\text{Na}^+$  and  $\text{K}^+$  channels as well as of basolateral  $\text{Na}^+$ - $\text{K}^+$  ATPases. Because this takes time, aldosterone **brings about its effects slowly** (hours to days) and cannot be used for short-term blood pressure control.

**Atrial natriuretic peptide (ANP)** is released by atrial cells of the heart in response to increased stretch (high blood pressure or volume). ANP **lowers blood pressure and blood volume** by decreasing the ADH, renin, and aldosterone production and by increasing the excretion of  $\text{Na}^+$  and water. ANP also increases vasodilation directly and indirectly by decreasing production of angiotensin II.

Three other hormones influence the  $\text{Na}^+$  balance as well:

1. **Estrogens** increase  $\text{Na}^+$  reabsorption leading to water retention during the menstrual cycle and pregnancy.
2. **Progesterone** decreases  $\text{Na}^+$  reabsorption and promotes loss of  $\text{Na}^+$  and water.
3. **Glucocorticoids** are structurally very close to aldosterone and, therefore, have similar mineralocorticoid effects, i.e., they increase  $\text{Na}^+$  reabsorption and can cause edema formation.

Cardiovascular **baroreceptors** alert the brain of an increase in blood volume or pressure. This leads to fewer sympathetic impulses to the kidneys, dilation of the glomerular afferent arterioles, increased GFR, and increased loss of  $\text{Na}^+$  and water.

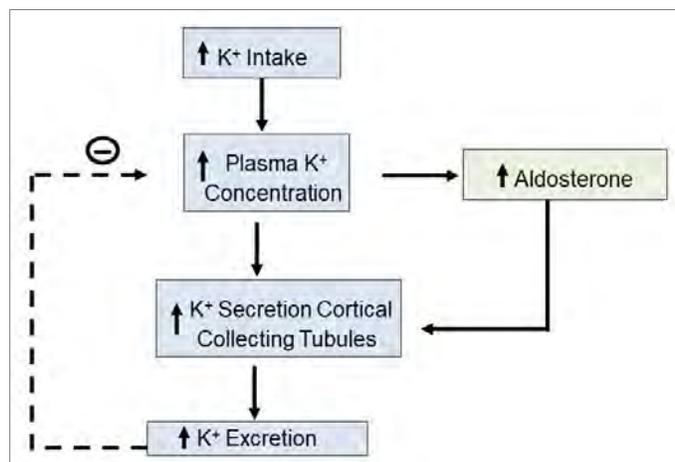
### Potassium

Potassium has a high concentration inside the cells (140 mEq/l) and a low concentration in the ECF (4-5 mEq/l). Because of its importance for the resting membrane potential (RMP), **changes to the ECF concentration of potassium will affect the function of neurons and muscle cells, especially cardiac muscle cells**.

An increase in the ECF concentration (**hyperkalemia**) will lead to less  $\text{K}^+$  moving out of the cell, and to the RMP being less negative (**depolarization**) and, subsequently, a **decreased excitability**. When the ECF concentration goes down (**hypokalemia**), more  $\text{K}^+$  will move out of the cell, the RMP will become more negative (**hyperpolarization**) and the **cells become nonresponsive**.

$\text{K}^+$  and  $\text{H}^+$  move in opposite directions to maintain cation balance. Therefore, **changes in the acid-base balance also have an influence on the resting membrane potential and the activity of excitable cells** (see below).

Figure 24.6 Regulation of potassium secretion



The **potassium balance** is controlled in the **cortical collecting ducts** by changing the amount of potassium secreted into filtrate. **High  $K^+$  content of the ECF stimulates principal cells to secrete  $K^+$** ; when  $K^+$  levels are low, intercalated cells reabsorb  $K^+$  from the filtrate.

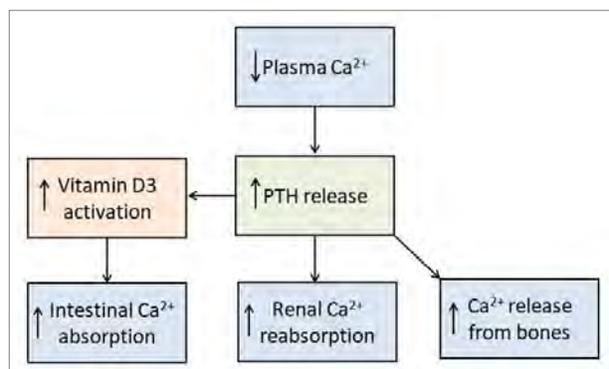
**Increased  $K^+$  plasma levels cause release of aldosterone** from the adrenal cortex and **secretion of  $K^+$**  into the urine in exchange for  $Na^+$ . Because of the still comparatively low potassium levels in the plasma (5.5-6 mEq/l), this exchange has almost no effect on the sodium level.

### Calcium

The **calcium balance** is regulated by two hormones:

- Calcitonin** from the thyroid is released in response to increased  $Ca^{2+}$  levels. It activates **osteoblasts**, which take  $Ca^{2+}$  out of the blood and deposit it as new matrix in the bone.
- Parathyroid hormone (PTH)** is released from the parathyroid glands in response to low  $Ca^{2+}$  levels. PTH promotes an increase in calcium levels by:
  - **Stimulating osteoclasts** to digest bone matrix.  $Ca^{2+}$  and phosphate are released into the blood.
  - **Enhancing the reabsorption of  $Ca^{2+}$**  and secretion of phosphate by the kidneys.
  - **Promoting the activation of vitamin D** by the kidneys and indirectly increasing **absorption of  $Ca^{2+}$  by the intestinal mucosa**.

Figure 24.7 Response to decreased plasma calcium



### Anions

**Chloride ( $Cl^-$ )** is the **major anion in the extracellular fluid**. **Inside the cells, phosphates and proteins** are the main anions. Chloride helps maintain the osmotic pressure of the blood. Almost all chloride (99%) is reabsorbed in the kidneys under normal pH conditions. When acidosis occurs, fewer chloride ions are reabsorbed.

## 24.7 Acid-Base Balance

The **normal pH of arterial blood is 7.4 (7.35-7.45)**. **Venous blood and interstitial fluid** have a slightly lower pH (7.35) and the pH of the **intracellular fluid is more or less neutral**. The **arterial blood pH is the most important pH in the body**.

**Most hydrogen ions, i.e., acids, are produced by our metabolism:**  $H^+$  is liberated when  $CO_2$  is converted to  $HCO_3^-$  in blood, fatty acids and ketone bodies come from lipolysis during the postabsorptive state, lactic acid is formed during anaerobic respiration of glucose in muscles during exercise or work, and phosphoric acid is created during the breakdown of phosphorus-containing proteins in the extracellular fluid.

There are **three mechanisms that help keep the pH within normal limits**:

- Chemical buffer systems** work rapidly and, therefore, are the first line of defense.
- Brain stem respiratory centers** that regulate breathing rate and depth react within 1–3 min.
- Renal mechanisms** are the most potent but require hours to days to effect pH changes.

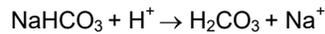
### Chemical Buffer Systems

Chemical buffer systems contain one or more compounds that act to resist pH changes when a strong acid or base is added. **Strong acids and bases dissociate completely in water** and, therefore, lower the pH dramatically (acids) or raise it fast by tying up  $H^+$  (bases). In contrast to that, **weak acids** dissociate partially only, while **weak bases** accept  $H^+$  more slowly.

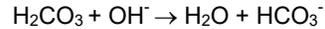
Each of the **three chemical buffer systems** in our body contains a weak acid and a weak base:

- The **bicarbonate buffer system** is a mixture of **carbonic acid ( $H_2CO_3$ )** and **bicarbonate salts** (e.g.,  $NaHCO_3$ , a weak base). It works inside and outside of cells but is **the only important buffer system of the extracellular fluid**.

If a strong acid is added, bicarbonate ties up  $H^+$  and forms carbonic acid. As this is a weak acid, the pH declines only slightly - as long as there is bicarbonate in the blood, which is, therefore, also called **alkaline reserve**.



**Addition of a strong base causes** carbonic acid to dissociate and **release  $H^+$** , which ties up the base and keeps the pH from rising.



2. The **phosphate buffer system** is a mixture of sodium salts of  $H_2PO_4^-$  (weak acid) and  $HPO_4^{2-}$  (weak base). It is **active in the urine and inside the cells** because of the high phosphate concentrations.
3. Protein molecules are amphoteric, i.e., they can function as both a weak acid and a weak base. **Protein buffer systems are important inside the cells and in the blood.**

### Physiological Buffer Systems

The physiological buffer systems, the respiratory and urinary system, **act more slowly** than chemical buffer systems **but have far more capacity**. Chemical buffers cannot eliminate excess acids or bases from the body, but **the lungs can eliminate volatile carbonic acid** by breathing out  $CO_2$  and **the kidneys can eliminate other fixed metabolic acids**. The **lungs and kidneys can also increase the available bicarbonate** by generating new bicarbonate ions.

The **respiratory system eliminates carbon dioxide from our body**. During  $CO_2$  loading in the tissue, released  $H^+$  is buffered by proteins in the plasma and hemoglobin in the erythrocytes. During  $CO_2$  unloading, the reaction shifts to the left and  $H^+$  is incorporated into water (see also **Chapter 21 Respiratory System**).

- Increased  $P_{CO_2}$  (**hypercapnia**) activates medullary chemoreceptors, while the declining plasma pH activates peripheral chemoreceptors. Breathing rate and depth go up and more  $CO_2$  is removed from the blood.
- Decreased  $P_{CO_2}$  (**hypocapnia**) depresses the respiratory center. The breathing rate and depth go down, leading to an increased  $CO_2$  level and a drop in pH.

**Renal mechanisms** are more complex as the kidneys can reabsorb or excrete  $HCO_3^-$  as well as generate new  $HCO_3^-$ . It can also secrete  $H^+$ . Bicarbonate ions cannot be reabsorbed from the filtrate, but **are created by combining  $CO_2$  with water** in PCT cells with the help of **carbonic anhydrase**. The newly formed  $H_2CO_3$  dissociates into  $HCO_3^-$  that is reabsorbed into capillary blood and  $H^+$  that is secreted into the filtrate. Thus, **generating or reabsorbing one  $HCO_3^-$  is the same as losing one  $H^+$** .

Hydrogen ions can be secreted by **intercalated cells** into urine directly or are added as **ammonium** ions by PCT cells.

### Abnormalities of Acid-Base Balance

As already mentioned above, the arterial blood pH is the most important pH, and the value we use in clinical medicine to assess the acid-base balance of the body.

If the arterial blood pH rises **above 7.45, we speak of alkalosis** (or alkalemia); if it falls **below 7.35**, the condition is called **acidosis** (or acidemia).

Both acidosis and alkalosis have an influence on the resting membrane potential and the activity of excitable cells because  **$K^+$  and  $H^+$  move in opposite directions to maintain cation balance**. In acidosis, the  $H^+$  concentration in the ECF goes up, and  $H^+$  will move into cells and  $K^+$  out. This exchange leads to hyperpolarization and unresponsiveness. A drop in the  $H^+$  concentration in alkalosis has the opposite effect.

**Abnormalities of the acid-base balance** are either called **respiratory**, if the cause is related to the **respiratory system**, or **metabolic**, if the **cause is outside the respiratory system**.

The **most important indicator of adequacy of respiratory function is the  $P_{CO_2}$  level** (normally 35–45 mm Hg). In **respiratory acidosis**, the most common cause of acid-base imbalance, the  $P_{CO_2}$  is **above 45 mm Hg** and the **pH is below 7.35**. This imbalance is due to a decrease in either pulmonary ventilation (**hypoventilation**) or the gas exchange in the alveoli, for example, in chronic obstructive pulmonary disorder (COPD). In hypoventilation, a slow and shallow breathing leads to a buildup of  $CO_2$  in the blood and respiratory acidosis. In COPD, the external respiration is impaired, leading to a buildup of  $CO_2$  and a drop in the pH.

If the breathing rate and depth increase (**hyperventilation**) due to stress or pain, for example, the pH rises above 7.45, the  $P_{CO_2}$  falls below 35 mm Hg, and a **respiratory alkalosis** develops.

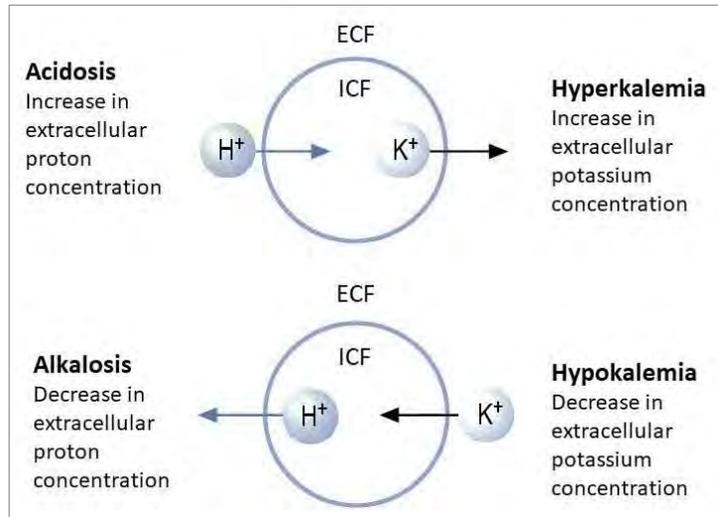
**Metabolic imbalances are indicated by abnormal  $\text{HCO}_3^-$  levels**, while the  $\text{P}_{\text{CO}_2}$  is normal. In **metabolic acidosis**, the pH is below 7.35 and the  $\text{HCO}_3^-$  level is low as it is used up to neutralize  $\text{H}^+$ . The **most common causes** are **ingestion of too much alcohol**, which is converted to acetic acid, **excessive loss of  $\text{HCO}_3^-$** , e.g., in persistent diarrhea, and **accumulation of lactic acid** in shock, ketosis in a diabetic crisis, starvation, and kidney failure.

The least common acid-base imbalance is **metabolic alkalosis**. It can be **caused by vomiting** or by **intake of excess bases** (e.g., **antacids**). It is indicated by a rising blood pH and  $\text{HCO}_3^-$  level.

If an **acid-base imbalance** is due to a malfunction of a physiological buffer system, the other system will try to compensate. In **metabolic acidosis**, the **respiratory system will remove as much  $\text{CO}_2$**  from the body as possible. Therefore, the rate and depth of breathing are elevated, and the  $\text{P}_{\text{CO}_2}$  is below normal. In **metabolic alkalosis**, the **respiratory system will compensate via a slow and shallow breathing**, thus **allowing  $\text{CO}_2$  to accumulate in the blood**.

The **kidney compensates for respiratory acid-base imbalances** by either **increasing** (acidosis) or **decreasing** (alkalosis) the  $\text{HCO}_3^-$  level.

#### 24.8 Effect of acidosis and alkalosis on plasma potassium levels



**Table 24.4 Determination of Acidosis and Alkalosis**

#### Basic facts

- Normal blood pH 7.35-7.45
- Normal  $\text{P}_{\text{CO}_2}$  35-45 mm Hg
- If pH changes are caused by an elevated or reduced  $\text{pCO}_2$ , they are called respiratory acidosis or alkalosis
- If the  $\text{pCO}_2$  is within the normal range pH, changes are called metabolic regardless of the underlying cause

#### Step 1: Look at pH

- pH < 7.35 = Acidosis
- pH > 7.45 = Alkalosis

#### Step 2: Respiratory or metabolic acidosis?

- pH < 7.35 and  $\text{P}_{\text{CO}_2}$  > 45 = Respiratory Acidosis
- pH < 7.35 and  $\text{P}_{\text{CO}_2}$  35-45 = Metabolic Acidosis

#### Step 3: Respiratory or metabolic alkalosis?

- pH > 7.45 and  $\text{P}_{\text{CO}_2}$  < 35 = Respiratory Alkalosis
- pH > 7.45 and  $\text{P}_{\text{CO}_2}$  35-45 = Metabolic Alkalosis

## 24.8 Test Your Knowledge

### Matching Word Parts

Select the correct answer option and write it in the middle column.

	Structure/Meaning	Correct Answer	Answer options
1.	blood condition	_____	natr(i)-
2.	potassium	_____	calc(i)-
3.	abnormal condition	_____	alkal(o)-
4.	sodium	_____	acid(o)-
5.	calcium	_____	-osis
6.	acid	_____	-emia
7.	alkali	_____	kal(i)-

### True/False

Write "T" on the line if the statement is true and "F" if the statement is false.

- Sodium is the most abundant mineral in the body. \_\_\_\_\_
- Interstitial fluid makes up 80% of the extracellular fluid. \_\_\_\_\_
- Aldosterone promotes water reabsorption by the kidneys. \_\_\_\_\_
- Inadequate exhalation of carbon dioxide can cause respiratory acidosis. \_\_\_\_\_
- The thirst center in the brain is located in the hypothalamus. \_\_\_\_\_
- Salts are lost from the body in perspiration, feces, and urine. \_\_\_\_\_
- A substance that dissociates into cations and hydroxyl ions is an acid. \_\_\_\_\_
- A pH of 8 indicates a weak base. \_\_\_\_\_
- If the interstitial fluid is hypertonic, the blood plasma has to be hypotonic. \_\_\_\_\_
- Hyperkalemia leads to aldosterone release from the adrenal cortex. \_\_\_\_\_

### Matching

Choose the item in column 2 that best matches each item in column 1.

- |                    |  |          |
|--------------------|--|----------|
| 1. Acidosis        | a) most abundant extracellular cation  | 1. _____ |
| 2. Electrolytes    | b) most important intracellular buffer | 2. _____ |
| 3. Vomiting        | c) negative water balance              | 3. _____ |
| 4. Na <sup>+</sup> | d) dissociate in water                 | 4. _____ |

- |     |                       |    |   |     |       |
|-----|-----------------------|----|---|-----|-------|
| 5.  | Aldosterone           | e) | can eliminate acid by breathing out CO <sub>2</sub> | 5.  | _____ |
| 6.  | Hypertonic            | f) | blood pH below 7.35                                 | 6.  | _____ |
| 7.  | Protein buffer        | g) | pH above 7.45, pCO <sub>2</sub> <35                 | 7.  | _____ |
| 8.  | Dehydration           | h) | promotes sodium reabsorption by the kidneys         | 8.  | _____ |
| 9.  | Lung                  | i) | most common cause of metabolic alkalosis            | 9.  | _____ |
| 10. | Respiratory alkalosis | j) | has a higher solute concentration than the cytosol  | 10. | _____ |

### Multiple Choice

Choose the one alternative that best completes the statement or answers the question.

