JOHN T. HANSEN

NETTER'S CLINICAL ANATOMY

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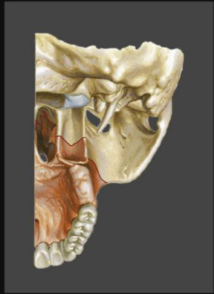

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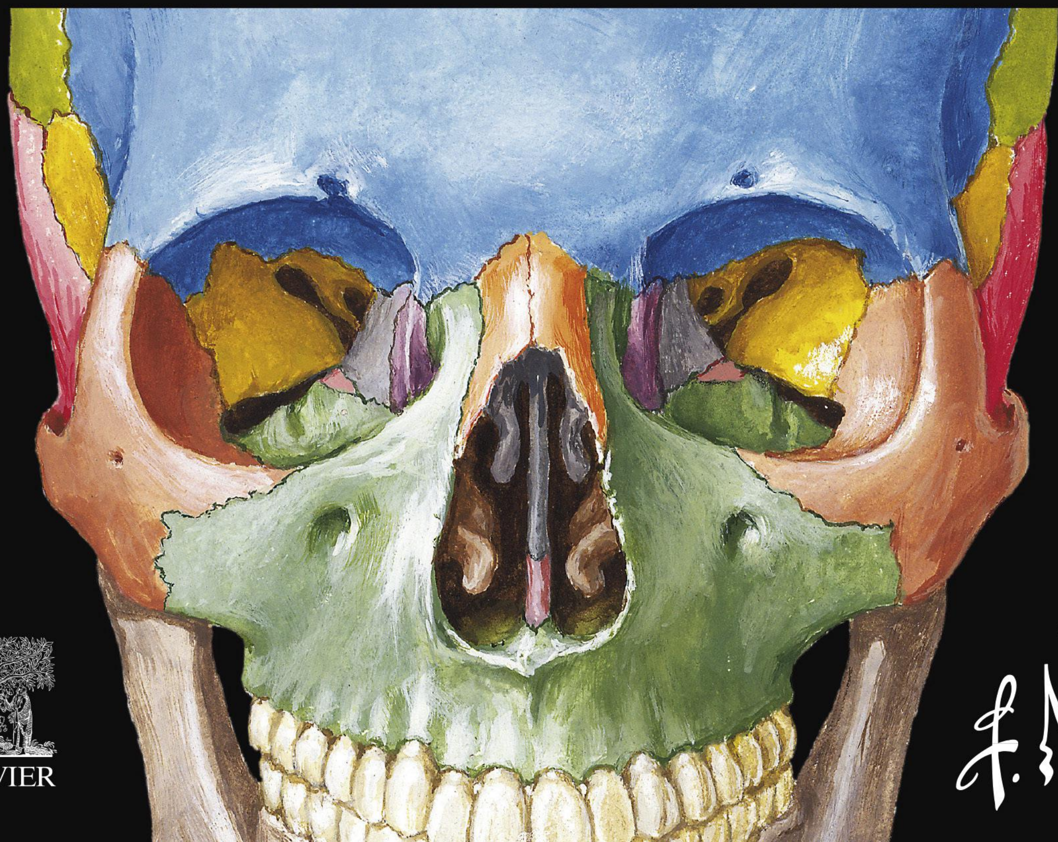

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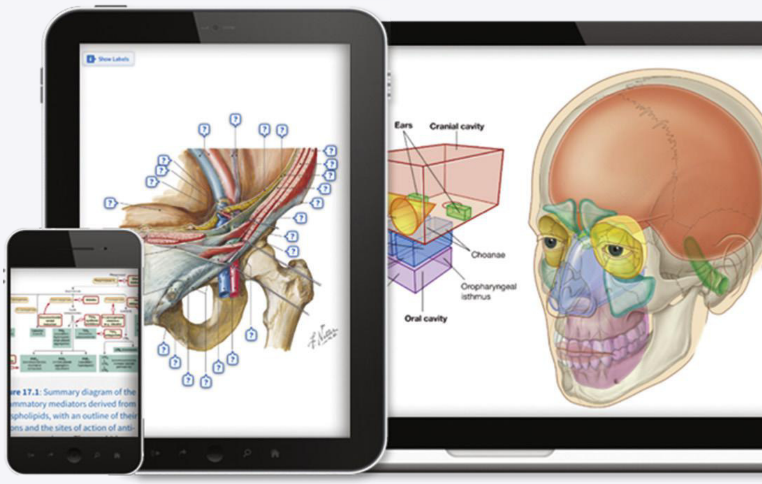

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FIFTH EDITION

NETTER'S CLINICAL ANATOMY

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Elsevier

1600 John F. Kennedy Blvd.
Ste. 1800
Philadelphia, PA 19103-2899

NETTER'S CLINICAL ANATOMY, FIFTH EDITION **ISBN: 978-0-323-82662-4**

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Library of Congress Control Number: 2021948448

Executive Content Strategist: Elyse O'Grady
Senior Content Development Specialist: Marybeth Thiel
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Senior Project Manager: Beula Christopher
Design: Renee Duenow

Printed in India

9 8 7 6 5 4 3 2 1

I dedicate this book to my wife

Paula,

and to my children

Amy and Sean,

and to my grandchildren

Abigail, Benjamin, and Jonathan.

Without their unconditional love, presence, and encouragement,
little would have been accomplished either personally or professionally.
Because we've shared so much, this effort, like all the others,
was multiauthored.

About the Artists

Frank H. Netter, MD

Frank H. Netter was born in 1906, in New York City. He studied art at the Art Students' League and the National Academy of Design before entering medical school at New York University, where he received his medical degree in 1931. During his student years, Dr. Netter's notebook sketches attracted the attention of the medical faculty and other physicians, allowing him to augment his income by illustrating articles and textbooks. He continued illustrating as a sideline after establishing a surgical practice in 1933, but he ultimately opted to give up his practice in favor of a full-time commitment to art. After service in the United States Army during World War II, Dr. Netter began his long collaboration with the CIBA Pharmaceutical Company (now Novartis Pharmaceuticals). This 45-year partnership resulted in the production of the extraordinary collection of medical art so familiar to physicians and other medical professionals worldwide.