- How much of the total volume of body fluid is intracellular fluid?
  - 10%
  - 1/2
  - 1/3
  - 2/3
- This occurs when water loss is greater than water gain.
  - Dehydration
  - Evaporation
  - Precipitation
  - Insensible loss
- The major hormone that corrects water loss is \_\_\_\_.
  - ANP
  - angiotensin II
  - renin
  - ADH
- PTH, vitamin D and calcitonin are \_\_\_\_.
  - the main regulators of magnesium in the blood
  - the main regulators of phosphate in the blood
  - the main regulators of calcium in the blood
  - the main regulators of sodium in the blood
- Exhaling carbon dioxide and excretion by the kidneys are all \_\_\_\_.
  - ways to balance interstitial fluid
  - means of balancing blood volume
  - ways to eliminate H<sup>+</sup> from the body
  - ways to increase blood volume
- A decrease in the osmolarity of the extracellular fluid would cause water to \_\_\_\_.
  - move into the cells
  - move into the interstitial fluid
  - move into the blood
  - move into the lymph
- The area of the brain that plays a major role in water and electrolyte balance is the \_\_\_\_.
  - cerebral cortex
  - hypothalamus
  - medulla
  - thalamus

8. The driving force for water intake is \_\_\_\_.
- a. ADH
  - b. thirst
  - c. decline in blood volume
  - d. decrease in plasma osmolarity
9. The most important buffer in our plasma is \_\_\_\_.
- a. bicarbonate
  - b. phosphate
  - c. protein
  - d. chloride
10. Hyperventilation leads to \_\_\_\_.
- a. respiratory acidosis
  - b. respiratory alkalosis
  - c. metabolic acidosis
  - d. respiratory compensation



## Appendix

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## Commonly Used Adjectives, Prefixes, and Suffixes

<b>Aa-</b>	no, not, without, away from or negative	<b>actin(o)-</b>	ray or radiation
<b>ab-</b>	away from, negative or absent	<b>acute</b>	of abrupt onset; rapidly progressive
<b>abdomin(o)-</b>	abdomen	<b>ad-</b>	toward, to, in the direction of
<b>abdominal</b>	relating to the abdomen	<b>aden(o)-</b>	gland
<b>abdominocardiac</b>	relating to abdomen and heart	<b>adip(o)-</b>	fat or lipids
<b>abdominopelvic</b>	relating to abdomen and pelvis	<b>adipose</b>	consisting of fat; fat
<b>abdominothoracic</b>	relating to abdomen and thorax	<b>adren(o)-</b>	adrenal gland
<b>abdominovesical</b>	relating to abdomen and urinary bladder	<b>adrenal</b>	relating to the adrenal gland
<b>-ac</b>	relating to	<b>adrenal(o)-</b>	adrenal gland
<b>acetabul(o)-</b>	acetabulum (hip socket)	<b>adrenic</b>	→ adrenal
<b>acetabular</b>	relating to the acetabulum	<b>adrenocortical</b>	relating to or arising from the adrenal cortex
<b>acid(o)-</b>	acid	<b>adult</b>	fully grown, grown-up, mature
<b>acidic</b>	having the properties of an acid, containing acid, having a pH of below 7	<b>adventitial</b>	relating to the adventitia
<b>acidotic, acidotic</b>	relating to, affected with, or characterized or caused by acidosis	<b>aer(o)-</b>	air, gas, or mist
<b>acinar, acinal, acinic, aciniform, acinose, acinous</b>	relating to or affecting an acinus; berry-shaped	<b>-ago</b>	disease or abnormal condition
<b>acoust(o)-</b>	hearing or sound	<b>-agra</b>	excessive pain or an attack of severe pain
<b>acoustic</b>	relating to hearing or the sense or organs of hearing	<b>-al</b>	relating to
<b>acr(o)-</b>	tip or extremity (hands and feet) or peak	<b>albumin(o)-</b>	albumin or protein
<b>acromi(o)-</b>	acromion	<b>alg(o)-, alge-, algese(o)-</b>	pain
<b>acromial</b>	relating to the acromion	<b>-algnesia</b>	pain (sense)
<b>acromioclavicular</b>	relating to acromion and clavicle	<b>-algesic</b>	painful
<b>acromiocracoid</b>	relating to coracoid process and acromion	<b>algi(o)-</b>	pain
<b>acromiohumeral</b>	relating to acromion and humerus	<b>-algia</b>	pain or painful condition
<b>acromioscapular</b>	relating to acromion and scapula	<b>aliment(o)-</b>	nourishment or food
<b>acromiothoracic</b>	relating to acromion and thorax	<b>alimentary</b>	relating to nourishment or sustenance
		<b>alkal(o)-</b>	alkali
		<b>alkaline</b>	having the properties of an alkali, containing alkali, having a pH of above 7
		<b>alkalotic</b>	relating to alkalosis, affected, characterized, or caused by it
		<b>all(o)-</b>	condition differing from the normal, or reversal, or re-

<b>allergic</b>	ferring to another relating to allergy, hyper-sensitive	<b>aorticopulmonary</b>	relating to aorta and pulmonary arteries/ trunk
<b>alopec(i)-</b>	baldness	<b>aorticorenal</b>	relating to aorta and kidneys
<b>alveol(o)-</b>	an air sac (alveolus) or a small sac	<b>aortocoronary</b>	relating to aorta and coronary arteries
<b>alveolar</b>	relating to alveoli	<b>aortopulmonary</b>	→ aorticopulmonary
<b>ambulatory</b>	<b>1.</b> able to walk, mobile; not bedridden <b>2.</b> movable; mobile	<b>aortorenal</b>	→ aorticorenal
<b>amni(o)-</b>	amnion	<b>ap(o)-</b>	separate or derivation from
<b>amniotic</b>	relating to the amnion	<b>aphth(o)-</b>	an ulcer
<b>amyl(o)-</b>	starch	<b>apic(o)-</b>	an apex
<b>an-</b>	no or not or without	<b>apical</b>	relating to an apex
<b>an(o)-</b>	anus	<b>append(o)-</b>	an appendix
<b>anal</b>	relating to the anus	<b>appendicular</b>	relating to an/the appendix
<b>anastomotic</b>	relating to an anastomosis	<b>aqu(i)-, aqu(o)-, aque(o)-</b>	water
<b>anatomical</b>	relating to anatomy	<b>aqueous</b>	of or containing water, like water, watery
<b>andr(o)-</b>	male	<b>-ar</b>	relating to
<b>anemic</b>	relating to anemia, suffering from anemia	<b>arrhythmic</b>	relating to or suffering from cardiac arrhythmia; not rhythmic; without rhythm,
<b>angi(o)-</b>	vessel, usually a blood vessel	<b>arteri(o)-</b>	an artery or arteries
<b>angiofollicular</b>	relating to lymphoid follicles and blood vessels	<b>arterial</b>	relating to arteries
<b>angiogenic</b>	relating to angiogenesis	<b>arteriocardillary</b>	relating to arteries and capillaries
<b>anis(o)-</b>	unequal or dissimilar	<b>arteriolar</b>	relating to arterioles
<b>ankyl(o)-</b>	crooked, bent or stiff	<b>arteriorenal</b>	relating to arteries and kidney(s)
<b>anovesical</b>	relating to anus and bladder	<b>arteriosclerotic</b>	affected by or associated with arteriosclerosis
<b>ante-</b>	in front of or before	<b>arterious</b>	→ arterial
<b>antebrachial</b>	relating to the forearm (antebrachium)	<b>arteriovenous</b>	relating to an artery or arteries and vein(s)
<b>antecubital</b>	relating to the area in front of the elbow	<b>arthr(o)-</b>	joint
<b>antenatal</b>	(occurring) before birth	<b>arthral</b>	→ articular
<b>ante partum</b>	occurring before delivery (from the mother's point of view)	<b>arthritic</b>	affected by or associated with arthritis
<b>anter(o)-</b>	front or before	<b>arthrodial</b>	relating to an arthrodial joint; having plane articular surfaces
<b>anterior</b>	closer to the front of the body	<b>articular</b>	relating to a joint
<b>anti-</b>	counteracting, effective against, opposing, or opposite	<b>-ary</b>	relating to
<b>aort(o)-</b>	aorta	<b>asymptomatic</b>	producing or showing no symptom
<b>aortic, aortal</b>	relating to the aorta	<b>ather(o)-</b>	plaque or fatty substance
		<b>atherosclerotic</b>	affected by or associated

	with atherosclerosis	<b>blephar(o)-</b>	eyelid
<b>atlant(o)-</b>	atlas	<b>brachi(o)-</b>	arm (brachium)
<b>atri(o)-</b>	atrium	<b>brachial</b>	relating to the arm
<b>atrial</b>	relating to an atrium	<b>brachiocarpal</b>	relating to forearm or radius and carpus
<b>atrioventricular</b>	relating to an atrium and a ventricle	<b>brachiocubital</b>	relating to upper arm and elbow or forearm
<b>atrophic</b>	relating to atrophy, shrunken, atrophied	<b>brachioradial</b>	relating to humerus and radius
<b>aud-, audi(o)-, audit(o)-</b>	hearing or the ear	<b>brachioulnar</b>	relating to humerus and ulna
<b>auditory</b>	relating to hearing or the sense or organs of hearing	<b>brachy-</b>	short
<b>aur(i)-, aur(o)-</b>	hearing or the ear	<b>brady-</b>	slow
<b>auricular</b>	relating to an auricle or to the ear	<b>bronch(i)-, bronch(o)</b>	bronchus or bronchi
<b>auscultatory</b>	relating to auscultation, determined or determinable by auscultation	<b>bronchi(o)-</b>	bronchiole or bronchioles
<b>auto-</b>	self	<b>bronchial</b>	relating to bronchi or the bronchial system
<b>autoimmune, autoallergic</b>	relating to autoimmunity	<b>bronchiol(o)-</b>	bronchiole (bronchioles)
<b>autonomic</b>	involuntary, unconscious	<b>bronchioloalveolar</b>	→ bronchoalveolar
<b>autosensitized</b>	→ autoimmune	<b>bronchitic</b>	affected by or associated with bronchitis
<b>axial</b>	relating to an axis, along an axis	<b>bronchoalveolar</b>	relating to bronchiole(s) and alveoli
<b>axill(o)-</b>	armpit (axilla)	<b>bronchoesophageal</b>	relating to the bronchi and esophagus
<b>axillary</b>	relating to the axilla	<b>bronchopleural</b>	relating to the bronchi and pleura
<b>bacteri(o)-</b>	bacteria	<b>bronchopulmonary</b>	relating to the bronchi and lung(s)
<b>bacterial, bacteriogenic, bacteriogenous, bacteritic</b>	relating to or caused by bacteria	<b>bronchotracheal</b>	relating to the bronchi and trachea
<b>balan(o)-</b>	glans penis	<b>bronchovesicular</b>	→ bronchoalveolar
<b>bar(o)-</b>	pressure or weight	<b>bucc(o)-</b>	cheek (bucca)
<b>basal</b>	relating to, of, at, or forming a base	<b>buccal</b>	relating to the cheek (bucca)
<b>basilateral</b>	relating to the base and side(s)	<b>bulboatrial</b>	relating to bulbus cordis and atrium
<b>benign</b>	not cancerous or malignant	<b>bulbourethral</b>	relating to bulb of penis and urethra
<b>bi-</b>	two, twice or double	<b>calcane(o)-</b>	heel or heel bone/calcaneus
<b>bi(o)-</b>	life or living organisms	<b>calcaneal</b>	relating to the calcaneus or the heel
<b>biarticular, biarticulate</b>	relating to or having two joints	<b>calcaneoastagaloid</b>	relating to talus and calcaneus
<b>bil(i)-</b>	bile	<b>calcaneocuboid</b>	relating to calcaneus and cuboid bone
<b>biliary, bilious</b>	relating to bile	<b>calcaneofibular</b>	relating to calcaneus and
<b>bimalleolar</b>	relating to two malleoli		
<b>biorhythmic</b>	relating to biorhythm		
<b>biventricular</b>	relating to both ventricles		

	fibula	<b>-cele</b>	hernia, tumor or swelling
<b>calcaneonavicular</b>	relating to calcaneus and navicular bone	<b>celi(o)-</b>	abdomen
<b>calcaneopantar</b>	relating to calcaneus and sole of the foot	<b>cellular</b>	relating to or consisting of cells
<b>calcaneoscaphoid</b>	→ calcaneonavicular	<b>-centesis</b>	surgical puncture (to remove fluid)
<b>calcaneotibial</b>	relating to calcaneus and tibia	<b>cephal(o)-</b>	head
<b>calci-</b>	calcium or calcium salts	<b>cephalic</b>	relating to the head
<b>cancerous</b>	relating to cancer, affected by cancer, of the nature of cancer	<b>cephalothoracic</b>	relating to head and thorax
<b>capill(o)-</b>	hair	<b>cerebell(o)-</b>	cerebellum
<b>capit(o)-</b>	head	<b>cerebellar</b>	relating to the cerebellum
<b>capsular</b>	relating to a capsule	<b>cerebr(o)-</b>	cerebrum
<b>carcin(o)-</b>	cancer or carcinoma	<b>cerebral</b>	relating to the cerebrum
<b>carcinomatous</b>	→ cancerous	<b>cerebrocardiac</b>	relating to brain and heart
<b>card(o)-, cardi(o)-</b>	heart	<b>cerebrospinal</b>	relating to brain and spinal cord
<b>cardia-</b>	heart or the cardia	<b>cerebrovascular</b>	relating to the blood vessels of the brain
<b>cardiac</b>	relating to the heart	<b>cervic(o)-</b>	neck or cervix
<b>cardioaortic</b>	relating to aorta and heart	<b>cervical</b>	relating to a neck or cervix
<b>cardiodiaphragmatic</b>	relating to diaphragm and heart	<b>cervicoaxillary</b>	relating to neck and axilla
<b>cardiohepatic</b>	relating to liver and heart	<b>cervicobrachial</b>	relating to neck and arm
<b>cardiomuscular</b>	relating to the cardiac muscle	<b>cervicodorsal</b>	relating to neck and back
<b>cardioneural</b>	relating to both heart and nervous system	<b>cervicofacial</b>	relating to neck and face
<b>cardiopulmonary</b>	relating to the heart and lung(s)	<b>cervicoscapular</b>	relating to neck and scapula
<b>cardiorenal</b>	relating to heart and kidney(s)	<b>cheil(o)-</b>	lip(s)
<b>cardiorespiratory</b>	relating to the heart and respiration	<b>cheir(o)-</b>	hand(s)
<b>cardiovascular</b>	relating to heart and circulation or blood vessels	<b>chem(o)-</b>	chemistry; chemical
<b>carp(o)-</b>	wrist/carpus	<b>chil(o)-</b>	lip(s)
<b>carpal</b>	relating to the wrist (carpus) or wrist bones	<b>chir(o)-</b>	hand(s)
<b>carpometa­carpal</b>	relating to carpus and metacarpus	<b>chlor(o)-</b>	green
<b>carpophalangeal</b>	relating to carpus and phalanges	<b>chol(e)-, chol(o)-</b>	bile
<b>cartilag(o)-</b>	cartilage	<b>cholangi(o)-</b>	bile duct(s)
<b>cartilaginous</b>	relating to cartilage, consisting of cartilage	<b>chole-</b>	bile
<b>cec(o)-</b>	cecum or blindness	<b>cholecyst(o)-</b>	gallbladder
<b>cecal</b>	relating to the cecum	<b>choledoch(o)-</b>	common bile duct (choledochus)
		<b>chondr(i)-, chondr(o)-</b>	cartilage
		<b>chondral</b>	relating to or consisting of cartilage
		<b>chondrocostal</b>	relating to costal cartilage
		<b>chondroepiphyseal</b>	relating to the epiphyseal (disk) cartilage
		<b>chondrogenic, chondrogenous</b>	relating to chondrogenesis, forming cartilage

<b>chondrosternal</b>	→ costosternal	<b>colovesical</b>	relating to colon and urinary bladder
<b>chord(o)-</b>	spinal cord or a cord	<b>colp(o)-</b>	vagina
<b>chori(o)-</b>	membrane	<b>com-, con-</b>	together or with
<b>chrom(o)-</b>	color	<b>condyl(o)-</b>	knuckle or condyle
<b>chromat(o)-</b>	color or chromatin	<b>condylar</b>	relating to a condyle
<b>chromosomal</b>	relating to or involving chromosomes	<b>congestive</b>	produced by or involving congestion
<b>chron(o)-</b>	time	<b>coni(o)-</b>	dust
<b>chronic</b>	persisting for a long time or constantly recurring	<b>conjunctiv(o)-</b>	conjunctiva
<b>cicatric(o)-</b>	scar	<b>contra-</b>	against, counter or opposite
<b>ciliary</b>	<b>1.</b> relating to or involving cilia <b>2.</b> relating to eyelashes or eyelid <b>3.</b> relating to the ciliary body of the eye	<b>contralateral</b>	on opposite sides of the body
<b>circadian</b>	recurring naturally on a twenty-four-hour cycle	<b>copr(o)-</b>	feces
<b>circulatory</b>	relating to the circulation	<b>cor(o)-, core(o)-</b>	pupil
<b>cirrh(o)-</b>	orange-yellow or tawny	<b>coracoacromial</b>	relating to coracoid process and acromion
<b>cirrhotic</b>	affected by or associated with cirrhosis	<b>coracobrachial</b>	relating to coracoid process and arm
<b>clavicul(o)-</b>	collar bone (clavicle)	<b>coracoclavicular</b>	relating to coracoid process and clavicle
<b>clavicular</b>	relating to the collar bone (clavicle)	<b>coracohumeral</b>	relating to coracoid process and humerus
<b>cleid(o)-</b>	collar bone (clavicle)	<b>cord(o)-</b>	cord or the spinal cord
<b>cleidal</b>	→ clavicular	<b>cordi(o)-</b>	heart
<b>cleidocranial</b>	relating to clavicle and cranium	<b>corne(o)-</b>	cornea
<b>clitor(o)-</b>	clitoris	<b>corneal</b>	relating to the cornea
<b>clitoral</b>	relating to the clitoris	<b>coronal</b>	<b>1.</b> relating to the crown of the head <b>2.</b> of or in the coronal plane
<b>co-</b>	together or with	<b>cortic(o)-</b>	cortex or outer region
<b>coagul(o)-</b>	clotting or coagulation	<b>corticoadrenal</b>	relating to or arising from the adrenal cortex
<b>coccyg(o)-</b>	tailbone (coccyx)	<b>cost(i)-, cost(o)-</b>	rib or ribs
<b>coccygeal</b>	relating to the coccyx (tailbone)	<b>costal</b>	relating to rib(s), belonging to the ribs
<b>cochle(o)-</b>	spiral or snail	<b>costicervical</b>	relating to the rib(s) and neck
<b>cochlear</b>	relating to the cochlea	<b>costispinal</b>	relating to ribs and spine
<b>col(o)-</b>	colon	<b>costocervical</b>	relating to the rib(s) and neck
<b>cole(o)-</b>	sheath or the vagina	<b>costochondral</b>	relating to costal cartilage
<b>collateral</b>	situated side by side; parallel	<b>costoclavicular</b>	relating to ribs and clavicle
<b>collodiaphyseal</b>	relating to femoral neck and diaphysis	<b>costocoracoid</b>	relating to the ribs and coracoid process
<b>colon(o)-</b>	colon	<b>costodiaphragmatic,</b>	relating to ribs and dia-
<b>colonic</b>	relating to the colon		
<b>colorectal</b>	relating to colon and rectum		