In 2005, Elsevier, Inc. purchased the Netter Collection and all publications from Icon Learning Systems. More than 50 publications featuring the art of Dr. Netter are available through Elsevier, Inc. (in the US: www.us.elsevierhealth.com/Netter and outside the US: www.elsevierhealth.com).

Dr. Netter's works are among the finest examples of the use of illustration in the teaching of medical concepts. The 14-book *Netter Collection of Medical Illustrations*, which includes the greater part of the more than 20,000 paintings created by Dr. Netter, became and remains one of the most famous medical works ever published. *The Netter Atlas of Human Anatomy*, first published in 1989, presents the anatomic paintings from the Netter Collection. Now translated into 16 languages, it is the anatomy atlas of choice among medical and health professions students the world over.

The Netter illustrations are appreciated not only for their aesthetic qualities but, more important, for their intellectual content. As Dr. Netter wrote in 1949, ". . . clarification of a subject is the aim and goal of illustration. No matter how beautifully painted, how delicately and subtly rendered a subject may be, it is of little value as a *medical illustration* if it does not serve to make clear some medical point." Dr. Netter's planning, conception, point of view, and approach are what inform his paintings and what make them so intellectually valuable.

Frank H. Netter, MD, physician and artist, died in 1991.

Learn more about the physician-artist whose work has inspired the Netter Reference collection: https://netterimages.com/artist-frank-h-netter.html.

Carlos A. G. Machado, MD

Carlos A. G. Machado was chosen by Novartis to be Dr. Netter's successor. He continues to be the main artist who contributes to the Netter collection of medical illustrations.

Self-taught in medical illustration, cardiologist Carlos Machado has contributed meticulous updates to some of Dr. Netter's original plates and has created many paintings of his own in the style of Netter as an extension of the Netter collection. Dr. Machado's photorealistic expertise and his keen insight into the physician/patient relationship inform his vivid and unforgettable visual style. His dedication to researching each topic and subject he paints places him among the premier medical illustrators at work today.

Learn more about his background and see more of his art at: https://netterimages.com/artist-carlos-a-g-machado.html.

About the Author

John T. Hansen, PhD, is Emeritus Professor of Neuroscience, the former Killian J. and Caroline F. Schmitt Professor and Chair of Neurobiology and Anatomy, and the Associate Dean for Admissions at the University of Rochester Medical Center, Rochester, New York.

Dr. Hansen is the recipient of numerous teaching awards from students at three different medical schools. From 1995–1998, he was Professor and a Robert Wood Johnson Dean's Senior Teaching Scholar. In 1999, he was the recipient of the *Alpha Omega Alpha* Robert J. Glaser Distinguished Teacher Award given annually by the Association of American Medical Colleges to nationally recognized medical educators. From 2004–2005, Dr. Hansen was Chair of the Northeast Group on Student Affairs for the Association of American Medical Colleges. He also was selected twice by Rochester's graduating medical school class to give their Faculty Commencement Address. In 2013, he was selected as an Honored Member of the American Association of Clinical Anatomists, that organization's highest recognition. In 2018, he was elected to membership in *Alpha Omega Alpha* by the Rochester Medical Class of 2018, and in 2020 was the recipient of the Alumni Service Award from the University of Rochester School of Medicine and Dentistry.

Dr. Hansen has served on the USMLE Step Anatomy Test Material Development Committee, and has given numerous Faculty Development Workshops on lecturing skills, exam writing, and basic science curriculum development at Rochester. He also has been invited to consult on basic science curricular development at a number of U.S. and foreign medical schools.

In 2010, Dr. Hansen was the first recipient of the *University of Rochester's Presidential Diversity Award* in recognition of his "advocacy, support, mentoring, planning, and leading the medical school's initiatives to increase the recruitment, retention, excellence, and graduation of students from diverse backgrounds."

Dr. Hansen's investigative research career encompassed the study of the peripheral and central nervous system's dopaminergic pathways, neural plasticity, and central nervous system inflammation. He is the recipient of a prestigious five-year National Institutes of Health Research Career Development Award, a number of foundation and NIH research grants, and has presented his research findings at major U.S. universities and national meetings, as well as at a number of international meetings. In addition to over 100 full-length research publications, he also is the co-author of the 2002 edition of the *Netter's Atlas of Human Physiology*, the lead consulting editor of the 3rd through the 7th editions of the *Netter's Atlas of Human Anatomy* (from 2003–2021), author of *Netter's Anatomy Flash Cards*, the *Essential Anatomy Dissector, Netter's Anatomy Coloring Book*, and is the co-author of the *TNM Staging Atlas with Oncoanatomy,* selected from 630 world wide entries as the Book of the Year in 2008 by the British Medical Association.

Acknowledgments

Compiling the illustrations, researching, and writing *Netter's Clinical Anatomy*, fifth edition, has been both enjoyable and educational, confirming again the importance of lifelong learning in the health professions.

Netter's Clinical Anatomy is for all my students, and I am indebted to all of them who, like many others, yearn for a better view to help them learn the relevant essential anatomy that informs the practice of medicine. Anatomy is a visual science, and Netter's illustrations are the gold standard of medical illustration.

Thanks and appreciation belong to my colleagues and reviewers who provided encouragement and constructive comments that clarified many aspects of the book. Especially, I wish to acknowledge David Lambert, MD, Senior Associate Dean for Undergraduate Medical Education at Rochester, who co-authored the first edition of this book with me and remains a treasured colleague and friend.

At Elsevier, it has been a distinct pleasure to work with dedicated, professional people who massaged, molded, and ultimately nourished the dream beyond even my wildest imagination. I owe much to the efforts of Marybeth Thiel, Senior Content Development Specialist, and Beula Christopher, Senior Project Manager, both of whom kept me organized, focused, and on time. Without them, little would have been accomplished. Thanks and appreciation also to Renee Duenow, Designer and Karen Giacomucci, Illustration Manager. A special thank you to Madelene Hyde, Publishing Director, and Elyse O'Grady, Executive Content Strategist, for believing in the idea and always supporting my efforts. This competent team defines the word "professionalism," and it has been an honor to work with all of them.

Special thanks to Carlos Machado, MD, for his beautiful artistic renderings that superbly complemented, updated, and extended the Netter anatomy collection. Also, I wish to express my thanks to my faculty colleagues at Rochester for their generous and constructive feedback.

Finally, I remain indebted to Frank H. Netter, MD, whose creative genius lives on in generations of biomedical professionals who have learned clinical anatomy from his rich collection of medical illustrations.

To all of these remarkable people, and others, "Thank you."

John T. Hansen, PhD

Preface

Human anatomy is the foundation upon which the education of our medical, dental, and allied health science students is built. However, today's biomedical science curriculum must cover an ever-increasing body of scientific knowledge, often in fewer hours, as competing disciplines and new technologies emerge. Many of these same technologies, especially those in the imaging science fields, have made understanding anatomy even more important and have moved our discipline firmly into the realm of clinical medicine. It is fair to say that competent clinicians and allied health professionals can no longer simply view their anatomical training in isolation from the clinical implications related to that anatomy.

In this context, I am proud to introduce the fifth edition of *Netter's Clinical Anatomy*. Generations of students have used Dr. Frank H. Netter's elegant anatomical illustrations to learn anatomy, and this book combines his beautiful anatomical and embryological renderings with numerous clinical illustrations to help students bridge the gap between normal anatomy and its clinical application across each region of the human body. Additional anatomical images are provided by Carlos Machado, MD. These newly created images by Dr. Machado are based on the latest clinical approaches and provide exquisite examples of the importance of clinical anatomy.

This fifth edition provides succinct text, key bulleted points, and ample summary tables, which offer students a concise textbook description of normal human anatomy, as well as a quick reference and review guide for clinical practitioners. Additionally, over 200 *Clinical Focus* boxes representing some of the more commonly encountered clinical conditions seen in medical practice are integrated with the normal anatomy throughout the textbook. These clinical correlations are drawn from a wide variety of medical fields including emergency medicine, radiology, orthopedics, and surgery, but also include relevant clinical anatomy related to the fields of cardiology, endocrinology, infectious diseases, neurology, oncology, reproductive biology, and urology. By design, the text and clinical correlations are not exhaustive, but are meant to help students focus on the essential elements of anatomy and begin to appreciate some of the clinical manifestations related to that anatomy. Other features of this edition include:

- An updated Introduction to the Human Body chapter designed to introduce students to anatomical terminology and orient them to the body's organ systems
- A set of end-of-chapter clinically oriented multiple choice review questions
- Basic embryology of each system that provides a contextual framework for human postnatal anatomy and several common congenital defects
- Online access with additional *Clinical Focus* boxes

My intent in writing this updated fifth edition of *Netter's Clinical Anatomy* is to provide a concise and focused introduction to clinical anatomy as a viable alternative to the more comprehensive anatomy textbooks, which few students read and/or often find too difficult to navigate when looking for the "essential" anatomical details. Moreover, this textbook serves as an excellent review text for students studying for their Step 1 USMLE examinations, or beginning their clinical clerkships and elective programs. It also serves as an excellent reference text that clinicians will find useful for their own review and for patient education.

The text is by no means comprehensive, but does provide the essential anatomy needed by the generalist physician-in-training that is commonly encountered in the first year of medical school. I have intentionally focused on the anatomy that a first-year student might be expected to grasp and carry forward into his or her clerkship training, especially in this day and age when anatomy courses are often streamlined and laboratory dissection exercises abbreviated. Those students, who by choice, choose to enter specialties where advanced anatomical training is required (e.g., surgical specialties, radiology, physical therapy, etc.) may encounter a need for additional anatomical expertise that will be provided by their graduate medical or allied health education. By meeting the needs of the beginning student and providing ample detail for subsequent review or handy reference, my hope is that *Netter's Clinical Anatomy* will be the anatomy textbook of choice that will actually be read and used by students throughout their undergraduate medical or allied health careers.

I hope that you, the health science student-in-training or the physician-in-practice, will find *Netter's Clinical Anatomy* the valuable link you've searched for to enhance your understanding of clinical anatomy as only Frank Netter can present it.

John T. Hansen, PhD

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Introduction to the Human Body

1. TERMINOLOGY

Anatomical Position

The study of anatomy requires a clinical vocabulary that defines position, movements, relationships, and planes of reference, as well as the systems of the human body. The study of anatomy can be by **body region** or by **body organ systems**. Generally, courses of anatomy in the United States approach anatomical study by regions, integrating all applicable body systems into the study of a particular region. This textbook therefore is arranged regionally, and for those studying anatomy for the first time, this initial chapter introduces you to the major body systems that you will encounter in your study of anatomy. You will find it extremely helpful to refer back to this introduction as you encounter various body systems in your study of regional anatomy.

By convention, anatomical descriptions of the human body are based on a person in the **anatomical position** (Fig. 1.1), as follows:

- Standing erect and facing forward
- Arms hanging at the sides with palms facing forward
- Legs placed together with feet facing forward

Terms of Relationship and Body Planes

Anatomical descriptions often are referenced to one or more of three distinct body planes (Fig. 1.2 and Table 1.1), as follows:

- **Sagittal plane:** a vertical plane that divides the body into equal right and left halves (median or midsagittal plane) or a plane parallel to the median sagittal plane (parasagittal) that divides the body into unequal right and left portions.
- **Frontal (coronal) plane:** a vertical plane that divides the body into anterior and posterior portions (equal or unequal); this plane is at right angles to the median sagittal plane.
- **Transverse (axial) plane:** a horizontal plane that divides the body into superior and inferior portions (equal or unequal) and is at right angles to both the median sagittal and the frontal planes (sometimes called *cross sections*).

Key terms of relationship used in anatomy and the clinic are summarized in Table 1.1. A structure or feature closer to the front of the body is considered *anterior* (ventral), and one closer to the back is termed *posterior* (dorsal). The terms *medial* and *lateral* are used to distinguish a structure or feature in relationship to the midline; the nose is medial to the ear, and in anatomical position, the nose also is anterior to the ear. Sometimes these terms of relationship are used in combination (e.g., *superomedial,* meaning closer to the head and nearer the median sagittal plane).

Movements

Body movements usually occur at the joints where two or more bones or cartilages articulate with one another. Muscles act on joints to accomplish these movements and may be described as follows: "The biceps muscle flexes the forearm at the elbow." Fig. 1.3 summarizes the terms of movement.