<b>costophrenic</b>	phragm	<b>dacryocyst(o)-</b>	tear sac
<b>costopleural</b>	relating to the ribs and the pleura	<b>dactyl(o)-</b>	finger or toe
<b>costoscapular</b>	relating to the ribs and the scapula	<b>de-</b>	lack of, from, not, or removal
<b>costosternal</b>	relating to the ribs and the sternum	<b>decubit(o)-</b>	lying down or lying on the back
<b>costovertebral</b>	relating to rib(s) and vertebra(e)	<b>deep</b>	farther away from the surface of the body
<b>cotyloid</b>	relating to the acetabulum	<b>degenerative</b>	characterized by progressive deterioration and loss of function
<b>cox(o)-</b>	hip or hip joint/coxa	<b>-dema</b>	swelling
<b>coxal</b>	relating to the hip or hip joint	<b>demi-</b>	half
<b>coxofemoral</b>	relating to hip and thigh or femur	<b>dent(o)-</b>	tooth or teeth
<b>crani(o)-</b>	skull (cranium)	<b>dental</b>	relating to a tooth or the teeth
<b>cranial</b>	relating to the cranium or skull; towards the head	<b>derm(o)-, derma-, dermat(o)-</b>	skin
<b>craniospinal</b>	relating to cranium and spinal column	<b>dermal</b>	relating to the skin
<b>craniovertebral</b>	relating to cranium and vertebra(e)	<b>dermatologic</b>	relating to dermatology
<b>cricotracheal</b>	relating to the cricoid cartilage and trachea	<b>-desis</b>	surgical fixation of a bone or joint
<b>crin(o)-</b>	secrete	<b>dextr(o)-</b>	right side
<b>-crine</b>	secretion	<b>di-</b>	two, twice or double
<b>cruciate</b>	cross-shaped, x-shaped	<b>dia-</b>	passing through; thoroughly, completely; going apart
<b>crural</b>	relating to the leg	<b>diabetic</b>	relating to or associated with diabetes
<b>crurotalar</b>	relating to the talus and the lower leg	<b>diaphor(o)-</b>	sweat
<b>cry(o)-</b>	cold	<b>diaphragm(o)-</b>	diaphragm
<b>crypt(o)-</b>	hidden or occult; crypt	<b>diaphragmatic</b>	relating to the diaphragm
<b>cubit(o)-</b>	elbow	<b>diaphysial, diaphyseal, diaphysary</b>	relating to a bone shaft (diaphysis)
<b>cubital</b>	relating to the ulna or the elbow (joint)	<b>diarrheal</b>	relating to diarrhea
<b>cubitoradial</b>	relating to ulna and radius	<b>diarthric, diarticular</b>	relating to two joints
<b>curative</b>	able to cure something, healing, remedial, restorative	<b>diastolic</b>	relating to diastole
<b>cutane(o)-</b>	skin	<b>didym(o)-</b>	testis or twins
<b>cyan(o)-</b>	blue	<b>digestive</b>	relating to the process of digesting food; promoting digestion
<b>-cyesis</b>	pregnancy	<b>digit(o)-</b>	finger(s) or toe(s)
<b>cyst(o)-</b>	cyst or a/the bladder	<b>digital</b>	relating to a digit (finger or toe)
<b>cyt(o)-</b>	cell	<b>diphther(o)-</b>	membrane
<b>-cyte</b>	cell	<b>dipl(o)-</b>	double
<b>cytoplasmic</b>	relating to the cytoplasm	<b>dips(o)-, -dipsia</b>	thirst
<b>dacry(o)-</b>	tears	<b>disc(o)-, disk(o)-</b>	disk or intervertebral disk

<b>distal</b>	farther away from the trunk/body		system; secreting into the inside of the body
<b>dors(i)-, dors(o)-</b>	back (of the body)	<b>endogenous</b>	growing or originating from inside the body
<b>dorsal</b>	relating to the back; towards the back	<b>endometrial</b>	relating to the endometrium
<b>dorsilumbar</b>	→ dorsolumbar	<b>endomyocardial</b>	relating to the endocardium and myocardium
<b>dorsispinal</b>	relating to back and vertebral column	<b>endosteal</b>	relating to the endosteum
<b>dorsolumbar</b>	relating to back and lumbar region	<b>ent(o)-</b>	inside
<b>ductal</b>	relating to a duct	<b>enter(o)-</b>	(small) intestines
<b>duoden(o)-</b>	duodenum	<b>enteral</b>	relating to the intestine
<b>duodenal</b>	relating to the duodenum	<b>enterohepatic</b>	relating to intestine(s) and liver
<b>-dural</b>	dura mater	<b>enterorenal</b>	relating to intestine(s) and kidney(s)
<b>-dynia</b>	pain	<b>eosin(o)-</b>	red or rosy
<b>dys-</b>	bad, disordered, painful	<b>epi-</b>	upon, above, or beside
<b>-eal</b>	relating to	<b>epicardial, epicardiac</b>	relating to the epicardium
<b>ech(o)-</b>	sound	<b>epicondylar, epicondylar, epicondylar, epicondylar</b>	relating to an epicondyle
<b>ect(o)-</b>	outside	<b>epidermal</b>	relating to the epidermis
<b>-ectasis</b>	stretching, dilation or enlargement	<b>epididym(o)-</b>	epididymis
<b>-ectomy</b>	surgical removal, excision or cutting out	<b>epididymal</b>	relating to the epididymis
<b>ectopic</b>	relating to ectopia, arising from a different location than normal	<b>epigastric</b>	located above the stomach
<b>edem-, edemat(o)-</b>	swelling, tumor, or fluid	<b>epiglott(o)-</b>	epiglottis
<b>-edema</b>	swelling	<b>epiphyseal</b>	relating to the epiphysis
<b>ejaculatory</b>	relating to ejaculation	<b>epipl(o)-</b>	omentum
<b>elective</b>	optional, by choice	<b>episi(o)-</b>	vulva
<b>electr(o)-</b>	electricity	<b>episternal</b>	relating to the episternum; (situated) on or above the sternum
<b>embol(o)-</b>	embolus	<b>epitheli(o)-</b>	epithelium
<b>embolic</b>	relating to embolism or an embolus	<b>epithelial</b>	relating to the epithelium, composed of epithelium
<b>embry(o)-</b>	embryo	<b>erg(o)-, -ergy</b>	work or exercise
<b>embryonic</b>	relating to an/the embryo	<b>erythem(o)-, erythemat(o)-</b>	redness; red
<b>-emesis</b>	vomiting	<b>erythr(o)-</b>	red or erythrocytes
<b>emet(o)-</b>	vomiting	<b>erythrocytic</b>	relating to red blood cells (erythrocytes)
<b>-emia</b>	blood or a blood condition	<b>erythropoietic</b>	relating to erythropoiesis
<b>encephal(o)-</b>	brain	<b>-esis</b>	disease or abnormal condition
<b>end(o)-</b>	inside	<b>esophag(o)-</b>	esophagus
<b>endocardial, endocardiac</b>	relating to the endocardium	<b>esophageal</b>	relating to the esophagus
<b>endocrin(o)-</b>	internal secretion, endocrine system or hormones	<b>esophagobronchial</b>	relating to esophagus and bronchi
<b>endocrine</b>	relating to endocrine glands or the endocrine		

<b>esophagoatracheal</b>	relating to the esophagus and trachea	<b>femoral</b>	relating to the femur
<b>essential</b>	1. crucial, vital, necessary for life 2. (disorder) with no known cause; idiopathic, primary	<b>femoroabdominal</b>	relating to femur and abdomen
<b>-esthesia, esthesi(o)-</b>	feeling, nervous sensation or the sense of perception	<b>femoroiliac</b>	relating to femur and ilium
<b>estr(o)-</b>	female	<b>femoropatellar</b>	relating to femur and patella
<b>-estro</b>	female	<b>femorotibial</b>	relating to femur and tibia
<b>ethm(o)-</b>	sieve	<b>fet(i)-, fet(o)-</b>	fetus or unborn child
<b>eti(o)-</b>	cause	<b>fetal</b>	relating to a/the fetus
<b>eu-</b>	good, normal, well or easy	<b>fibr(o)-</b>	fibers
<b>ex(o)-</b>	outside	<b>fibrin(o)-</b>	fibrin or fibers
<b>exanthemat(o)-</b>	rash	<b>fibrinous</b>	relating to or composed of fibrin
<b>excremental, excrementitious</b>	relating to or containing feces	<b>fibrocartilaginous</b>	relating to fibrocartilage, made up of fibrocartilage
<b>exocrin(o)-</b>	external secretion	<b>fibros(o)-</b>	fibrous connective tissue
<b>exocrine</b>	secreting into the outside of the body or onto surfaces	<b>fibrous</b>	consisting of or characterized by fibers
<b>exogenous</b>	originating from outside the body	<b>fibul(o)-</b>	calf bone (fibula)
<b>expir(o)-, expirat(o)-</b>	breathing out (expiration)	<b>fibular</b>	relating to the fibula
<b>expiratory</b>	relating to expiration	<b>fibulocalcaneal</b>	relating to fibula and calcaneus
<b>extra-</b>	outside of, beyond, or in addition to	<b>fiss(o)-, fissur(o)-</b>	crack, split or cleft
<b>extracapsular</b>	outside the capsule	<b>fistul(o)-</b>	fistula or tube
<b>extracellular</b>	located outside a cell	<b>focal</b>	relating to a focus
<b>extrinsic</b>	coming or operating from the outside	<b>follicull(o)-</b>	follicle
<b>faci(o)-</b>	face	<b>foramin(o)-</b>	an opening or foramen
<b>facial</b>	relating to the face	<b>fore-</b>	before or in front of
<b>faciocervical</b>	relating to the face and neck	<b>front(o)-</b>	forehead or the front
<b>facioscapulohumeral</b>	relating to face, scapula, and humerus	<b>frontal</b>	relating to or situated near the forehead or the frontal bone; parallel to the surface
<b>familial</b>	relating to or occurring in a family or its members	<b>fund(o)-</b>	fundus, bottom, base or ground
<b>fasci(o)-</b>	band or fascia	<b>fung(i)-</b>	fungi
<b>fascicul(o)-</b>	small band or fascia	<b>fungial</b>	relating to or caused by fungi
<b>fauc(i)-</b>	throat	<b>galact(o)-</b>	milk
<b>febr(i)-</b>	fever	<b>gamet(o)-</b>	sex cells (eggs and sperm); husband or wife
<b>fecal</b>	relating to or containing feces	<b>gangli(o)-</b>	ganglion
<b>female</b>	relating to or characteristic of women	<b>gastr(o)-</b>	stomach
<b>femor(o)-</b>	thigh/femur	<b>gastric</b>	relating to the stomach
		<b>gastrocardiac</b>	relating to stomach and heart
		<b>gastrodiaphragmatic</b>	→ gastrophrenic

<b>gastroesophageal</b>	relating to stomach and esophagus	<b>-gnosia</b>	knowledge of
<b>gastrointestinal</b>	relating to stomach and (small) intestine	<b>gon-</b>	knee
<b>gastrolial</b>	relating to stomach and spleen	<b>gon(o)-</b>	semen or seed or the reproductive organs
<b>gastrophrenic</b>	relating to stomach and diaphragm	<b>gonad(o)-</b>	sex glands (gonads)
<b>gastropulmonary</b>	relating to stomach and lungs	<b>gonadal, gonadial</b>	relating to a gonad or the gonads
<b>gastrosplenic</b>	→ gastrolial	<b>gony-</b>	knee
<b>generalized</b>	(disorder) affecting much or all of the body; not localized	<b>gouty</b>	relating to or associated with gout
<b>-genesis</b>	creation or production	<b>-gram</b>	picture or recording
<b>genetic</b>	relating to genes or heredity	<b>granul(o)-</b>	granules or grains
<b>genit(o)-</b>	reproductive organs (genitals) or birth	<b>granulocytic</b>	relating to granulocytes
<b>genital</b>	relating to the sexual organs or reproduction	<b>-graph</b>	picture or recording or apparatus for recording
<b>genitofemoral, genitocrural</b>	relating to genitals or genital region and thigh or femur	<b>-graphy</b>	recording or the process of producing a picture/recording
<b>genitourinary</b>	relating to the urogenital apparatus	<b>gravid(o)-</b>	pregnancy
<b>ger(i)-, geront(o)-</b>	old age	<b>-gravida</b>	pregnant
<b>gest(o)-, gestat(o)-</b>	pregnancy	<b>gust(o)-</b>	taste or the sense of taste
<b>gigant(o)-</b>	giant or very large	<b>gustatory</b>	relating to taste or tasting
<b>gingiv(o)-</b>	gums or gingival tissue	<b>gynec(o)-</b>	woman; female
<b>glandular, glandulous</b>	relating to a gland	<b>gynecologic</b>	relating to gynecology
<b>glanular</b>	relating to a the glans penis	<b>hal(o)-</b>	breath
<b>glauc(o)-</b>	gray	<b>hem(o)-, hema-, hemat(o)-</b>	blood
<b>glen(o)-</b>	socket or pit	<b>hematogenous</b>	originating in or carried by the blood
<b>glenohumeral</b>	relating to glenoid cavity and humerus	<b>hematologic</b>	relating to hematology
<b>gli(o)-</b>	nervous tissue	<b>hemi-</b>	half
<b>glomerul(o)-</b>	renal glomeruli	<b>hemolytic</b>	relating to or involving the rupture or destruction of red blood cells
<b>glomerular</b>	relating to a (renal) glomerulus	<b>hemopoietic</b>	relating to hemopoiesis (blood cells formation)
<b>gloss(o)-</b>	tongue	<b>hemorrhagic</b>	accompanied by or produced by hemorrhage (bleeding)
<b>gluc(o)-</b>	sugar or glucose	<b>hepat(o)-, hepatic(o)-</b>	liver
<b>glute(o)-</b>	buttocks	<b>hepatic</b>	relating to the liver
<b>gluteal</b>	relating to the buttock muscles or the buttocks	<b>hepaticopulmonary</b>	→ hepatopulmonary
<b>glyc(o)-, glycos(o)-</b>	sugar or glucose	<b>hepatobronchial</b>	relating to liver and bronchus
<b>gnath(o)-</b>	jaw	<b>hepatodiaphragmatic</b>	relating to liver and diaphragm
		<b>hepatolial</b>	relating to liver and spleen

<b>hepatonephric</b>	→ hepatorenal	<b>hystero</b>	relating to uterus and bladder
<b>hepatopleural</b>	relating to the liver and pleura or pleural cavity	<b>-ia</b>	abnormal condition or disease
<b>hepatopneumonic</b>	→ hepatopulmonary	<b>-ial</b>	relating to
<b>hepatopulmonary</b>	relating to the liver and lung(s)	<b>-ian</b>	specialist
<b>hereditary</b>	determined by genetic factors, congenital, inborn, inherited, innate	<b>-iasis</b>	or abnormal condition or disease
<b>herni(o)-</b>	hernia	<b>iatr(o)-</b>	treatment or doctors (physicians)
<b>heter(o)-</b>	other, different, or abnormal	<b>-iatrics</b>	a field of medicine or healing
<b>heterotopic</b>	relating to ectopia, arising from a different location than normal	<b>-iatrist</b>	specialist
<b>hidr(o)-</b>	sweat	<b>-iatry</b>	a field of medicine
<b>hilar</b>	relating to a hilum	<b>-ic</b>	relating to
<b>hist(o)-, histi(o)-</b>	tissue	<b>-ical</b>	relating to
<b>histologic</b>	relating to histology	<b>ichthy(o)-</b>	dry or scaly
<b>holo-</b>	all	<b>-ician</b>	specialist
<b>hom(o)-</b>	same, like or alike	<b>icter(o)-</b>	jaundice
<b>home(o)-</b>	unchanging or constant	<b>idi(o)-</b>	self (produced), separate, one's own
<b>hormon(o)-</b>	hormone	<b>idiopathic</b>	relating to or denoting any disease or condition that arises spontaneously or for which the cause is unknown
<b>hormonal</b>	relating to hormones	<b>idioventricular</b>	relating to or affecting one ventricle only
<b>humer(o)-</b>	humerus	<b>ile(o)-</b>	ileum
<b>humeral</b>	relating to the upper arm or humerus	<b>ileal</b>	relating to the ileum
<b>humero</b>		<b>ili(o)-</b>	ilium
<b>humero</b>		<b>iliac</b>	relating to the ilium
<b>humero</b>		<b>iliocostal</b>	relating to ilium and ribs
<b>humero</b>		<b>iliofemoral</b>	relating to ilium and thigh or femur
<b>humero</b>		<b>iliolumbar</b>	relating to ilium and lumbar regions
<b>humero</b>		<b>iliotibial</b>	relating to ilium and tibia
<b>humero</b>		<b>immun(o)-</b>	immune system
<b>humero</b>		<b>immunologic</b>	relating to immunology
<b>humero</b>		<b>-ine</b>	relating to
<b>hyper-</b>	above, beyond, more than normal, or excessive	<b>inferior</b>	below, lower
<b>hyperopic</b>	relating to hyperopia, farsighted	<b>inflammatory</b>	relating to or causing inflammation
<b>hypertrophic</b>	relating to or caused by hypertrophy	<b>infra-</b>	inferior to, below, or beneath
<b>hypogastric</b>	located below the stomach	<b>inguin(o)-</b>	groin
<b>hypothalamic</b>	relating to the hypothalamus		
<b>hyster(o)-</b>	uterus		