Anatomical Variability

The human body is remarkably complex and remarkably consistent anatomically, but normal variations do exist, often related to size, gender,

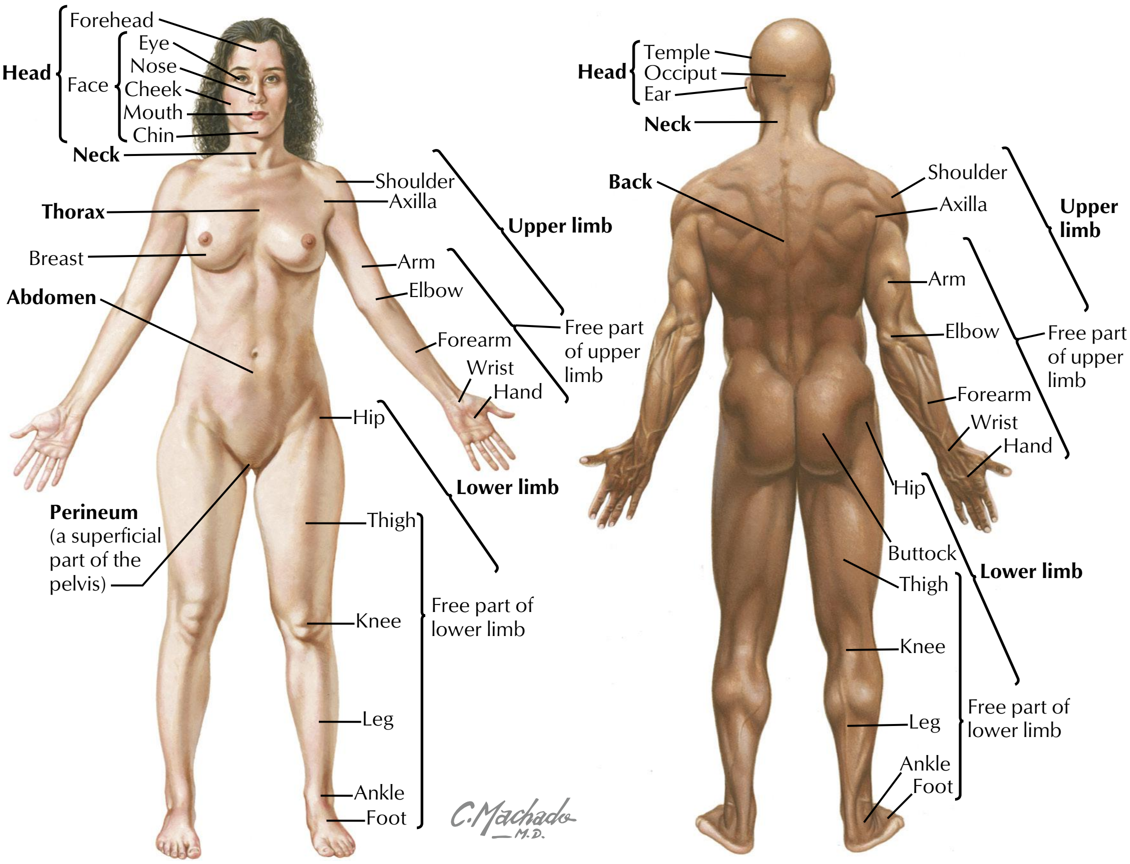


FIGURE 1.1 Surface Anatomy: Regions. (From *Netter's atlas of human anatomy*, ed 8, Plates 2 and 3; S-2 and S-3.)

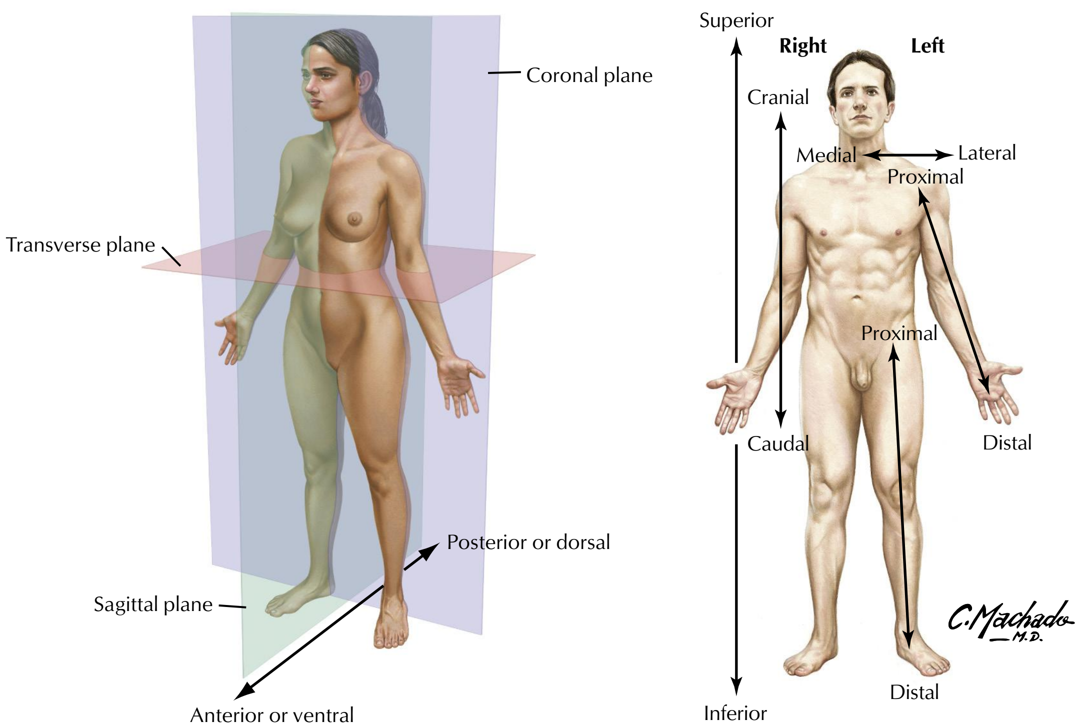


FIGURE 1.2 Body Planes and Terms of Anatomical Relationship. (From *Netter's atlas of human anatomy*, ed 8, Plate 1; S-1.)