<b>inguinal</b>	relating to the groin	<b>ischiofibular</b>	relating to ischium and fibula
<b>inguinocrural</b>	relating to groin and thigh or femur	<b>ischiovertebral</b>	relating to ischium and spinal column
<b>inguinoscrotal</b>	relating to groin and scrotum	<b>-ism</b>	condition or state of
<b>inhal(o)-, inhalat(o)-</b>	breathing in (inhalation)	<b>iso-</b>	equal, alike, the same, or uniform
<b>inspir(o)-, inspirat(o)-</b>	breathing in (inspiration)	<b>-ist</b>	specialist or person who practices in a field
<b>inspiratory</b>	relating to inspiration	<b>-itis</b>	inflammation
<b>integumentary</b>	relating to the skin (integument)	<b>jejun(o)-</b>	jejunum
<b>inter-</b>	between or among	<b>jejunal</b>	relating to the jejunum
<b>intercellular</b>	located or happening between cells	<b>jugul(o)-</b>	throat
<b>intercostal</b>	located or happening between ribs	<b>jugular</b>	relating to the jugular vein
<b>intermediate</b>	between a medial and a lateral structure	<b>juxta-</b>	situated near or adjoining
<b>interstitial</b>	relating to the intersitium	<b>kerat(o)-</b>	cornea
<b>intestin(o)-</b>	intestines	<b>kines(o)-, kinesi(o)-, -kinesia</b>	movement
<b>intestinal</b>	relating to the intestine(s)	<b>-kinesis</b>	motion
<b>intra-</b>	within, into, or during	<b>koil(o)-</b>	hollow or concave
<b>intracapsular</b>	inside the capsule	<b>krau(o)-</b>	dry
<b>intracellular</b>	located inside a cell	<b>kyph(o)-</b>	bent or hump
<b>intramuscular</b>	situated or taking place within, or administered into, a muscle	<b>kyphotic</b>	relating to kyphosis
<b>intrauterine</b>	(occurring or located) inside the uterus	<b>labi(o)-</b>	lip(s)
<b>intravenous</b>	taking place within, or administered into, a vein or veins	<b>labial</b>	relating to lips
<b>intro-</b>	within or into	<b>labioglossolaryngeal</b>	relating to lips, tongue, and larynx
<b>-ion</b>	action, process, state or condition	<b>lacrim(o)-</b>	tears or the tear duct
<b>-ior</b>	relating to	<b>lacrimal</b>	relating to tears or the secretion of tears
<b>ipsi-</b>	same	<b>lact(i)-, lact(o)-</b>	milk
<b>ipsilateral</b>	on the same side of the body	<b>lapar(o)-</b>	abdomen
<b>ir(i)-, ir(o)-, irid(o)-, irit(o)-</b>	iris	<b>-lapse</b>	fall or sliding (in/out)
<b>ischemic</b>	relating to or associated with ischemia	<b>laryng(o)-</b>	larynx
<b>ischi(o)-</b>	hip or ischium	<b>laryngeal</b>	relating to the larynx
<b>ischial</b>	relating to the ischium	<b>laryngopharyngeal</b>	relating to the larynx and pharynx
<b>ischiobulbar</b>	relating to ischium and bulb of penis	<b>laryngotracheal</b>	relating to the larynx and trachea
<b>ischiofemoral</b>	relating to ischium and thigh or femur	<b>lateral</b>	away from the midline of the body
		<b>leiomy(o)-</b>	smooth muscle
		<b>leip(o)-</b>	fat or lipid
		<b>lent(o)-</b>	lens
		<b>-lepsy</b>	seizure
		<b>leuc(o)-, leuk(o)-</b>	white or denoting relation

	to leukocytes	<b>lymphocytic</b>	relating to lymphocytes
<b>leukemic</b>	relating to or suffering from leukemia	<b>lymphoid</b>	relating to or resembling lymph or lymphatic tissue
<b>leukocytic</b>	relating to white blood cells (leukocytes)	<b>-lysis</b>	breakdown, separation, destruction or loosening
<b>leukopoietic</b>	relating to leukopoiesis (white blood cells formation)	<b>macr(o)-</b>	large, or of abnormal size or length
<b>lien(o)-</b>	spleen	<b>macroscopic</b>	visible to the naked eye; not microscopic
<b>lienal</b>	relating to the spleen	<b>mal-</b>	bad, poor or evil
<b>lienopancreatic</b>	relating to spleen and pancreas	<b>-malacia</b>	abnormal softening
<b>lienorenal</b>	relating to spleen and kidney	<b>male</b>	relating to or characteristic of men
<b>ligament(o)-</b>	ligament	<b>malignant</b>	<b>1.</b> (disease) virulent, infectious, invasive <b>2.</b> (tumor) cancerous
<b>ligamentous</b>	relating to a ligament	<b>malle(o)-</b>	malleus or hammer
<b>lingu(o)-</b>	tongue	<b>malleol(o)-</b>	malleolus or small hammer
<b>lingual</b>	relating to the tongue	<b>malleolar</b>	relating to ankle (malleolus) or ankle region
<b>lipid(o)-, lip(o)-</b>	fat or lipid	<b>mamil-</b>	nipple or a nipple-like structure
<b>-listhesis</b>	slipping	<b>mamilli-</b>	nipple or a nipple-like structure
<b>lith(o)-, -lith</b>	stone or stones	<b>mamm(o)-</b>	breast or mammary gland
<b>-lithiasis</b>	a presence of stones	<b>mammary</b>	relating to the breast (mamma)
<b>lob(o)-</b>	lobe or lobes	<b>man(i)-, man(o)-</b>	hand or the hands
<b>localized</b>	restricted to a particular place, contained	<b>mandibul(o)-</b>	lower jaw (bone)
<b>-logist</b>	specialist or person who studies a certain subject	<b>mandibular</b>	relating to the lower jaw (mandible)
<b>-logy</b>	study of	<b>manual</b>	relating to the hand
<b>lordotic</b>	relating to lordosis	<b>manubriosternal</b>	relating to manubrium and sternum
<b>lumb(o)-</b>	lower back or loin	<b>mast(o)-</b>	breast or mammary gland
<b>lumbar</b>	relating to the loins	<b>mastic(o)-, masticat(o)-</b>	chewing
<b>lumbocostal</b>	relating to lumbar region or lumbar vertebrae and ribs (costae)	<b>matern(o)-</b>	motherhood or a mother
<b>lumbosacral</b>	relating to lumbar vertebrae and sacrum	<b>maxill(o)-</b>	upper jaw (bone)
<b>lumbothoracic</b>	relating to the lumbar spine and thorax	<b>maxillary</b>	relating to the upper jaw (maxilla)
<b>lun(o)-, lunat(o)-</b>	moon	<b>medial</b>	toward the midline of the body
<b>lute(o)-</b>	yellow	<b>median</b>	situated in the middle
<b>lymph(o)-</b>	lymph, lymphatic tissue, lymphatics, or lymphocytes	<b>mediastinal</b>	relating to the mediastinum, (situated) in the mediastinum
<b>lymphaden(o)-</b>	lymph nodes	<b>medic(o)-</b>	medicine, physician or
<b>lymphangi(o)-</b>	lymph vessels		
<b>lymphatic</b>	relating to or containing lymph		
<b>lymphocapillary</b>	relating to lymph capillaries		

<b>medicat(o)-</b>	healing	<b>muc(o)-</b>	mucus or a mucous membrane
<b>medull(o)-</b>	medication or healing	<b>muci-</b>	mucus or mucin
<b>medullary, medullar</b>	marrow	<b>mucous</b>	relating to, consisting of, or resembling mucus
<b>mega-, megal(o)-</b>	relating to (bone) marrow	<b>multi-</b>	many or much
<b>melan(o)-</b>	large, of abnormal size or length	<b>multiarticular</b>	relating to or affecting several or many joints
<b>men(o)-</b>	black	<b>muscul(o)-</b>	muscle(s)
<b>mening(o)-</b>	menstruation or menses	<b>muscular</b>	relating to muscle(s)
<b>meningeal</b>	meninges or membranes	<b>my(o)-</b>	muscle (tissue)
<b>meningovascular</b>	relating to the meninges	<b>myc(o)-</b>	fungus
<b>meniscal</b>	relating to meninges and the blood vessels	<b>myel(o)-</b>	marrow or bone marrow or spinal cord, or myelin
<b>meniscosynovial</b>	relating to a meniscus	<b>myelinated</b>	having a myelin sheath
<b>menopausal</b>	relating to meniscus and synovial membrane	<b>myeloid</b>	relating to or resembling bone marrow, derived from bone marrow
<b>mens(o)-</b>	relating to menopause	<b>myocardial, myocardi-</b>	relating to the myocardium
<b>menstrual</b>	menstruation or menses	<b>myometrial</b>	relating to the myometrium
<b>ment(o)-</b>	relating to menstruation	<b>myoneural</b>	relating to nerves and muscles, arising from nerves and muscles
<b>metabolic</b>	mind	<b>myopic</b>	relating to myopia, near-sighted
<b>metacarp(o)-</b>	relating to or deriving from the metabolism	<b>myos(o)-</b>	muscle (tissue)
<b>metacarpal</b>	metacarpus or bones of the hand	<b>myring(o)-</b>	tympanic cavity or the tympanic membrane
<b>metacarpocarpal</b>	relating to the metacarpus	<b>myx(o)-</b>	mucus or slime
<b>metacarpophalangeal</b>	relating to carpus and metacarpus	<b>nar(i)-</b>	nostrils
<b>metatars(o)-</b>	relating to metacarpus and phalanges	<b>nas(o)-</b>	nose
<b>metatarsal</b>	metatarsus or bones of the foot	<b>nasal</b>	relating to the nose
<b>metatarsophalangeal</b>	relating to the metatarsus or metatarsal bone(s)	<b>nasotracheal</b>	relating to the nose and trachea
<b>-meter</b>	relating to metatarsal bones and phalanges	<b>nat(i)-</b>	birth
<b>metra-, metr(i)-, metr(o)-</b>	measure or an instrument used to measure	<b>nauseous</b>	affected with nausea; inclined to vomit, queasy
<b>micr(o)-</b>	uterus	<b>ne(o)-</b>	new
<b>microscopic</b>	small size	<b>necr(o)-</b>	death or a dead body, cells, or tissue
<b>milli-</b>	relating to microscopy or a microscope, of very small size	<b>-necrosis</b>	tissue death
<b>mitral</b>	one-thousandth	<b>neonatal</b>	relating to the first four week (28 days) after birth
<b>mono-</b>	relating to the mitral valve	<b>neph(r)o-</b>	kidney(s)
<b>monocytic</b>	one or single	<b>nephric</b>	relating to the kidney
<b>mortal(i)-</b>	relating to monocytes	<b>nephritic</b>	→ nephric
	death		

<b>nephroabdominal</b>	relating to kidney and abdominal wall	<b>-ology</b>	study of or science of
<b>nephrocardiac</b>	relating to kidney and heart	<b>om(o)-</b>	shoulder
<b>nephrogenic</b>	→ nephric	<b>-oma</b>	tumor or neoplasm
<b>nephrogenous</b>	→ nephric	<b>oment(o)-</b>	omentum
<b>nephrologic</b>	relating to nephrology	<b>omphal(o)-</b>	umbilical cord or the navel
<b>nervous</b>	relating to or affecting the nerves	<b>onc(o)-</b>	mass, swelling, or tumor
<b>neur(i)-, neur(o)-</b>	nerve or nervous system	<b>oncologic</b>	relating to oncology
<b>neural</b>	relating to a nerve or the nervous system	<b>onych(o)-</b>	nail or nails
<b>neurocardiac</b>	relating to both heart and nervous system	<b>oophor(o)-</b>	ovary
<b>neurocirculatory</b>	relating to the nervous system and circulation	<b>ophthalm(o)-</b>	eye
<b>neurologic</b>	relating to neurology	<b>ophthalmologic</b>	relating to ophthalmology
<b>neuromuscular</b>	relating to nerves and muscles, arising from nerves and muscles	<b>-opia</b>	condition of the eye
<b>neurovascular</b>	relating to the nervous system and vascular system	<b>-opsia, -opsis, -opsy</b>	vision or view of
<b>nev(o)-</b>	nevus or mole	<b>opt(i)-, optic(o)-, opt(o)-</b>	vision or eye
<b>nod(o)-</b>	knot or swelling	<b>optic</b>	relating to the eye or sight
<b>nodal</b>	relating to a node	<b>or(o)-</b>	mouth
<b>nodul(o)-</b>	little knot or swelling	<b>oral</b>	relating to the mouth; through the mouth, by way of the mouth, per os
<b>non-</b>	no or none	<b>orbital</b>	relating to the orbit
<b>nos(o)-</b>	disease	<b>orchi(o)-, orchid(o)-</b>	testis
<b>nuch(o)-</b>	nape (back of the neck)	<b>organ(o)-</b>	organ
<b>nutri(o)-, nutrit(o)-</b>	food or nourishment	<b>oropharyngeal</b>	relating to mouth and pharynx
<b>nyct(o)-</b>	night	<b>orotracheal</b>	relating to mouth and trachea
<b>o(o)-</b>	an egg or ovum	<b>orth(o)-</b>	straight, normal or correct
<b>obese</b>	grossly fat or overweight	<b>orthostatic</b>	relating to an erect position
<b>obstetr(i)-, obstetr(o)-</b>	midwife	<b>-ory</b>	relating to
<b>occipit(o)-</b>	back of the skull (occiput)	<b>oscheal</b>	relating to the scrotum
<b>occipital</b>	relating to the back of the head or skull	<b>-osis</b>	disease or abnormal condition
<b>ocul(o)-</b>	eye	<b>-osmia</b>	smell or odor
<b>odont(o)-</b>	tooth or teeth	<b>osmotic</b>	relating to osmosis
<b>odyn(o)-</b>	pain	<b>ossi-</b>	bone or the bones
<b>olecran(o)-</b>	elbow (olecranon)	<b>ossicul(o)-</b>	small bone or bones
<b>olecranal</b>	relating to the elbow (joint)	<b>ossicular, ossiculate</b>	relating to ossicles, especially the auditory ossicles
<b>olfact(o)-</b>	smell or sense of smell	<b>ost(e)-, oste(o)-</b>	bone or the bones
<b>olfactory</b>	relating to the sense of smell	<b>osteoarticular</b>	relating to bones and joints
<b>olig(o)-</b>	few	<b>osteoclastic</b>	relating to an osteoclast
<b>-ologist</b>	specialist	<b>osteogenetic, osteogenic, osteogenous</b>	relating to bone formation (osteogenesis)
		<b>osteolytic</b>	relating to dissolution of bone (osteolysis), destruc-

<b>osteomalacic</b>	tive to bony tissue relating to osteomalacia	<b>parenteral</b>	administered elsewhere in the body than the mouth and alimentary canal
<b>osteoperiosteal</b>	relating to the periosteum	<b>-paresis</b>	partial or incomplete paralysis
<b>osteoplastic</b>	→ osteogenetic	<b>paretic</b>	partly incapable of movement; affected by paresis
<b>osteoporotic</b>	relating to, affected by, characterized by, or caused by osteoporosis	<b>parietal</b>	relating to or situated near the side and top of the skull or the parietal bone; relating to or arising from a wall
<b>-ostomy</b>	creation of an opening or the opening	<b>parosteal</b>	→ periosteal
<b>ot(o)-</b>	ear or hearing	<b>parturit(o)-</b>	childbirth or labor
<b>otic</b>	relating to an auricle or to the ear	<b>patell(a)-, patell(o)-</b>	kneecap (patella)
<b>-otomy</b>	cutting or a surgical incision	<b>patellar</b>	relating to the patella
<b>-ous</b>	relating to	<b>patellofemoral</b>	relating to patella and femur
<b>ov(i)-, ov(o)-</b>	egg or ovum	<b>path(o)-</b>	disease
<b>ovari(o)-</b>	ovary	<b>pathogenic</b>	(pathogen) causing disease
<b>ovarian</b>	relating to the ovaries	<b>pathologic</b>	relating to pathology; morbid, diseased
<b>ovulatory</b>	relating to ovulation	<b>-pathy</b>	disease, feeling or emotion
<b>ox(i)-, ox(o)-, ox(y)-</b>	oxygen	<b>pectoral</b>	relating to the thorax or chest region
<b>-oxia</b>	oxygen or oxygen condition	<b>ped(o)-</b>	foot or a child
<b>pachy-</b>	thick or heavy	<b>pedi(a)-</b>	child or childhood
<b>palat(o)-</b>	palate	<b>pelvi(o)-</b>	pelvis
<b>palatine</b>	relating to the palate	<b>pelvic</b>	relating to the/a pelvis
<b>palmar</b>	relating to the or occurring on the palm of the hand	<b>pelvifemoral</b>	relating to pelvis and femur
<b>palpatory</b>	relating to palpation	<b>-penia</b>	deficiency or lack of something
<b>palpebr(o)-</b>	eyelid(s)	<b>penile, penial</b>	relating to the penis
<b>palpebral</b>	relating to the eyelids (palpebrae)	<b>penoscrotal</b>	relating to penis and scrotum
<b>pan-</b>	all, every or entire	<b>peps(i)-, pept(o)-, -pepsia</b>	digestion
<b>pancrea-, pancreat(o)-, pancreatic(o)-, pancre(o)-</b>	pancreas	<b>peptic</b>	relating to digestion, especially protein digestion with pepsin
<b>pancreatic</b>	relating to the pancreas	<b>per-</b>	throughout, completely, or extremely
<b>papill(i)-, papill(o)-</b>	nipple-like	<b>peri-</b>	around
<b>para-</b>	near, adjacent, resembling, beyond, apart from, or abnormal	<b>pericardial, pericardi-ac</b>	relating to the pericardium
<b>-para</b>	birth	<b>pericardiopleural</b>	relating to the pericardium and pleura
<b>paralyzed</b>	partly or wholly incapable of movement	<b>perilymphatic</b>	relating to the perilymph
<b>paranasal</b>	surrounding the nasal cavity		
<b>parasitic</b>	relating to or caused by parasites		
<b>parathyroid(o)-</b>	parathyroid glands		

<b>perinatal</b>	relating to the period from about five months (week 20) before birth to one month after birth	<b>-pheresis</b>	removal
<b>perine(o)-</b>	perineum	<b>-philia</b>	attraction to or love for
<b>perineal</b>	relating to the perineum	<b>-phithisis</b>	wasting away
<b>periodontal</b>	surrounding a tooth or teeth	<b>phleb(o)-</b>	vein or veins
<b>periosteal, periosteous</b>	relating to the periosteum	<b>phleboid</b>	relating to a vein or veins
<b>peripartum</b>	occurring during the last month of pregnancy and the first five months after delivery (from the mother's point of view)	<b>-phobia</b>	fear
<b>peritone(o)-</b>	peritoneum	<b>phon(o)-</b>	voice or sound
<b>peritoneal</b>	relating to the peritoneum; inside the peritoneal cavity	<b>-phoria</b>	feeling or mental state
<b>pernicious</b>	having a harmful effect, malignant, noxious	<b>phot(o)-</b>	light
<b>perone(o)-</b>	fibula	<b>phren(o)-, phrenic(o)-</b>	diaphragm, the phrenic nerve, or the mind
<b>peroneal</b>	relating to the fibula or peroneal nerve	<b>phrenic</b>	relating to the diaphragm
<b>peroneotibial</b>	relating to fibula and tibia	<b>phrenicocostal</b>	relating to ribs and diaphragm
<b>perspir(o)-</b>	sweating or sweat	<b>phrenicogastric</b>	relating to diaphragm and stomach
<b>-pexy</b>	surgical fixation	<b>phrenicohepatic</b>	relating to diaphragm and liver
<b>phac(o)-</b>	lens of the eye	<b>phrenicolienal</b>	relating to diaphragm and spleen
<b>phag(o)-</b>	eating or swallowing	<b>phrenicomediastinal</b>	relating to diaphragm and mediastinum
<b>-phagia</b>	eating or swallowing	<b>phrenicopleural</b>	relating diaphragm and pleura
<b>phagocytic</b>	relating to phagocytes or phagocytosis	<b>phrenicosplenic</b>	→ phrenicolienal
<b>phak(o)-</b>	lens of the eye	<b>phrenocostal</b>	→ phrenicocostal
<b>phalang(o)-</b>	phalanx	<b>phrenogastric</b>	→ phrenicogastric
<b>phalangeal</b>	relating to a phalanx	<b>phrenohepatic</b>	→ phrenicohepatic
<b>phall(i)-, phall(o)-</b>	penis	<b>phrenosplenic</b>	→ phrenicolienal
<b>phallic</b>	relating to the phallus	<b>phys(o)-</b>	air or gas
<b>pharmac(o)-, pharmaceutical(o)-</b>	drugs	<b>physiologic</b>	relating to physiology; normal, being in accord with or characteristic of the normal functioning of an organ or the body
<b>pharyng(o)-</b>	pharynx	<b>pi(o)-</b>	fat or lipid
<b>pharyngeal</b>	relating to the pharynx	<b>pil(i)-, pil(o)-</b>	hair
<b>pharyngolaryngeal</b>	relating to the pharynx and larynx	<b>pimel(o)-</b>	fat or lipid
<b>pharyngotracheal</b>	relating to the pharynx and trachea	<b>pineal(o)-</b>	pineal gland
<b>pharyngotympanic</b>	relating to the pharynx and the middle ear (tympanic cavity)	<b>pituit(o)-, pituitar(o)-</b>	pituitary gland
<b>-phasia</b>	speech	<b>placental</b>	relating to the placenta
		<b>plant(i)-, plant(o)-</b>	sole of the foot
		<b>plantar</b>	relating to the or occurring on the sole of the foot
		<b>-plasia</b>	development, growth or formation
		<b>plasm(o)-</b>	plasma

<b>plasmacellular, plasmacytic</b>	relating to a plasma cell	<b>postnatal</b>	(occurring) after birth
<b>-plasty</b>	surgical repair	<b>postpartum</b>	occurring after delivery (from the mother's point of view)
<b>-plegia</b>	paralysis or stroke	<b>-prandial</b>	meal
<b>pleio-, pleo-</b>	many or much	<b>pre-</b>	before or anterior
<b>pleur(o)-</b>	pleura	<b>precancerous</b>	not cancerous yet
<b>pleural</b>	relating to the pleura	<b>prenatal</b>	(occurring) before birth
<b>pleuropericardial</b>	relating to the pleura and pericardium	<b>prepartum</b>	occurring before delivery (from the mother's point of view)
<b>pleuroperitoneal</b>	relating to the pleura and peritoneum	<b>preputial</b>	relating to the prepuce
<b>pleuropulmonary</b>	relating to the pleura and lung(s)	<b>presby(o)-</b>	old age
<b>pleurovisceral</b>	relating to the pleura and the viscera	<b>presso-</b>	weight or pressure
<b>pluri-</b>	many or much	<b>priap(o)-</b>	penis
<b>-pnea</b>	breathing	<b>pro-</b>	before, forward, or in favor of
<b>pneum(o)-, pneumat(o)-</b>	air/gas or breath/breathing or lung or lung inflammation/pneumonia	<b>proct(o)-</b>	rectum
<b>pneumal</b>	→ pulmonary	<b>prostatic</b>	relating to the prostate
<b>pneumatic</b>	relating to pneumatics; relating to (compressed) air or gas or breathing; air-containing	<b>proximal</b>	nearer/closer to the trunk/body
<b>pneumocardial</b>	relating to the lung(s) and heart	<b>pseud(o)-</b>	false or spurious
<b>pneumogastric</b>	relating to the stomach and lung(s)	<b>psor(i)-, psor(o)-</b>	itching
<b>pneumonic</b>	→ pulmonary	<b>psych(o)-</b>	mind
<b>pod(o)-</b>	foot or feet	<b>psychiatric</b>	relating to psychiatry
<b>-poiesis</b>	formation	<b>psychologic</b>	relating to psychology
<b>poli(o)-</b>	gray matter of brain and spinal cord	<b>-ptosis</b>	droop, sag, prolapse or fall
<b>poly-</b>	many or much	<b>ptyal(o)-</b>	saliva or salivary glands
<b>polyarticular, polyarthric</b>	relating to or affecting several or many joints	<b>pub(o)-</b>	pubic bone or pubic area
<b>polyostotic</b>	relating to several bones	<b>pubic</b>	relating to the pubic bone or pubes
<b>poplit(o)-</b>	back of the knee	<b>pubofemoral</b>	relating to pubic bone and femur
<b>popliteal</b>	relating to the back of the knee or the popliteal fossa	<b>puboprostatic</b>	relating to pubic bone and prostate
<b>-porosis</b>	porous condition	<b>pubovesical</b>	relating to pubes and bladder
<b>post-</b>	after, behind, or posterior	<b>pudend(o)-</b>	pudendum
<b>poster(o)-</b>	behind, toward the back or the posterior	<b>puerper(i)-</b>	childbearing or labor
<b>posterior</b>	closer to the back of the body	<b>pulm(o)-, pulmon(o)-</b>	lung
<b>postmortem</b>	(occurring) after death	<b>pulmonary, pulmonal, pulmonic</b>	relating to the lungs
		<b>pulmonoperitoneal, pulmoperitoneal</b>	relating to the lung(s) and peritoneum
		<b>pupill(o)-</b>	pupil
		<b>pur(o)-</b>	pus
		<b>purpur(o)-</b>	purple

<b>purul(o)-</b>	pus-filled		resembling rheumatism
<b>purulent</b>	full of, containing, or consisting of pus	<b>rhin(o)-</b>	nose
<b>py(o)-</b>	pus	<b>rhinal</b>	relating to the nose
<b>pyel(o)-</b>	pelvis	<b>rhiz(o)-</b>	root
<b>pyle-</b>	portal vein	<b>roentgen(o)-</b>	x-rays
<b>pylor(o)-</b>	pylorus	<b>-rrhagia</b>	bleeding or abnormal/excessive fluid discharge
<b>pyr(o)-, pyret(o)-</b>	fever	<b>-rrhaphy</b>	surgical suturing
<b>pyretic</b>	fevered, feverish, or inducing fever	<b>-rrhea</b>	flow or discharge
<b>quadr(i)-, quadr(o)-</b>	four	<b>sacchar(o)-</b>	sugar
<b>rachi(o)-</b>	spine or vertebrae	<b>sacr(o)-</b>	sacrum
<b>radi(o)-</b>	rays or radiation or the radius or radium	<b>sacral</b>	relating to the sacrum
<b>radial</b>	relating to the radius, towards the radial side	<b>sacrolumbar</b>	relating to sacrum and lumbar vertebrae
<b>radicul(o)-</b>	(nerve) root	<b>sacrospinal</b>	relating to sacrum and spine
<b>radiocarpal</b>	relating to radius and wrist (carpus)	<b>sacrovertebral</b>	relating to sacrum and vertebrae
<b>radiohumeral</b>	relating to radius and humerus	<b>saliv(o)-</b>	saliva
<b>radiologic</b>	relating to radiology	<b>salivary</b>	relating to saliva
<b>radioulnar</b>	relating to radius and ulna	<b>salping(o)-</b>	eustachian tube or fallopian tube
<b>rect(o)-</b>	rectum	<b>sangui-, sanguin(o)-</b>	blood
<b>rectal</b>	relating to the rectum	<b>sarc(o)-</b>	muscle or flesh
<b>rectourethral</b>	relating to rectum and urethra	<b>scapul(o)-</b>	shoulder blade (scapula)
<b>rectouterine</b>	relating to rectum and uterus	<b>scapular</b>	relating to the scapula
<b>rectovesical</b>	relating to rectum and bladder	<b>scapulocostal</b>	relating to the scapula and ribs
<b>ren(o)-</b>	kidney(s)	<b>scapulohumeral</b>	relating to scapula and humerus
<b>renal</b>	relating to the kidney	<b>scat(o)-</b>	feces or dung
<b>renointestinal</b>	relating to kidney and intestine	<b>scirrh(o)-</b>	hardening of tissue
<b>renovascular</b>	relating to the renal vessels	<b>scler(o)-</b>	hard or hardened, or denoting relation to the sclera
<b>respiratory</b>	relating to respiration	<b>scleral</b>	relating to the sclera
<b>reticul(o)-</b>	reticulum or a reticular structure	<b>-sclerosis</b>	abnormal hardening
<b>retin(o)-</b>	retina	<b>scoli(o)-</b>	bent or crooked
<b>retinal</b>	relating to the retina	<b>scoliotic</b>	relating to or associated with scoliosis
<b>retr(o)-</b>	backward or behind	<b>-scope</b>	or instrument for visual examination
<b>rhabdomy(o)-</b>	skeletal muscle	<b>-scopy</b>	visual examination
<b>rhachi(o)-</b>	back or vertebral column or spinal column	<b>scrotal</b>	relating to the scrotum
<b>rheum(o)-, rheumat(o)-</b>	watery flow	<b>seb(o)-</b>	sebum
<b>rheumatoid</b>	relating to, affected by, or	<b>sebaceous</b>	relating to oil or fat
		<b>semi-</b>	half

<b>semilunar</b>	half-moon or crescent shaped	<b>sphygm(o)-</b>	pulse
<b>semin(i)-</b>	semen, seed or sperm	<b>spin(o)-</b>	thorn or spine or the back-bone/spinal column
<b>seminal</b>	relating to the semen	<b>spinal</b>	relating to the spine or the spinal cord
<b>sen(i)-</b>	old	<b>spinosacral</b>	relating to spine and sacrum
<b>senil(o)-</b>	old age	<b>spinous</b>	having spines; spiny
<b>senile</b>	relating to or showing signs of old age	<b>spir(o)-</b>	to breath
<b>sept(o)-</b>	sepsis, infection or a partition (septum)	<b>splanchn(o)-</b>	viscera or the splanchnic nerve
<b>septal</b>	relating to a septum	<b>splen(o)-</b>	spleen
<b>septic</b>	infected with bacteria; containing or involving pus	<b>splenic</b>	relating to the spleen
<b>septile</b>	→ septal	<b>splenocolic</b>	relating to spleen and colon
<b>ser(o)-</b>	serum	<b>splenonephric</b>	→ splenorenal
<b>serous</b>	relating to serum; resembling serum; watery	<b>splenopancreatic</b>	relating to spleen and pancreas
<b>sial(o)-</b>	saliva or salivary glands	<b>splenorenal</b>	relating to spleen and kidney
<b>sialaden(o)-</b>	salivary glands	<b>spondyl(o)-</b>	vertebra or the spinal column
<b>sider(o)-</b>	iron	<b>spondylous</b>	relating to a vertebra
<b>sigmoid(o)-</b>	sigmoid	<b>spongi(o)-</b>	like a sponge or spongy
<b>sin(o)-, sinu-</b>	sinus	<b>-stasis</b>	the control or maintenance of a constant level
<b>sinistr(o)-</b>	left side	<b>steat(o)-</b>	fat, lipid or sebum
<b>sinoatrial</b>	relating to sinus node and atrium	<b>sten(o)-</b>	constricted or narrow
<b>sinoventricular</b>	relating to sinus node and ventricle of the heart	<b>-stenosis</b>	or abnormal narrowing
<b>sinuatrial</b>	→ sinoatrial	<b>sterc(o)-</b>	feces
<b>sinus(o)-</b>	sinus	<b>stercoral, stercora-ceous, stercorous</b>	relating to or containing feces
<b>sinuventricular</b>	→ sinoventricular	<b>stern(o)-</b>	sternum
<b>-sis</b>	disease or abnormal condition	<b>sternal</b>	relating to the sternum
<b>skelet(o)-</b>	skeleton	<b>sternoclavicular, sternocleidal</b>	relating to sternum and clavicle
<b>skeletal</b>	relating to the skeleton	<b>sternocostal</b>	relating to sternum and ribs
<b>soma-, somat(o)-</b>	body	<b>sternopericardial</b>	relating to sternum and pericardium
<b>somatic</b>	of the body; bodily; physical	<b>sternoscapular</b>	relating to sternum and scapula
<b>somn(i)-, somn(o)-</b>	sleep	<b>sternothyroid</b>	relating to sternum and thyroid gland or thyroid cartilage
<b>son(o)-</b>	sound	<b>sternotracheal</b>	relating to sternum and trachea
<b>sopor(o)-</b>	sleep	<b>sternovertebral</b>	relating to sternum and vertebrae
<b>-spasm</b>	sudden involuntary cramping or contraction		
<b>sperm(o)-, spermat(o)-</b>	semen/sperm		
<b>spermatic</b>	relating to sperm		
<b>spermiogenetic</b>	relating to spermiogenesis		
<b>sphen(o)-</b>	wedge		

<b>steth(o)-</b>	chest	<b>talofibular</b>	relating to talus and fibula
<b>-sthenia</b>	strength	<b>talometatarsal</b>	relating to talus and metatarsus
<b>stom(o)-, stomat(o)-</b>	mouth or oral cavity	<b>talotibial</b>	relating to talus and tibia
<b>-stomy</b>	formation of a new opening	<b>tars(o)-</b>	tarsus
<b>sub-</b>	inferior to, below, or beneath	<b>tarsal</b>	relating to the tarsus or tarsal bones
<b>subclavian</b>	located below the clavicle	<b>tarsometatarsal</b>	relating to tarsus and metatarsus
<b>subcutaneous</b>	located beneath the skin, applied under the skin	<b>tarsophalangeal</b>	relating to tarsus and phalanges
<b>subdural</b>	located below the dura mater	<b>tarsotibial</b>	→ tibiotarsal
<b>sublingual</b>	located beneath the tongue, applied under the tongue	<b>tele-</b>	end or operating at a distance, or far away
<b>sudor(i)-</b>	sweat	<b>temporal</b>	relating to the temple or a temporal bone
<b>sudoriferous</b>	sweat-producing	<b>temporomandibular</b>	relating to temporal bone and mandible
<b>super-</b>	above, beyond, more than normal, or excessive	<b>ten(o)-, tend(o)-, tendin(o)-</b>	tendon
<b>superficial</b>	close(r) to the surface	<b>terat(o)-</b>	malformed fetus
<b>superior</b>	above; higher	<b>test(i)-, test(o)-</b>	testis
<b>suppur(o)-, suppurate(o)-</b>	pus formation	<b>testicular</b>	relating to the testes
<b>supra-</b>	above or over	<b>tetra-</b>	four
<b>sural</b>	relating to the calf	<b>thalam(o)-</b>	thalamus
<b>surgical</b>	relating to or used in surgery	<b>thalamic</b>	relating to the thalamus
<b>sym-</b>	with, together or joined together	<b>thanas(o)-, thanat(o)-</b>	death
<b>sympath(o)-, sympathetic(o)-</b>	sympathetic nervous system	<b>thel(o)-, thele-</b>	nipple or a nipple-like structure
<b>symptomatic</b>	serving as a symptom or sign	<b>-thelium</b>	tissue
<b>syn-</b>	union or association	<b>therm(o)-</b>	heat
<b>syndesm(o)-</b>	ligament	<b>thorac(o)-</b>	thorax
<b>synovi(o)-, synov(o)-</b>	synovia or a synovial membrane	<b>thoracic</b>	relating to the thorax or chest region
<b>synovial</b>	relating to synovia or synovium	<b>thoracicoabdominal</b>	→ thoracoabdominal
<b>syring(o)-</b>	fistula or a tube	<b>thoracicoacromial</b>	→ thoracoacromial
<b>systolic</b>	relating to the systole	<b>thoracicohumeral</b>	relating to thorax and humerus
<b>tachy-</b>	swift or rapid	<b>thoracicolumbar</b>	→ thoracolumbar
<b>tal(o)-</b>	talus	<b>thoracoabdominal</b>	relating to thorax and abdomen
<b>talar</b>	relating to the talus	<b>thoracoacromial</b>	relating to thorax and acromion
<b>talocalcaneal, talocalcanean</b>	relating to talus and calcaneus	<b>thoracolumbar</b>	relating to thorax and lumbar spine
<b>talocrural</b>	relating to the talus and the lower leg	<b>-thorax</b>	thorax or chest
		<b>thromb(o)-</b>	clot or thrombus