TABLE 1.1 General Terms of Anatomical Relationship

TERM	DEFINITION	TERM	DEFINITION
Anterior (ventral)	Near the front	Median plane	Divides body into equal right and left parts
Posterior (dorsal)	Near the back		
Superior (cranial)	Upward, or near the head	Midsagittal plane	Median plane
Inferior (caudal)	Downward, or near the feet	Sagittal plane	Divides body into unequal right and left parts
Medial	Toward the midline or median plane		
		Frontal (coronal) plane	Divides body into equal or unequal anterior and posterior parts
Lateral	Farther from the midline or median plane		
Proximal	Near a reference point	Transverse plane	Divides body into equal or unequal superior and inferior parts (cross sections)
Distal	Away from a reference point		
Superficial	Closer to the surface		
Deep	Farther from the surface		

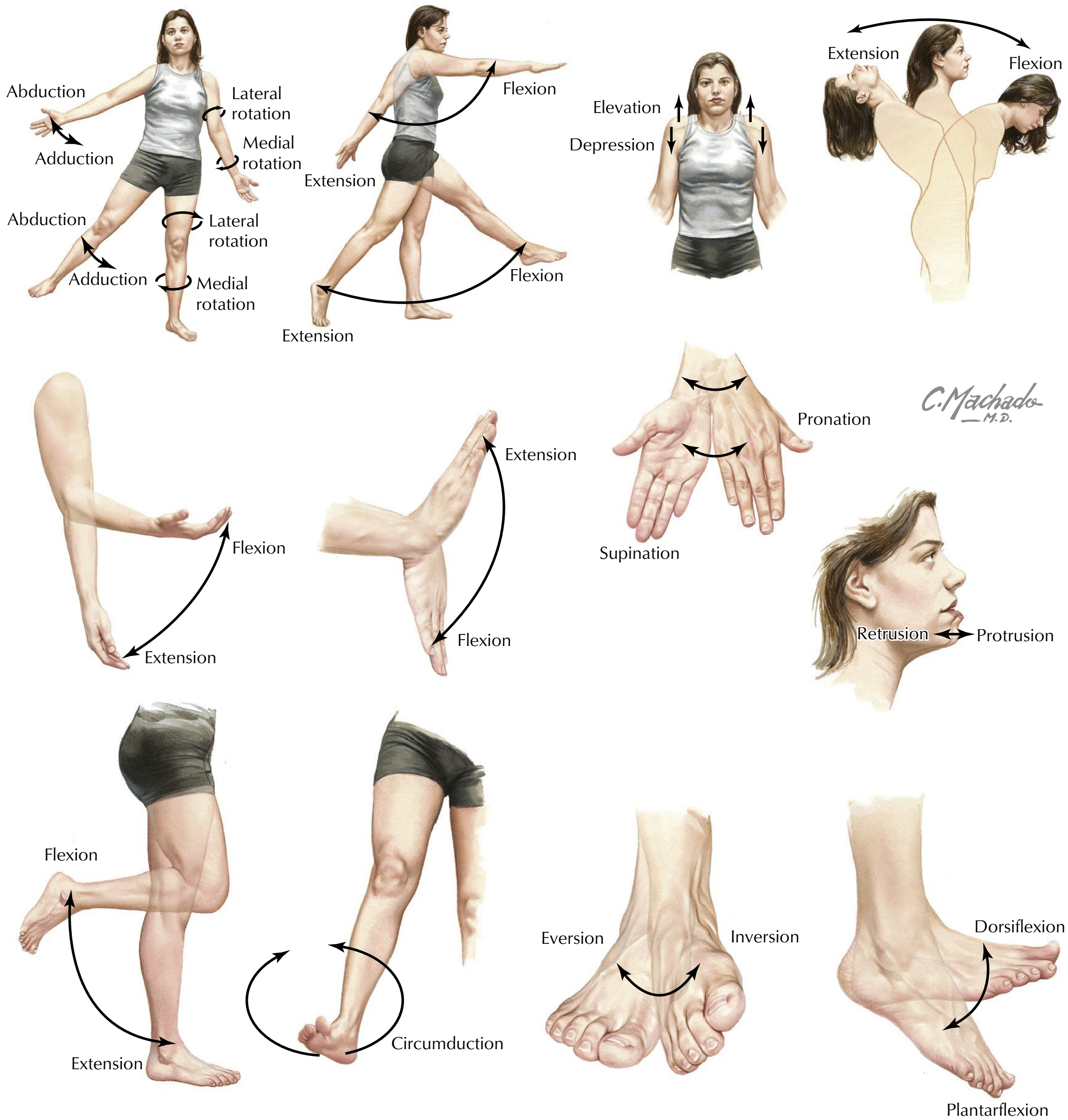


FIGURE 1.3 Terms of Movement. (From *Netter's atlas of human anatomy*, ed 8, Plate 11; S-265.)

age, number, shape, and attachment. Variations are particularly common in the following structures:

- **Bones:** the fine features of bones (processes, spines, articular surfaces) may be variable depending on the forces working on a bone.
- **Muscles:** they vary with size and fine details of their attachments (it is better to learn their actions and general attachments rather than focus on detailed exceptions).
- **Organs:** the size and shape of some organs will vary depending on their normal physiology or pathophysiologic changes that have occurred previously.
- **Arteries:** they are surprisingly consistent, although some variation is seen in the branching patterns, especially in the lower neck (subclavian branches) and in the pelvis (internal iliac branches).
- **Veins:** they are consistent, although variations, especially in size and number of veins, can occur and often can be traced to their complex embryologic development; veins generally are more numerous than arteries, larger, and more variable.

2. SKIN

The skin is the largest organ in the body, accounting for about 15% to 20% of the total body mass, and has the following functions:

- *Protection:* against mechanical abrasion and in immune responses, as well as prevention of dehydration.
- *Temperature regulation:* largely through vasodilation, vasoconstriction, fat storage, or activation of sweat glands.
- *Sensations:* to touch by specialized mechanoreceptors such as pacinian and Meissner's corpuscles; to pain by nociceptors; and to temperature by thermoreceptors.
- *Endocrine regulation:* by secretion of hormones, cytokines, and growth factors, and by synthesis and storage of vitamin D.
- *Exocrine secretions:* by secretion of sweat and oily sebum from sebaceous glands.