<b>thrombocytic</b>	relating to platelets (thrombocytes)	<b>traumat(o)-</b>	injury or wound or trauma
<b>thrombotic</b>	relating to or associated with thrombosis	<b>tri-</b>	three
<b>thym(o)-</b>	thymus	<b>trich(o)-</b>	hair
<b>-thymia</b>	state of mind	<b>troph(o)-</b>	food or nutrition
<b>thyr(o)-, thyre(o)-, thyroid(o)-</b>	thyroid gland	<b>-troph</b>	development or nourishment
<b>thyrocardiac</b>	relating to thyroid and heart	<b>truncal</b>	relating to the trunk
<b>tibi(o)-</b>	tibia	<b>tub(o)-</b>	ovarian tube or auditory tube
<b>tibial</b>	relating to the tibia	<b>tubercular, tuberculated</b>	relating to or resembling a tubercle
<b>tibiocalcaneal, tibio-calcanean</b>	relating to tibia and calcaneus	<b>tuss(i)-</b>	cough or coughing
<b>tibiofemoral</b>	relating to tibia and femur	<b>tymp(ano)-</b>	tympanic cavity or the tympanic membrane
<b>tibiofibular</b>	relating to tibia and fibula	<b>typhl(o)-</b>	cecum or blindness
<b>tibionavicular</b>	relating to tibia and navicular bone	<b>ulcer(o)-</b>	ulcer or ulceration
<b>tibioperoneal</b>	→ tibiofibular	<b>uln(o)-</b>	ulna
<b>tibioscap(ulo)id</b>	→ tibionavicular	<b>ulnar</b>	relating to the ulna, situated on the ulnar side
<b>tibiotarsal</b>	relating to tibia and tarsus	<b>ulnocarpal</b>	relating to ulna and wrist (carpus)
<b>-tic</b>	relating to	<b>ulnoradial</b>	relating to ulna and radius
<b>toc(o)-, tocia-, -tocin</b>	labor	<b>ultra-</b>	excess or beyond
<b>tom(o)-</b>	cutting or slicing	<b>umbilic(o)-</b>	navel
<b>-tome</b>	or instrument for cutting	<b>umbilical</b>	relating to the umbilicus (navel) or umbilical cord
<b>-tomy</b>	the process of cutting	<b>ungu(o)-</b>	nail
<b>ton(o)-</b>	tension, tone or stretching	<b>uni-</b>	one
<b>tonsill(o)-</b>	tonsils	<b>ur(o)-</b>	urine or the urinary tract
<b>topical</b>	relating or applied directly to a part of the body	<b>uran(o)-, uranisc(o)-</b>	palate
<b>tort(i)-</b>	twisted	<b>ure(o)-</b>	urea
<b>tox(o)-, toxic(o)-</b>	poisonous	<b>-uresis</b>	urination
<b>trache(i)-, trache(o)-</b>	trachea	<b>ureter(o)-</b>	ureter(s)
<b>tracheal</b>	relating to the trachea	<b>ureteric, ureteral</b>	relating to the ureter
<b>trachel(o)-</b>	neck or neck-like structure	<b>ureteropelvic</b>	relating to ureter and renal pelvis
<b>trachelian</b>	relating to a neck or cervix	<b>ureterovesical</b>	relating to ureter and bladder
<b>tracheobronchial</b>	relating to the trachea and bronchi	<b>urethr(o)-</b>	urethra
<b>tracheoesophageal</b>	relating to the trachea and esophagus	<b>urethral</b>	relating to the urethra
<b>tracheolaryngeal</b>	relating to the trachea and larynx	<b>urethrobulbar</b>	relating to urethra and bulb of penis
<b>tracheopharyngeal</b>	relating to the trachea and pharynx	<b>urethroperineal</b>	relating to urethra and perineum
<b>trans-</b>	through, across, or beyond	<b>urethroperineoscrotal</b>	relating to urethra, perineum, and scrotum
<b>transdermal</b>	denoting the application of a medicine or drug through the skin	<b>urethrorectal</b>	relating to urethra and rec-

	tum		body; in front of
<b>urethroscrotal</b>	relating to urethra and scrotum	<b>ventricul(o)-</b>	(brain/heart) ventricle
<b>urethrovaginal</b>	relating to urethra and vagina	<b>ventricular</b>	relating to a ventricle
<b>urethrovesical</b>	relating to urethra and bladder	<b>ventriculoatrial</b>	relating to ventricle and atrium
<b>-uria</b>	urination or urine	<b>venul(o)-</b>	small vein
<b>uric(o)-</b>	urine or uric acid	<b>verruc(o)-</b>	wart or wart-like structure
<b>urin(o)-</b>	urine	<b>vertebr(o)-</b>	vertebra
<b>urinary</b>	relating to urine	<b>vertebral</b>	relating to a vertebra
<b>urinogenital</b>	→ urogenital	<b>vertebrochondral</b>	relating to vertebrae and rib cartilage
<b>urinous</b>	relating to urine	<b>vertebrocostal</b>	relating to vertebrae and rib(s)
<b>urogenital</b>	relating to the urogenital apparatus	<b>vertebrosacral</b>	relating to vertebrae and sacrum
<b>urologic</b>	relating to urology	<b>vertebrosternal</b>	relating to vertebrae and sternum
<b>uron(o)-</b>	urine or urinary tract	<b>vesic(o)-</b>	bladder
<b>urtic(o)-</b>	nettle, rash or hives	<b>vesical</b>	relating to the bladder
<b>uter(i)-, uter(o)-</b>	uterus	<b>vesicoabdominal</b>	relating to urinary bladder and abdomen
<b>uterine</b>	relating to the uterus	<b>vesicoprostatic</b>	relating to urinary bladder and prostate
<b>uterovesical</b>	relating to uterus and bladder	<b>vesicopubic</b>	relating to urinary bladder and pubes
<b>uve(o)-</b>	iris, choroid, or ciliary body	<b>vesicorenal</b>	relating to urinary bladder and kidney
<b>uveal</b>	relating to the uvea	<b>vesicoureteric,</b>	relating to urinary bladder and ureter(s)
<b>uvul(o)-</b>	uvula	<b>vesicoureteral</b>	
<b>vaccin(i)-, vaccin(o)-</b>	vaccine or vaccination	<b>vesicourethral</b>	relating to urinary bladder and urethra
<b>vag(o)-</b>	vagus nerve	<b>vesicouterine</b>	relating to urinary bladder and uterus
<b>vagal</b>	relating to the vagus nerve	<b>vesicouterovaginal</b>	relating to urinary bladder, uterus, and vagina
<b>vagin(o)-</b>	sheath or the vagina	<b>vesicovaginal</b>	relating to urinary bladder and vagina
<b>vaginal</b>	relating to the/a vagina	<b>vesicovaginorectal</b>	relating to urinary bladder, vagina, and rectum
<b>vagino-vesical</b>	→ vesicovaginal	<b>vesicul(o)-</b>	small bladder, blister or the seminal vesicle
<b>valv(o)-, valvul(o)-</b>	valve	<b>vestibul(o)-</b>	vestibule
<b>valvular</b>	relating to a valve or valves	<b>vir(o)-</b>	virus or a poison
<b>vas(o)-</b>	vessel	<b>viral</b>	relating to or caused by viruses
<b>vascul(o)-</b>	vessel	<b>vis(o)-</b>	seeing or sight
<b>vascular</b>	relating to (blood) vessels	<b>viscer(o)-</b>	internal organs (viscera)
<b>vasculocardiac</b>	→ cardiovascular	<b>visceral</b>	relating to internal organs
<b>veinous</b>	→ venous		
<b>ven(o)-, veni-</b>	vein		
<b>venoatrial</b>	relating to vena cava and right atrium		
<b>venoauricular</b>	→ venoatrial		
<b>venous</b>	relating to a vein or veins		
<b>ventr(o)-</b>	belly (frontal) side of the body		
<b>ventral</b>	toward or at the front of the		

<b>viscerocardiac</b>	(viscera) relating to viscera and heart	<b>vulv(o)-</b>	vulva
<b>visceropleural</b>	relating to viscera and pleura	<b>xanth(o)-</b>	yellow
<b>visual</b>	relating to seeing or sight	<b>xen(o)-</b>	strange or foreign
<b>vit(o)-</b>	life	<b>xer(o)-</b>	dry
<b>viti(o)-</b>	blemish or defect	<b>xiphocostal</b>	relating to xiphoid process and ribs
<b>vitre(o)-</b>	glass-like, glassy, or made of glass	<b>xiphoid</b>	relating to the xiphoid process; sword-shaped
<b>voc(i)-</b>	voice	<b>zo(o)-</b>	animal life
		<b>zygomat(o)-</b>	cheek bone



## Abbreviations, Acronyms, and Symbols

<b>A</b>	1. anterior 2. blood group A	<b>AML</b>	acute myeloid leukemia
<b>A, Ab</b>	antibody	<b>AMN</b>	amniocentesis
<b>AB</b>	blood group AB	<b>AMS</b>	acute mountain sickness
<b>ABC</b>	1. airways, breathing, circulation 2. aspiration biopsy cytology	<b>anat</b>	anatomy
<b>Abd, Abdo</b>	abdomen	<b>ANP</b>	atrial natriuretic peptide
<b>ABG</b>	arterial blood gases	<b>ANS</b>	autonomic nervous system
<b>ABP</b>	1. androgen-binding protein 2. arterial blood pressure	<b>AOD</b>	1. adult-onset diabetes mellitus 2. arterial occlusive disease
<b>AC</b>	anticoagulant	<b>AP</b>	anterior pituitary
<b>a.c.</b>	before meals	<b>AR</b>	aortic regurgitation
<b>ACB</b>	aorto-coronary bypass	<b>ARF</b>	1. acute renal failure 2. acute respiratory failure 3. acute rheumatic fever
<b>ACE</b>	angiotensin-converting enzyme	<b>ARMD</b>	age-related macular degeneration
<b>ACEI</b>	angiotensin-converting enzyme inhibitors	<b>ART</b>	assisted reproductive technology
<b>ACI</b>	acute coronary insufficiency	<b>AS</b>	1. aortic stenosis 2. left ear (auris sinister)
<b>ACL</b>	anterior cruciate ligament	<b>ASA</b>	acetylsalicylic acid (aspirin)
<b>ACS</b>	acute coronary syndrome	<b>ASCVD</b>	1. arteriosclerotic cardiovascular disease 2. arteriosclerotic cerebrovascular disease
<b>ACTH</b>	adrenocorticotrophic hormone	<b>ASD</b>	atrial septal defect
<b>AD</b>	1. Alzheimer's disease 2. right ear (auris dexter)	<b>ASHD</b>	arteriosclerotic heart disease
<b>ADD</b>	attention deficit disorder	<b>Astig</b>	astigmatism
<b>ADH</b>	antidiuretic hormone	<b>ATF</b>	amniotic fluid test
<b>ADHD</b>	attention deficit/hyperactivity disorder	<b>ATP</b>	adenosine triphosphate
<b>ad lib</b>	as desired, as needed	<b>AU</b>	each ear or both ears (auris uterque)
<b>ADR</b>	adverse drug reaction	<b>AV</b>	aortic valve
<b>AED</b>	automated external defibrillator	<b>AVD</b>	atrioventricular dissociation
<b>AF, A fib</b>	atrial fibrillation	<b>AVE</b>	atrioventricular extrasystole
<b>AG, Ag</b>	antigen	<b>AVHD</b>	acquired valvular heart disease
<b>AH</b>	arterial hypertension	<b>AVM</b>	arteriovenous malformation
<b>AI</b>	1. aortic insufficiency 2. artificial insemination	<b>AVP</b>	aortic valve prolapse
<b>AIDS</b>	acquired immune deficiency syndrome	<b>AWO</b>	airway obstruction
<b>AIS</b>	aortic isthmic stenosis	<b>B</b>	blood group B
<b>ALL</b>	acute lymphocytic leukemia	<b>BA</b>	bronchial asthma
<b>ALS</b>	amyotrophic lateral sclerosis	<b>BB</b>	Blue Bloater
<b>AMI</b>	1. acute myocardial infarction 2. anterior myocardial infarction	<b>BBB</b>	1. blood-brain barrier 2. bundle-branch block

<b>BCC</b>	basal cell carcinoma	<b>CI</b>	conjunctivitis
<b>BG</b>	blood glucose	<b>CICU</b>	coronary intensive care unit
<b>BGA</b>	blood gas analysis	<b>cir, cirr</b>	cirrhosis
<b>bid, b.i.d.</b>	twice a day	<b>CIRC, cir-cum</b>	circumcision
<b>bili</b>	bilirubin	<b>CKD</b>	chronic kidney disease
<b>BM</b>	bowel movement	<b>CLL</b>	chronic lymphocytic leukemia
<b>BMD</b>	1. Becker muscular dystrophy 2. bone mass density	<b>CML</b>	chronic myeloid leukemia
<b>BMI</b>	body mass index	<b>CNS</b>	central nervous system
<b>BMR</b>	basal metabolic rate	<b>C/O</b>	complains of
<b>BMT</b>	bone marrow transplant	<b>CO</b>	cardiac output
<b>BP</b>	blood pressure	<b>COA</b>	coarctation of the aorta
<b>BPH</b>	benign prostatic hyperplasia	<b>COCM</b>	congestive cardiomyopathy
<b>bpm</b>	beats per minute	<b>COD</b>	cause of death
<b>BS</b>	breathing sounds	<b>COL</b>	colonoscopy
<b>BSA</b>	body surface area	<b>COPD</b>	chronic obstructive pulmonary disease
<b>BW</b>	1. birth weight 2. body weight	<b>CPAP</b>	continuous positive airway pressure
<b>C1</b>	cervical vertebra 1	<b>CPPB</b>	continuous positive pressure breathing
<b>C2</b>	cervical vertebra 2	<b>CPR</b>	cardiopulmonary resuscitation
<b>CA</b>	coronary artery	<b>CR</b>	1. clinical records 2. complete remission
<b>CA, ca</b>	cancer	<b>CRD</b>	1. chronic renal disease 2. chronic respiratory disease
<b>CAD</b>	coronary artery disease	<b>CRF</b>	chronic renal failure
<b>CAS</b>	coronary artery stenosis	<b>CRH</b>	corticotropin-releasing hormone
<b>cath</b>	catheterization	<b>CRI</b>	chronic respiratory insufficiency
<b>CBC</b>	complete blood count	<b>CRP</b>	1. chronic rheumatoid polyarthritis 2. C-reactive protein
<b>CBF</b>	coronary blood flow	<b>CS</b>	clinical staging
<b>CC</b>	chief complaint	<b>CSF</b>	cerebrospinal fluid
<b>CC, card cath</b>	cardiac catheterization	<b>CT</b>	computed tomography
<b>CCCR</b>	closed chest cardiac resuscitation	<b>CTS</b>	carpal tunnel syndrome
<b>CCI</b>	chronic coronary insufficiency	<b>CVA</b>	1. cerebrovascular accident (stroke) 2. costovertebral angle
<b>CCM</b>	congestive cardiomyopathy	<b>CVI</b>	1. cerebrovascular insufficiency 2. chronic venous insufficiency
<b>CCU</b>	coronary care unit	<b>CVS</b>	chorionic villus sampling
<b>CD</b>	communicable disease	<b>CXR</b>	chest X-ray
<b>CDH</b>	congenital dislocation of the hip	<b>cysto</b>	cystoscopy
<b>CF</b>	cystic fibrosis	<b>cyt</b>	1. cytology 2. cytoplasm
<b>CHB</b>	complete heart block	<b>D</b>	dorsal
<b>CHF</b>	congestive heart failure	<b>DAP</b>	diastolic aortic pressure
<b>CHI</b>	closed head injury		
<b>chole</b>	cholecystectomy		
<b>CI</b>	cardiac index		

<b>dB</b>	decibel	<b>EGD</b>	esophagogastroduodenoscopy
<b>DBC</b>	differential blood count	<b>EIA</b>	exercise-induced asthma
<b>DBW</b>	desirable body weight	<b>EM, em</b>	emmetropia
<b>D&amp;C</b>	dilation and curettage	<b>EMG</b>	electromyogram; electromyography
<b>DC</b>	death certificate	<b>ENT</b>	otolaryngologist (ear, nose, throat physician)
<b>DCM</b>	dilated cardiomyopathy	<b>EP</b>	ectopic pregnancy
<b>DD</b>	differential diagnosis	<b>EPAN</b>	epidural anesthesia
<b>D, dptr</b>	diopter	<b>EPAP</b>	expiratory positive airway pressure
<b>debm</b>	debridement	<b>Epi</b>	epidural anesthesia
<b>DH</b>	delayed hypersensitivity	<b>epidem</b>	epidemic
<b>DI</b>	diabetes insipidus	<b>EPO</b>	erythropoietin
<b>DIC</b>	disseminated intravascular coagulation	<b>ER</b>	1. ejection rate 2. Emergency Room 3. epigastric region
<b>DIP</b>	distal interphalangeal joint	<b>ERT</b>	estrogen replacement therapy
<b>DIPJ</b>	distal interphalangeal joint	<b>ESP</b>	end-systolic pressure
<b>DISH</b>	diffuse idiopathic skeletal hyperostosis	<b>ESRD</b>	end-stage renal disease
<b>DIU</b>	drug induced ulcer	<b>ESV</b>	end-systolic volume
<b>DJD</b>	degenerative joint disease	<b>EUP</b>	extrauterine pregnancy
<b>DLE</b>	disseminated lupus erythematosus	<b>FAP</b>	familial adenomatous polyposis
<b>DM</b>	1. diabetes mellitus 2. diastolic murmur	<b>FBM</b>	fat body mass
<b>DMD</b>	Duchenne muscular dystrophy	<b>FBS</b>	fasting blood sugar
<b>DNA</b>	deoxyribonucleic acid	<b>Fe</b>	iron
<b>DR, DRP</b>	diabetic retinopathy	<b>FECG</b>	fetal electrocardiogram
<b>DRE</b>	digital rectal examination	<b>FEV1</b>	forced expiratory volume in 1 second
<b>DUS</b>	Doppler ultrasound	<b>FFA</b>	free fatty acids
<b>DVT</b>	deep vein thrombosis	<b>FFP</b>	fresh frozen plasma
<b>D5W</b>	dextrose, 5% in water	<b>FH</b>	family history
<b>Dx</b>	diagnosis	<b>FHR</b>	fetal heart rate
<b>EA</b>	enteral alimentation	<b>FHS</b>	fetal heart sound
<b>EB</b>	ectopic beat	<b>FHx</b>	family history
<b>EBV</b>	Epstein-Barr virus	<b>FM</b>	fetal movements
<b>ECF</b>	extracellular fluid	<b>FMP</b>	first menstrual period
<b>ECG, EKG</b>	electrocardiogram	<b>fMRI</b>	functional magnetic resonance imaging
<b>Ecz</b>	eczema	<b>FNA</b>	fine needle aspiration biopsy
<b>ED</b>	erectile dysfunction	<b>FNTC</b>	fine-needle transhepatic cholangiography
<b>ED50</b>	mean effective dose	<b>FPG</b>	fasting plasma glucose
<b>EDAP</b>	end-diastolic aortic pressure	<b>FSH</b>	follicle-stimulating hormone
<b>EDP</b>	end-diastolic pressure	<b>FT</b>	Falot's tetralogy
<b>EDV</b>	end-diastolic volume	<b>FUB</b>	functional uterine bleeding
<b>EEG</b>	electroencephalogram		
<b>EGA</b>	estimated gestational age		