The skin consists of two layers (Fig. 1.4):

- **Epidermis:** is the outer protective layer consisting of a keratinized stratified squamous epithelium derived from the embryonic ectoderm.
- **Dermis:** is the dense connective tissue layer that gives skin most of its thickness and support, and is derived from the embryonic mesoderm.

Fascia is a connective tissue sheet that may contain variable amounts of fat. It can interconnect structures, provide a conduit for vessels and nerves (termed **neurovascular bundles**), and provide a sheath around structures (e.g., muscles) that permits them to slide over one another easily. **Superficial**

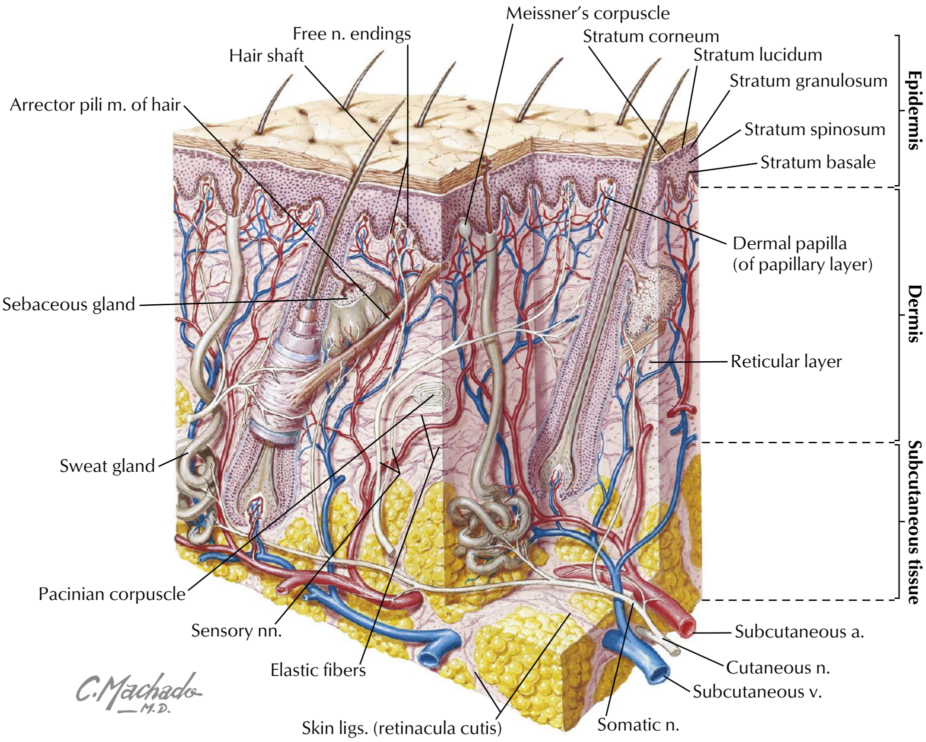
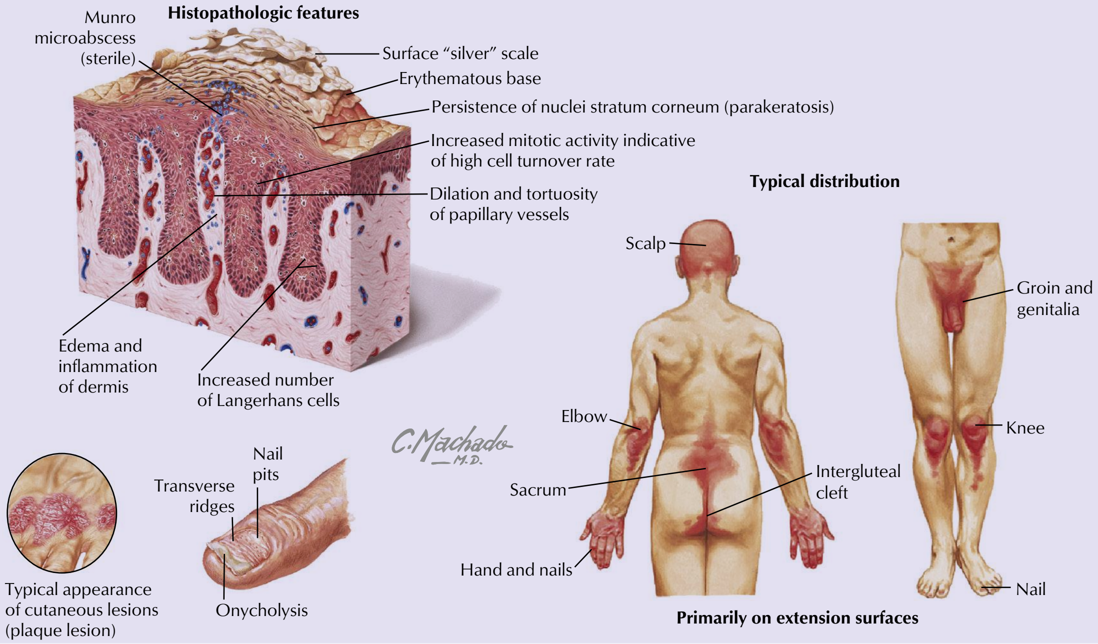


FIGURE 1.4 Layers of the Skin. (From *Netter's atlas of human anatomy*, ed 8, Plate 12; S-4.)

Clinical Focus 1.1

Psoriasis

Psoriasis is a chronic inflammatory skin disorder that affects approximately 1% to 3% of the population (women and men equally). It is characterized by defined red plaques capped with a surface scale of desquamated epidermis. Although the pathogenesis is unknown, psoriasis seems to involve a genetic predisposition.



fascia is attached to and lies just beneath the dermis of the skin and can vary in thickness and density; it acts as a cushion, contains variable amounts of fat, and allows the skin to glide over its surface. **Deep fascia** usually consists of a dense connective tissue, is attached to the deep surface of the superficial fascia, and often ensheathes muscles and divides them into functional groupings. Extensions of the deep fascia encasing muscles also may course inward and attach to the skeleton, dividing groups of muscles with **intermuscular septa.** Common injuries to the skin include abrasions, cuts (lacerations), and burns. Burns are classified as follows:

- **First-degree:** burn damage that is limited to the superficial layers of the epidermis; termed a *superficial* burn, clinically it causes erythema (redness of the skin).
- **Second-degree:** burn damage that includes all of the epidermis and extends into the superficial dermis; termed a *partial-thickness* burn, it causes blisters but spares the hair follicles and sweat glands.
- **Third-degree:** burn damage that includes all the epidermis and dermis and may even involve the subcutaneous tissue and underlying deep fascia and muscle; termed a *full-thickness* burn, it causes charring.