<b>Fx</b>	fracture	<b>HPI</b>	history of present illness
<b>g</b>	gram	<b>HPV</b>	human papillomavirus
<b>G, glc</b>	glaucoma	<b>HR</b>	heart rate
<b>GA</b>	general anesthesia	<b>HRP</b>	high risk pregnancy
<b>GBS</b>	Guillan-Barré syndrome	<b>HRT</b>	hormone replacement therapy
<b>GCS</b>	Glasgow Coma Score	<b>HS</b>	heart sounds
<b>GD</b>	Graves' disease	<b>h.s.</b>	at bedtime (hour of sleep)
<b>GE</b>	gastroenteritis	<b>Hx</b>	history
<b>GERD</b>	gastroesophageal reflux disease	<b>Hz</b>	Hertz
<b>GFR</b>	glomerular filtration rate	<b>HZV</b>	herpes zoster virus
<b>GH</b>	growth hormone	<b>IAS</b>	interatrial septum
<b>GI</b>	gastrointestinal	<b>IBD</b>	inflammatory bowel disease
<b>GIH</b>	gastrointestinal hemorrhage	<b>IBS</b>	irritable bowel syndrome
<b>GITT</b>	glucose insulin tolerance test	<b>IC</b>	intermittent claudication
<b>GnRH</b>	gonadotropin-releasing hormone	<b>ICF</b>	intracellular fluid
<b>GTT</b>	glucose tolerance test	<b>ICP</b>	1. infantile cerebral palsy 2. intracranial pressure
<b>GU</b>	genitourinary	<b>ICU</b>	intensive care unit
<b>GVHR</b>	graft-versus-host reaction	<b>ICV</b>	intracellular volume
<b>GYN</b>	gynecology	<b>ICW</b>	intracellular water
<b>HAV</b>	hepatitis A virus	<b>IDD</b>	insulin-dependent diabetes
<b>HB</b>	heart block	<b>IF</b>	interstitial fluid
<b>Hb</b>	hemoglobin	<b>IG, Ig</b>	immunoglobulin
<b>HbA</b>	hemoglobin A	<b>IgA</b>	immunoglobulin A
<b>HBB</b>	His bundle block	<b>IgD</b>	immunoglobulin D
<b>HBE</b>	His bundle electrogram	<b>IgE</b>	immunoglobulin E
<b>HbF</b>	hemoglobin F	<b>IGF</b>	insulin-like growth factor
<b>HbS</b>	hemoglobin S	<b>IgG</b>	immunoglobulin G
<b>HBV</b>	hepatitis B virus	<b>IgM</b>	immunoglobulin M
<b>hCG</b>	human chorionic gonadotropin	<b>IH</b>	inguinal hernia
<b>HCT</b>	hematocrit	<b>IHD</b>	ischemic heart disease
<b>HCV</b>	hepatitis C virus	<b>IM</b>	intramuscular
<b>HDL</b>	high-density lipoprotein	<b>IO</b>	intestinal obstruction
<b>HDV</b>	hepatitis D virus	<b>IOP</b>	intraocular pressure
<b>HF</b>	heart failure	<b>IPPB</b>	intermittent positive pressure breathing
<b>HG</b>	hypoglycemia	<b>ITT</b>	insulin tolerance test
<b>HIV</b>	human immunodeficiency virus	<b>IUD</b>	intrauterine device
<b>HL</b>	Hodgkin lymphoma	<b>IUP</b>	intrauterine pregnancy
<b>HLA</b>	human leukocyte antigen	<b>IV</b>	intravenous
<b>HLR</b>	heart-lung resuscitation	<b>IVDU</b>	intravenous drug use
<b>H&amp;P</b>	history and physical	<b>IVF</b>	in-vitro fertilization

<b>IVS</b>	interventricular septum	<b>MFP</b>	mean filling pressure
<b>JRA</b>	juvenile rheumatoid arthritis	<b>MG</b>	myasthenia gravis
<b>KCl</b>	potassium chloride	<b>mg</b>	milligram
<b>kg</b>	kilogram	<b>MH</b>	1. marital history 2. medical history 3. menstrual history 4. mental health
<b>L</b>	liter	<b>MHC</b>	major histocompatibility complex
<b>LA</b>	left atrium	<b>MHR</b>	maximal heart rate
<b>LAB</b>	left anterior fascicular block	<b>MI</b>	1. mitral insufficiency 2. myocardial infarction
<b>LAHB</b>	left anterior hemiblock	<b>MID</b>	multi-infarction dementia
<b>LASIK</b>	laser-assisted in situ keratomileusis	<b>MIDCAB</b>	minimally invasive direct coronary artery bypass
<b>LBBB</b>	left bundle-branch block	<b>mL, ml</b>	milliliter
<b>LBP</b>	low back pain	<b>MM, mm</b>	malignant melanoma
<b>LBW</b>	low birth weight	<b>mm HG</b>	millimeter mercury
<b>LCA</b>	left coronary artery	<b>MMR</b>	measles, mumps, rubella
<b>LCL</b>	lateral collateral ligament	<b>mono</b>	mononucleosis
<b>L&amp;D</b>	labor and delivery	<b>MP</b>	menstrual period
<b>LDL</b>	low-density lipoprotein	<b>MPB</b>	male pattern baldness
<b>LE</b>	lupus erythematosus	<b>MRI</b>	magnetic resonance imaging
<b>LED</b>	lupus erythematosus disseminatus	<b>MS</b>	1. mitral stenosis 2. multiple sclerosis
<b>LEP, LPT</b>	leptin	<b>MTPJ</b>	metatarsophalangeal joint
<b>LES</b>	lower esophageal sphincter	<b>MV</b>	minute volume
<b>LGL</b>	Lown-Ganong-Levine syndrome	<b>MVCAD</b>	multivessel coronary artery disease
<b>LH</b>	luteinizing hormone	<b>MVD</b>	mitral valve disease
<b>LLQ</b>	left lower quadrant	<b>MVP</b>	mitral valve prolapse
<b>LM</b>	lunar month	<b>NaCl</b>	sodium chloride
<b>LMC</b>	left main coronary	<b>NAFLD</b>	nonalcoholic fatty liver disease
<b>LMP</b>	lumbar puncture	<b>NCGS</b>	non-celiac gluten sensitivity
<b>LN</b>	lymph node	<b>NCWS</b>	non-celiac wheat sensitivity
<b>LOC</b>	levels of consciousness	<b>NE</b>	norepinephrine
<b>LP</b>	lumbar puncture	<b>NER</b>	no evidence of recurrence
<b>LSS</b>	Life Supporting System	<b>NHL</b>	non-Hodgkin lymphoma
<b>LTM</b>	long-term memory	<b>NICU</b>	neonatal intensive care unit
<b>LUQ</b>	left upper quadrant	<b>NPO, npo</b>	nothing by mouth
<b>LV</b>	1. left ventricle 2. left ventricular	<b>NREM</b>	nonrapid eye movement
<b>MAB</b>	monoclonal antibody	<b>NSA</b>	no significant abnormalities
<b>MAOI</b>	monoamine oxidase inhibitor	<b>NSCLC</b>	non-small cell lung cancer
<b>MAP</b>	mean arterial pressure	<b>NSR</b>	normal sinus rhythm
<b>mcg</b>	microgram	<b>O</b>	blood group O
<b>MCL</b>	medial collateral ligament	<b>OAD</b>	occlusive arterial disease
<b>MD</b>	1. macular degeneration 2. muscular dystrophy		
<b>MDR</b>	minimum daily requirement		

<b>OB/GYN</b>	obstetrics and gynecology	<b>PLMI</b>	posterolateral myocardial infarction
<b> OCD</b>	obsessive-compulsive disorder	<b>PM</b>	polymyositis
<b>OD</b>	right eye (oculus dexter)	<b>PM</b>	presystolic murmur
<b>oGTT</b>	oral glucose tolerance test	<b>PMB</b>	postmenopausal bleeding
<b>OPD</b>	outpatient department	<b>PMH</b>	past medical history
<b>OPV</b>	oral polio vaccine	<b>PMI</b>	point of maximal intensity
<b>OR</b>	operating room	<b>PMT</b>	premenstrual tension
<b>ORT</b>	oral rehydration therapy	<b>PNS</b>	peripheral nervous system
<b>OS</b>	left eye (oculus sinister)	<b>p.o., PO</b>	by mouth, orally
<b>OSA</b>	obstructive sleep apnea	<b>pO<sub>2</sub></b>	partial pressure of oxygen
<b>OT</b>	occupational therapy	<b>POM</b>	prescription only medicine
<b>OTC</b>	over the counter	<b>POSTOP;</b> <b>postop</b>	postoperative
<b>OU</b>	each eye or both eyes (oculus uterque)	<b>PP</b>	1. partial pressure 2. posterior pituitary 3. pulse pressure
<b>P</b>	1. physiology 2. posterior	<b>PPH</b>	postpartum hemorrhage
<b>PAD</b>	1. peripheral artery disease 2. prema- ture atrial depolarization	<b>PPI</b>	performance-pulse index
<b>PAM</b>	1. primary amebic meningoencephalitis 2. pulmonary artery mean pressure	<b>PPV</b>	positive pressure ventilation
<b>PAO<sub>2</sub></b>	alveolar oxygen partial pressure	<b>PR</b>	1. partial remission 2. pulse rate
<b>PAP</b>	pulmonary artery pressure	<b>PREOP;</b> <b>preop</b>	preoperative
<b>PAT</b>	paroxysmal atrial tachycardia	<b>PRL</b>	prolactin
<b>p.c.</b>	after meals	<b>PRN, prn</b>	whenever necessary
<b>PCA</b>	patient controlled analgesia	<b>PS</b>	1. pathological staging 2. pulmonary stenosis
<b>PCL</b>	posterior cruciate ligament	<b>PS, ps</b>	psoriasis
<b>pCO<sub>2</sub></b>	partial pressure of carbon dioxide	<b>PSA</b>	prostate-specific antigen
<b>PCV</b>	packed-cell volume	<b>PSVT</b>	paroxysmal supraventricular tachycar- dia
<b>PDGF</b>	platelet-derived growth factor	<b>PT</b>	1. physical therapy 2. prothrombin time
<b>PE</b>	1. physical exam 2. pulmonary embo- lism	<b>PTC</b>	percutaneous transhepatic cholangi- ography
<b>PET</b>	pre-eclamptic toxemia	<b>PTCA</b>	percutaneous transluminal coronary angioplasty
<b>PF<sub>3</sub></b>	platelet factor 3	<b>PTCR</b>	percutaneous transluminal coronary recanalization
<b>PFP</b>	platelet-free plasma	<b>PTE</b>	pulmonary thromboembolism
<b>PFSH</b>	personal, family, social history	<b>PTH</b>	parathyroid hormone
<b>PFT</b>	pulmonary function test	<b>PTR</b>	patella tendon reflex
<b>PHC</b>	primary health care	<b>PTS</b>	post-thrombotic syndrome
<b>PICU</b>	pulmonary intensive care unit	<b>PU</b>	peptic ulcers
<b>PID</b>	pelvic inflammatory disease	<b>PUD</b>	peptic ulcer disease
<b>PIH</b>	pregnancy-induced hypertension		
<b>PIP</b>	proximal interphalangeal joint		
<b>PKD</b>	polycystic kidney disease		
<b>PKU</b>	phenylketonuria		

<b>pulse ox</b>	pulse oximeter	<b>SAP</b>	systemic arterial pressure
<b>PVC</b>	premature ventricular contraction	<b>SBE</b>	shortness of breath on exertion
<b>PVD</b>	peripheral venous disease	<b>SBP</b>	systolic blood pressure
<b>PVR</b>	peripheral vascular resistance	<b>SCA</b>	sickle cell anemia
<b>PVS</b>	1. persistent vegetative state 2. premature ventricular systole	<b>SCC</b>	squamous cell cancer or carcinoma
<b>PVT</b>	paroxysmal ventricular tachycardia	<b>SCD</b>	sickle cell disease
<b>PVVD</b>	peripheral vascular disease	<b>SCID</b>	severe combined immunodeficiency syndrome
<b>qd, q.d.</b>	every day	<b>SCLC</b>	small cell lung cancer
<b>qid., q.i.d.</b>	four times a day	<b>SDH</b>	subdural hematoma
<b>RA</b>	1. rheumatoid arthritis 2. right atrium	<b>SEP</b>	systolic ejection period
<b>RAAS</b>	renin-angiotensin-aldosterone system	<b>SER</b>	systolic ejection rate
<b>RAP</b>	right atrial pressure	<b>SGLT1</b>	sodium-glucose-cotransporter 1
<b>RBBB</b>	right bundle-branch block	<b>SGLT2</b>	sodium-glucose-cotransporter 2
<b>RBC</b>	1. red blood cell 2. red blood count	<b>SIDS</b>	sudden infant death syndrome
<b>RBF</b>	renal blood flow	<b>SLE</b>	systemic lupus erythematosus
<b>RD</b>	retinal detachment	<b>SM</b>	systolic murmur
<b>REM</b>	rapid eye movement	<b>SOB</b>	shortness of breath
<b>Rh-</b>	rhesus negative	<b>SP</b>	systolic pressure
<b>Rh+</b>	rhesus positive	<b>SSS</b>	1. sick sinus syndrome 2. subclavian steal syndrome
<b>RHF</b>	right heart failure	<b>STD</b>	sexually transmitted disease
<b>RHR</b>	resting heart rate	<b>STI</b>	sexually transmitted infection
<b>RLQ</b>	right lower quadrant	<b>STM</b>	short-term memory
<b>RM</b>	range of movement	<b>subq, SubQ,</b>	subcutaneous
<b>RNA</b>	ribonucleic acid	<b>subcu</b>	
<b>RP</b>	radial pulse	<b>SV</b>	stroke volume
<b>RPF</b>	renal plasma flow	<b>SVA</b>	supraventricular arrhythmia
<b>RR</b>	1. recovery room 2. respiratory rate	<b>SVE</b>	supraventricular extrasystole
<b>RSD</b>	repetitive stress disorder	<b>SVES</b>	supraventricular extrasystole
<b>RUQ</b>	right upper quadrant	<b>SVI</b>	stroke volume index
<b>RV</b>	right ventricle	<b>SVRT</b>	supraventricular re-entry tachycardia
<b>Rx</b>	prescription	<b>SVT</b>	supraventricular tachycardia
<b>S1</b>	first heart sound	<b>SWR</b>	sleep-wake rhythm
<b>S2</b>	second heart sound	<b>T3</b>	triiodothyronine
<b>S3</b>	third heart sound	<b>T4</b>	tetraiodothyronine ( thyroxin)
<b>S4</b>	fourth heart sound	<b>tab</b>	tablet
<b>SA</b>	sinus arrhythmia	<b>TAP</b>	transluminal angioplasty
<b>SAA</b>	sinoatrial arrhythmia	<b>TAVB</b>	total atrioventricular block
<b>SAB</b>	subarachnoid bleeding	<b>TB</b>	tuberculosis
<b>SABP</b>	systemic arterial blood pressure	<b>TBA</b>	transluminal balloon angioplasty
<b>SAD</b>	seasonal affective disorder		

<b>TBI</b>	total body irradiation	<b>TW</b>	total body water
<b>TBV</b>	total blood volume	<b>Tx</b>	treatment
<b>TBW</b>	total body water	<b>U/A</b>	urinalysis
<b>TC</b>	1. cytotoxic T cell 2. total cholesterol	<b>UC</b>	ulcerative colitis
<b>TD</b>	tetanus and diphtheria toxoid	<b>UO</b>	urinary output
<b>TEE</b>	transesophageal echocardiography	<b>URI</b>	upper respiratory infection
<b>TENS</b>	transcutaneous electrical nerve stimulation	<b>U/S</b>	ultrasound
<b>TEP</b>	total endoprosthesis	<b>US</b>	ultrasound
<b>TES</b>	transcutaneous electrostimulation	<b>UT</b>	urinary tract
<b>TESD</b>	total end-systolic diameter	<b>UTI</b>	urinary tract infection
<b>TEV</b>	total ejected volume	<b>V, VA</b>	visual acuity
<b>TF</b>	tissue factor	<b>V, vent, ventr</b>	ventral
<b>TH</b>	1. T helper cell 2. thyroid hormone	<b>VBG</b>	venous blood gases
<b>TI</b>	therapeutic index	<b>VD</b>	venereal disease
<b>TIA</b>	transient ischemic attack	<b>VEB</b>	ventricular ectopic beat
<b>Tid, t.i.d.</b>	three times a day	<b>VEGF</b>	vascular-endothelial growth factor
<b>TLA</b>	transluminal angioplasty	<b>VES</b>	ventricular extrasystole
<b>TLC</b>	total lung capacity	<b>VF, V fib</b>	ventricular fibrillation
<b>TMD</b>	temporomandibular disorder	<b>VLDL</b>	very low-density lipoprotein
<b>TMJ</b>	temporomandibular joint	<b>VPB</b>	ventricular premature beat
<b>TMJS</b>	temporomandibular joint syndrome	<b>VPC</b>	1. ventricular premature contraction 2. volume packed cells
<b>TOF</b>	tetralogy of Fallot	<b>VPRC</b>	volume of packed red cells
<b>TOPV</b>	trivalent oral polio vaccine	<b>VS</b>	vital signs
<b>TORCH</b>	toxoplasmosis, other infections, rubella, cytomegalovirus infection, and herpes simplex	<b>VSD</b>	ventricular septal defect
<b>TOS</b>	thoracic outlet syndrome	<b>VT</b>	ventricular tachycardia
<b>tPA</b>	tissue plasminogen activator	<b>VTA</b>	ventricular tachyarrhythmia
<b>TPR</b>	temperature, pulse, respiration	<b>V tach</b>	ventricular tachycardia
<b>TR</b>	temperature, taken rectally	<b>VUR</b>	vesico-ureteral reflux
<b>trach (tube)</b>	tracheostomy tube	<b>VWF</b>	von Willebrand factor
<b>TRH</b>	thyrotropin-releasing hormone	<b>VZV</b>	varicella-zoster virus
<b>Trich</b>	trichomoniasis	<b>WB</b>	whole blood
<b>TSE</b>	testicular self-examination	<b>WBC</b>	1. white blood cell 2. white blood count
<b>TSH</b>	thyroid-stimulating hormone	<b>WBS</b>	whole body scan
<b>TT</b>	tetanus toxoid	<b>WC</b>	whooping cough
<b>TURP</b>	transurethral resection of prostate	<b>WPW</b>	Wolf-Parkinson-White syndrome
<b>TURT</b>	transurethral resection of tumor	<b>ZES</b>	Zollinger-Ellison syndrome
<b>TVH</b>	total vaginal hysterectomy	<b>ZPB</b>	zero pressure breathing

## Answer Keys Test Your Knowledge

### Chapter 1

#### Matching Word Parts

- |             |           |              |              |              |
|-------------|-----------|--------------|--------------|--------------|
| 1. poli(o)- | 2. pre-   | 3. proct(o)- | 4. peri-     | 5. -oma      |
| 6. -algia   | 7. hyper- | 8. inter-    | 9. sterc(o)- | 10. -malacia |