3. SKELETAL SYSTEM

Descriptive Regions

The human skeleton is divided into two descriptive regions (Fig. 1.5):

- **Axial skeleton:** includes the bones of the skull, vertebral column (spine), ribs, and sternum, which form the "axis" or central line of the body (80 bones).
- **Appendicular skeleton:** includes the bones of the limbs, including the pectoral and pelvic girdles, which attach the limbs to the body's axis (134 bones).

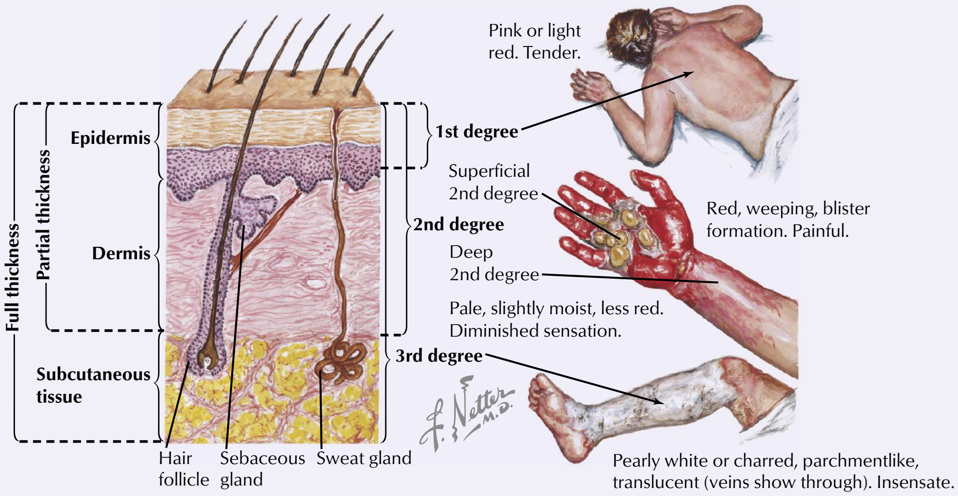
Shapes and Function of Bones

The skeleton is composed of a living, dynamic, rigid connective tissue that forms the bones and cartilages.

Clinical Focus 1.2

Burns

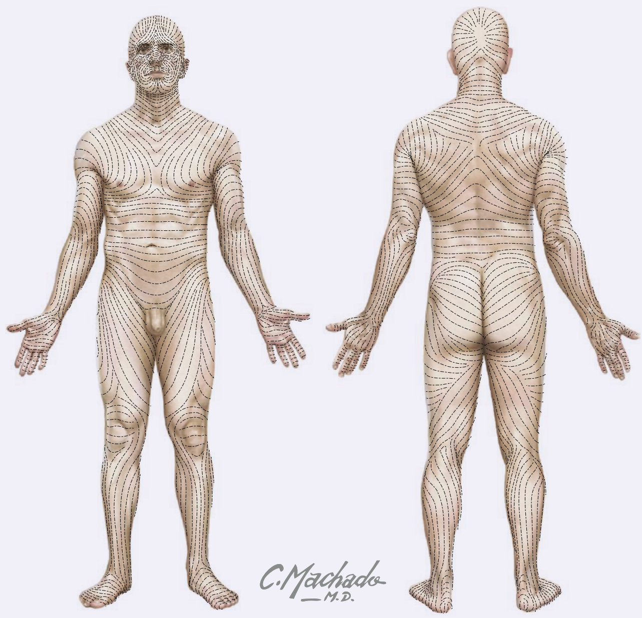
Burns to the skin are classified into three degrees of severity based on the depth of the burn:



Clinical Focus 1.3

Langer's Lines

Collagen in the skin creates tension lines called *Langer's lines.* Surgeons sometimes use these lines to make skin incisions; other times, they may use the natural skin folds. The resulting incision wounds tend to gape less when the incision is parallel to Langer's lines, resulting in a smaller scar after healing. However, skin fold incisions also may conceal the scar following healing of the incision.