#### True/False

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. T  | 2. F  | 3. T  | 4. F  | 5. T  |
| 6. F  | 7. F  | 8. T  | 9. F  | 10. T |
| 11. T | 12. F | 13. T | 14. F | 15. T |

#### Matching

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. g | 2. f | 3. e | 4. i | 5. h  |
| 6. j | 7. b | 8. d | 9. a | 10. c |

#### Multiple Choice

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. B | 2. C | 3. B | 4. D | 5. B  |
| 6. D | 7. C | 8. A | 9. C | 10. C |

### Chapter 2

#### Matching Word Parts

- |             |             |        |            |                |
|-------------|-------------|--------|------------|----------------|
| 1. adip(o)- | 2. cyt(o)-  | 3. bi- | 4. tetra-  | 5. sacchar(o)- |
| 6. poly-    | 7. hydr(o)- | 8. co- | 9. end(o)- | 10. olig(o)-   |

#### True/False

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. T | 3. F | 4. F | 5. F  |
| 6. T | 7. F | 8. T | 9. F | 10. T |

#### Matching

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. f | 2. i | 3. a | 4. h | 5. j  |
| 6. b | 7. e | 8. g | 9. c | 10. d |

#### Multiple Choice

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. B | 2. D | 3. D | 4. A | 5. C  |
| 6. A | 7. C | 8. C | 9. C | 10. D |

### Chapter 3

#### Matching Word Parts

- |               |              |              |                |            |
|---------------|--------------|--------------|----------------|------------|
| 1. thorac(o)- | 2. crani(o)- | 3. ventr(o)- | 4. abdomin(o)- | 5. hyp(o)- |
| 6. gastr(o)-  |              |              |                |            |

**True/False**

- |       |       |      |      |       |
|-------|-------|------|------|-------|
| 1. T  | 2. T  | 3. F | 4. F | 5. T  |
| 6. F  | 7. T  | 8. T | 9. F | 10. T |
| 11. F | 12. F |      |      |       |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. i | 2. d | 3. a | 4. e | 5. h  |
| 6. c | 7. j | 8. g | 9. f | 10. b |

**Multiple Choice**

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. B  | 2. C  | 3. C  | 4. A  | 5. D  |
| 6. B  | 7. A  | 8. A  | 9. C  | 10. D |
| 11. A | 12. B | 13. D | 14. A | 15. B |

---

**Chapter 4**

**Matching Word Parts**

- |         |             |            |              |         |
|---------|-------------|------------|--------------|---------|
| 1. -oma | 2. hist(o)- | 3. -plasia | 4. -necrosis | 5. neo- |
|---------|-------------|------------|--------------|---------|

**True/False**

- |       |       |      |      |       |
|-------|-------|------|------|-------|
| 1. F  | 2. T  | 3. T | 4. F | 5. F  |
| 6. T  | 7. T  | 8. F | 9. T | 10. T |
| 11. F | 12. T |      |      |       |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. h | 2. e | 3. i | 4. a | 5. j  |
| 6. b | 7. d | 8. g | 9. c | 10. f |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. C | 2. D | 3. D | 4. C | 5. A  |
| 6. D | 7. B | 8. C | 9. C | 10. B |

---

**Chapter 5**

**Matching Word Parts**

- |               |              |              |            |               |
|---------------|--------------|--------------|------------|---------------|
| 1. cutane(o)- | 2. trich(o)- | 3. onych(o)- | 4. xer(o)- | 5. alopec(i)- |
| 6. melan(o)-  |              |              |            |               |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. F | 3. T | 4. T | 5. T  |
| 6. T | 7. F | 8. T | 9. F | 10. F |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. j | 2. e | 3. a | 4. i | 5. b  |
| 6. c | 7. d | 8. f | 9. g | 10. h |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. D | 2. B | 3. A | 4. D | 5. A  |
| 6. D | 7. D | 8. B | 9. C | 10. D |

**Chapter 6**

**Matching Word Parts**

- |              |              |           |           |             |
|--------------|--------------|-----------|-----------|-------------|
| 1. arthr(o)- | 2. myelo(o)- | 3. calci- | 4. -blast | 5. oste(o)- |
| 6. dia-      |              |           |           |             |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. F | 3. T | 4. F | 5. T  |
| 6. F | 7. T | 8. F | 9. T | 10. F |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. g | 2. j | 3. f | 4. a | 5. i  |
| 6. b | 7. c | 8. d | 9. e | 10. h |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. A | 2. B | 3. D | 4. C | 5. C  |
| 6. A | 7. C | 8. D | 9. B | 10. C |

**Chapter 7**

**Matching Word Parts**

- |               |             |                |             |               |
|---------------|-------------|----------------|-------------|---------------|
| 1. brachi(o)- | 2. orth(o)- | 3. spondyl(o)- | 4. pod(o)-  | 5. lumb(o)-   |
| 6. cost(o)-   | 7. chir(o)- | 8. cervic(o)-  | 9. carp(o)- | 10. scoli(o)- |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. T | 2. T | 3. T | 4. F | 5. T  |
| 6. F | 7. F | 8. T | 9. T | 10. T |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. g | 2. j | 3. f | 4. a | 5. i  |
| 6. b | 7. c | 8. d | 9. e | 10. h |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. A | 2. D | 3. B | 4. A | 5. C  |
| 6. D | 7. B | 8. C | 9. B | 10. D |

**Chapter 8**

**Matching Word Parts**

- |                |              |              |              |            |
|----------------|--------------|--------------|--------------|------------|
| 1. glen(o)-    | 2. femor(o)- | 3. cubit(o)- | 4. arthr(o)- | 5. cox(o)- |
| 6. calcane(o)- |              |              |              |            |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. F | 3. F | 4. F | 5. T  |
| 6. F | 7. F | 8. T | 9. F | 10. T |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. e | 2. i | 3. a | 4. j | 5. h  |
| 6. b | 7. c | 8. d | 9. f | 10. g |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. C | 2. A | 3. A | 4. B | 5. D  |
| 6. D | 7. B | 8. C | 9. B | 10. B |
- 

**Chapter 9**

**Matching Word Parts**

- |              |             |          |           |            |
|--------------|-------------|----------|-----------|------------|
| 1. erg(o)-   | 2. sarc(o)- | 3. -gram | 4. -lysis | 5. ten(o)- |
| 6. fasci(o)- | 7. my(o)-   |          |           |            |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. T | 2. F | 3. F | 4. F | 5. T  |
| 6. T | 7. T | 8. T | 9. F | 10. F |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. j | 2. d | 3. g | 4. a | 5. i  |
| 6. b | 7. c | 8. e | 9. f | 10. h |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. C | 2. C | 3. A | 4. C | 5. B  |
| 6. B | 7. C | 8. A | 9. B | 10. D |
- 

**Chapter 10**

**Matching Word Parts**

- |          |              |               |           |        |
|----------|--------------|---------------|-----------|--------|
| 1. ad-   | 2. gloss(o)- | 3. kinesi(o)- | 4. supra- | 5. ab- |
| 6. anti- | 7. quadr(i)- |               |           |        |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. T | 2. F | 3. T | 4. F | 5. T  |
| 6. T | 7. F | 8. F | 9. T | 10. T |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. g | 2. e | 3. a | 4. i | 5. b  |
| 6. j | 7. d | 8. c | 9. f | 10. h |

**Multiple Choice**

- |      |      |      |      |      |
|------|------|------|------|------|
| 1. B | 2. D | 3. C | 4. A | 5. C |
|------|------|------|------|------|

6. A                      7. B                      8. B                      9. A                      10. C

## Chapter 11

### Matching Word Parts

1. cephal(o)-            2. encephal(o)-        3. ment(o)-            4. poli(o)-            5. gli(o)-  
 6. myel(o)-            7. neur(o)-

### True/False

1. T                      2. F                      3. T                      4. T                      5. F  
 6. T                      7. F                      8. T                      9. T                      10. F

### Matching

1. j                      2. e                      3. g                      4. a                      5. b  
 6. i                      7. h                      8. c                      9. d                      10. f

### Multiple Choice

1. D                      2. C                      3. A                      4. C                      5. A  
 6. C                      7. B                      8. B                      9. D                      10. D

## Chapter 12

### Matching Word Parts

1. encephal(o)-        2. cerebr(o)-            3. -algia            4. myel(o)-            5. spin(o)-  
 6. cerebell(o)-

### True/False

1. T                      2. T                      3. T                      4. T                      5. F  
 6. T                      7. T                      8. T                      9. T                      10. F

### Matching

1. f                      2. h                      3. a                      4. j                      5. b  
 6. c                      7. d                      8. i                      9. g                      10. e

### Multiple Choice

1. A                      2. B                      3. D                      4. A                      5. A  
 6. B                      7. A                      8. B                      9. C                      10. A

## Chapter 13

### Matching Word Parts

1. radicul(o)-        2. neur(o)-            3. sympatric(o)-        4. crani(o)-            5. para-

### True/False

1. T                      2. F                      3. F                      4. T                      5. T  
 6. F                      7. T                      8. F                      9. T                      10. F

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. e | 2. h | 3. i | 4. a | 5. g  |
| 6. b | 7. c | 8. d | 9. j | 10. f |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. D | 2. C | 3. A | 4. D | 5. A  |
| 6. C | 7. B | 8. A | 9. C | 10. A |

---

**Chapter 14**

**Matching Word Parts**

- |               |                |              |               |              |
|---------------|----------------|--------------|---------------|--------------|
| 1. acoust(o)- | 2. blephar(o)- | 3. kerat(o)- | 4. olfact(o)- | 5. scler(o)- |
| 6. dacry(o)-  | 7. gusto(o)-   | 8. phac(o)-  | 9. irid(o)-   | 10. ot(o)-   |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. T | 2. F | 3. F | 4. T | 5. T  |
| 6. T | 7. F | 8. F | 9. T | 10. F |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. e | 2. h | 3. j | 4. a | 5. i  |
| 6. c | 7. b | 8. f | 9. g | 10. d |

**Multiple Choice**

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. C  | 2. C  | 3. D  | 4. A  | 5. B  |
| 6. A  | 7. C  | 8. A  | 9. B  | 10. A |
| 11. B | 12. C | 13. C | 14. A | 15. C |

---

**Chapter 15**

**Matching Word Parts**

- |              |               |              |               |              |
|--------------|---------------|--------------|---------------|--------------|
| 1. adeno(o)- | 2. thym(o)-   | 3. kerat(o)- | 4. olfact(o)- | 5. scler(o)- |
| 6. gluc(o)-  | 7. cortic(o)- |              |               |              |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. T | 3. T | 4. F | 5. F  |
| 6. T | 7. T | 8. T | 9. T | 10. T |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. d | 2. h | 3. j | 4. a | 5. b  |
| 6. i | 7. e | 8. c | 9. g | 10. f |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. D | 2. D | 3. C | 4. C | 5. B  |
| 6. B | 7. D | 8. A | 9. B | 10. A |

## Chapter 16

### Matching Word Parts

- |               |             |              |                |             |
|---------------|-------------|--------------|----------------|-------------|
| 1. andr(o)-   | 2. colp(o)- | 3. orchi(o)- | 4. salping(o)- | 5. mast(o)- |
| 6. oophor(o)- | 7. metra-   |              |                |             |

### True/False

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. F  | 2. T  | 3. T  | 4. F  | 5. T  |
| 6. F  | 7. F  | 8. F  | 9. F  | 10. T |
| 11. T | 12. T | 13. T | 14. F | 15. T |
| 16. F | 17. F | 18. T | 19. T | 20. T |

### Matching

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. d  | 2. h  | 3. r  | 4. a  | 5. g  |
| 6. b  | 7. i  | 8. c  | 9. e  | 10. f |
| 11. t | 12. j | 13. p | 14. k | 15. s |
| 16. n | 17. m | 18. q | 19. o | 20. l |

### Multiple Choice

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. B  | 2. C  | 3. A  | 4. C  | 5. A  |
| 6. A  | 7. C  | 8. D  | 9. B  | 10. B |
| 11. C | 12. B | 13. C | 14. A | 15. B |
| 16. B | 17. A | 18. C | 19. C | 20. A |

## Chapter 17

### Matching Word Parts

- |               |               |            |             |             |
|---------------|---------------|------------|-------------|-------------|
| 1. veni-      | 2. aort(o)-   | 3. vas(o)- | 4. card(o)- | 5. atri(o)- |
| 6. valvul(o)- | 7. arteri(o)- |            |             |             |

### True/False

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. T  | 2. F  | 3. T  | 4. F  | 5. F  |
| 6. T  | 7. T  | 8. F  | 9. T  | 10. F |
| 11. F | 12. T | 13. F | 14. T | 15. F |

### Matching

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. d  | 2. n  | 3. k  | 4. a  | 5. o  |
| 6. b  | 7. c  | 8. l  | 9. e  | 10. m |
| 11. f | 12. i | 13. g | 14. j | 15. h |

### Multiple Choice

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. B  | 2. B  | 3. D  | 4. C  | 5. A  |
| 6. C  | 7. D  | 8. C  | 9. C  | 10. D |
| 11. B | 12. D | 13. A | 14. D | 15. D |

## Chapter 18

### Matching Word Parts

- |             |              |           |              |            |
|-------------|--------------|-----------|--------------|------------|
| 1. tachy-   | 2. ather(o)- | 3. hyper- | 4. phleb(o)- | 5. hyp(o)- |
| 6. angi(o)- | 7. brady-    |           |              |            |

### True/False

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. T  | 2. F  | 3. T  | 4. F  | 5. T  |
| 6. T  | 7. F  | 8. T  | 9. F  | 10. T |
| 11. F | 12. T | 13. T | 14. T | 15. T |

### Matching

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. g  | 2. i  | 3. e  | 4. b  | 5. a  |
| 6. n  | 7. d  | 8. o  | 9. l  | 10. m |
| 11. c | 12. h | 13. k | 14. j | 15. f |

### Multiple Choice

- |       |       |       |       |       |
|-------|-------|-------|-------|-------|
| 1. A  | 2. B  | 3. D  | 4. C  | 5. A  |
| 6. B  | 7. B  | 8. B  | 9. B  | 10. A |
| 11. B | 12. D | 13. B | 14. D | 15. B |
- 

## Chapter 19

### Matching Word Parts

- |              |              |               |               |               |
|--------------|--------------|---------------|---------------|---------------|
| 1. eosin(o)- | 2. leuk(o)-  | 3. thromb(o)- | 4. erythr(o)- | 5. coagul(o)- |
| 6. -blast    | 7. embol(o)- |               |               |               |

### True/False

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. F | 3. T | 4. F | 5. F  |
| 6. T | 7. T | 8. F | 9. T | 10. F |

### Matching

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. i | 2. f | 3. e | 4. a | 5. j  |
| 6. b | 7. c | 8. d | 9. g | 10. h |

### Multiple Choice

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. B | 2. D | 3. C | 4. B | 5. B  |
| 6. A | 7. B | 8. D | 9. B | 10. B |
- 

## Chapter 20

### Matching Word Parts

- |                  |                  |              |                |              |
|------------------|------------------|--------------|----------------|--------------|
| 1. lymph(o)-     | 2. lymphaden(o)- | 3. splen(o)- | 4. tonsill(o)- | 5. immun(o)- |
| 6. lymphangi(o)- |                  |              |                |              |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. T | 2. F | 3. T | 4. F | 5. T  |
| 6. F | 7. T | 8. T | 9. T | 10. F |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. e | 2. f | 3. g | 4. i | 5. b  |
| 6. j | 7. d | 8. c | 9. a | 10. h |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. B | 2. C | 3. B | 4. D | 5. A  |
| 6. B | 7. D | 8. D | 9. C | 10. A |

**Chapter 21**

**Matching Word Parts**

- |                |               |              |               |             |
|----------------|---------------|--------------|---------------|-------------|
| 1. alveol(o)-  | 2. laryng(o)- | 3. pneum(o)- | 4. pulmon(o)- | 5. rhin(o)- |
| 6. pharyng(o)- | 7. bronch(o)- |              |               |             |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. T | 2. F | 3. T | 4. T | 5. F  |
| 6. T | 7. T | 8. F | 9. T | 10. T |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. d | 2. i | 3. e | 4. a | 5. h  |
| 6. c | 7. j | 8. b | 9. g | 10. f |

**Multiple Choice**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. B | 2. B | 3. C | 4. B | 5. D  |
| 6. D | 7. D | 8. B | 9. D | 10. D |

**Chapter 22**

**Matching Word Parts**

- |                  |              |              |              |            |
|------------------|--------------|--------------|--------------|------------|
| 1. chol(e)-      | 2. hepat(o)- | 3. lapar(o)- | 4. proct(o)- | 5. col(o)- |
| 6. cholecyst(o)- | 7. enter(o)- | 8. gastr(o)- |              |            |

**True/False**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. F | 2. T | 3. F | 4. F | 5. F  |
| 6. F | 7. T | 8. F | 9. T | 10. F |

**Matching**

- |      |      |      |      |       |
|------|------|------|------|-------|
| 1. g | 2. j | 3. a | 4. i | 5. c  |
| 6. h | 7. d | 8. e | 9. b | 10. f |

**Multiple Choice**

- |      |      |      |      |      |
|------|------|------|------|------|
| 1. C | 2. B | 3. D | 4. A | 5. D |
|------|------|------|------|------|

6. C                      7. A                      8. C                      9. B                      10. D
- 

## Chapter 23

### Matching Word Parts

1. -uria                      2. urethr(o)-                      3. ureter(o)-                      4. nephr(o)-                      5. cyst(o)-  
6. pyel(o)-                      7. lith(o)-

### True/False

1. T                      2. F                      3. T                      4. T                      5. F  
6. F                      7. T                      8. F                      9. T                      10. T

### Matching

1. e                      2. g                      3. i                      4. j                      5. a  
6. b                      7. c                      8. d                      9. f                      10. h

### Multiple Choice

1. A                      2. A                      3. D                      4. C                      5. D  
6. B                      7. B                      8. A                      9. B                      10. D
- 

## Chapter 24

### Matching Word Parts

1. -emia                      2. kal(i)-                      3. -osis                      4. natr(i)-                      5. calc(i)-  
6. acid(o)-                      7. alkal(o)-

### True/False

1. F                      2. T                      3. F                      4. T                      5. T  
6. T                      7. F                      8. T                      9. F                      10. T

### Matching

1. f                      2. d                      3. i                      4. a                      5. h  
6. j                      7. b                      8. c                      9. e                      10. g

### Multiple Choice

1. D                      2. A                      3. D                      4. C                      5. C  
6. A                      7. B                      8. B                      9. A                      10. B
-

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# Principles of **Anatomy & Physiology**

Second edition

Part 1 – Course Companion

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