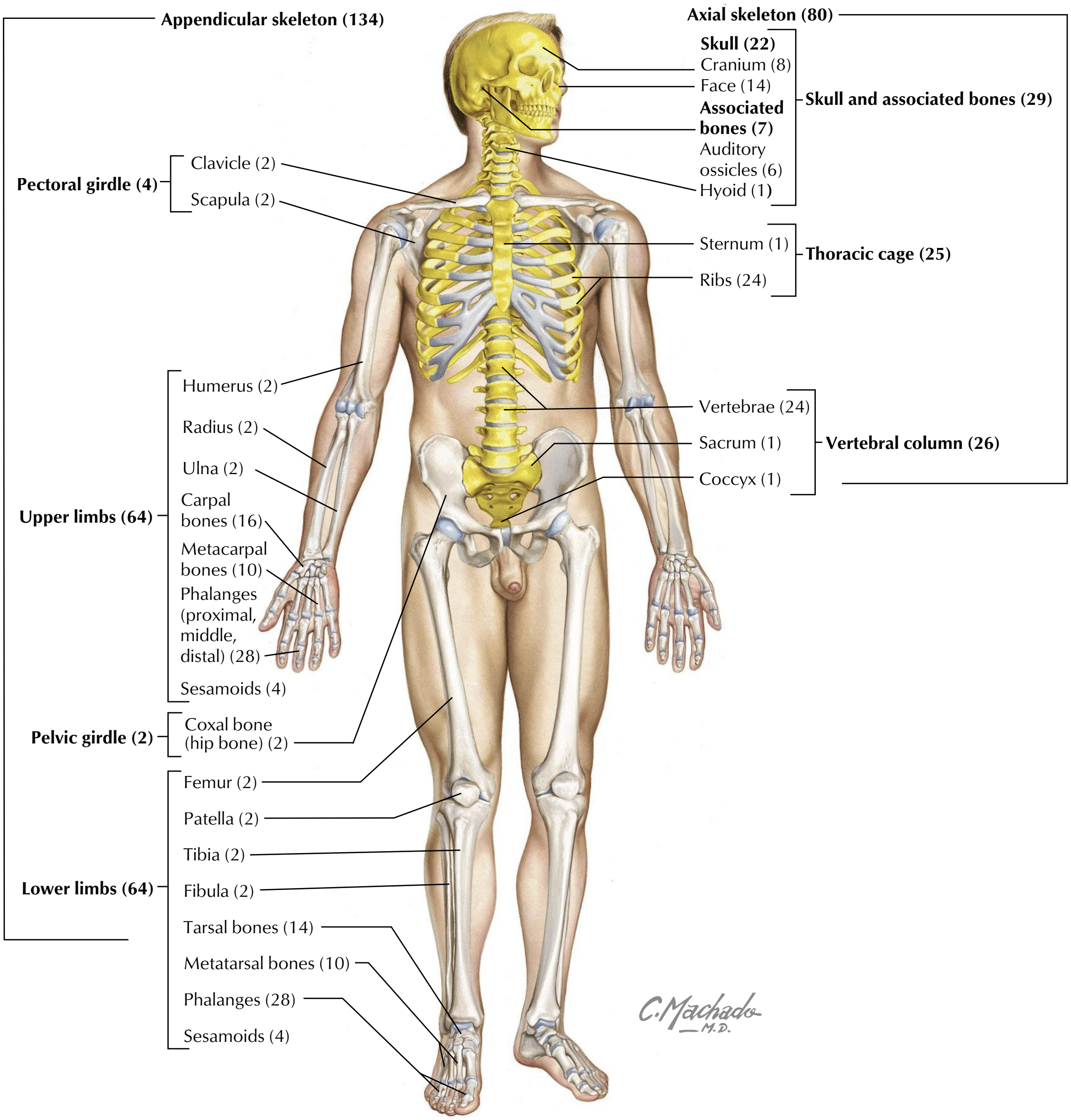


FIGURE 1.5 Axial and Appendicular Regions of Skeleton. (From *Netter's atlas of human anatomy*, ed 8, Plate 8; S-120.)

Generally, humans have about 214 bones, although this number varies, particularly in the number of small sesamoid bones that may be present. (Typically, we have 8 sesamoid bones of the hands and feet.) Cartilage is attached to some bones, especially where flexibility is important, or covers the surfaces of bones at points of articulation. About 99% of the body's calcium is stored in bone, and many bones possess a central cavity that contains bone marrow—a collection of hemopoietic (blood-forming) cells. Most of the bones can be classified into one of the following five shapes (Fig. 1.6):

- Long.
- Short.
- Flat.
- Irregular.
- Sesamoid.

The functions of the skeletal system include:

- Support.
- Protection of vital organs.
- A mechanism, along with muscles, for movement.
- Storage of calcium and other salts, growth factors, and cytokines.
- A source of blood cells.

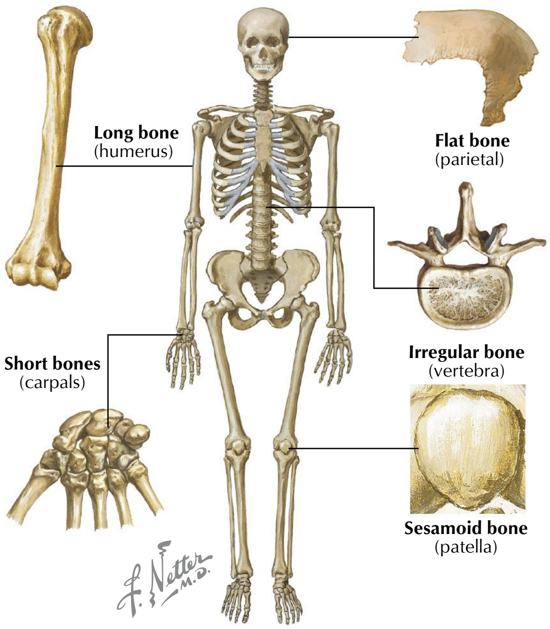


FIGURE 1.6 Bone Classification Based on Shape.

There are two types of bone:

- **Compact:** is a relatively solid mass of bone, commonly seen as a superficial layer of bone, that provides strength.
- **Spongy** (trabecular or cancellous): is a less dense trabeculated network of bone spicules making up the substance of most bones and surrounding an inner marrow cavity.

Long bones also are divided into the following descriptive regions (Fig. 1.7):

- **Epiphysis:** the ends of long bones, which develop from secondary ossification centers.
- **Epiphysial plate:** the site of growth in length; it contains cartilage in actively growing bones.
- **Metaphysis:** the site where the bone's shaft joins the epiphysis and epiphysial plate.
- **Diaphysis:** the shaft of a long bone, which represents the primary ossification center and the site where growth in width occurs.

As a living, dynamic tissue, bone receives a rich blood supply from:

- *Nutrient arteries:* usually one or several larger arteries that pass through the diaphysis and supply the compact and spongy bone, as well as the bone marrow.
- *Metaphysial and epiphysial arteries:* usually arise from articular branches supplying the joint.
- *Periosteal arteries:* numerous small arteries from adjacent vessels that supply the compact bone.

Markings on the Bones

Various surface features of bones (ridges, grooves, and bumps) result from the tension placed on them by the attachment of tendons, ligaments, and fascia, as well as by neurovascular bundles or other structures that pass along the bone. Descriptively, these features include the following:

- **Condyle:** a rounded articular surface covered with articular (hyaline) cartilage.
- **Crest:** a ridge (narrow or wide) of bone.
- **Epicondyle:** a prominent ridge or eminence superior to a condyle.
- **Facet:** a flat, smooth articular surface, usually covered with articular (hyaline) cartilage.
- **Fissure:** a very narrow "slitlike" opening in a bone.
- **Foramen:** a round or oval "hole" in the bone for passage of another structure (nerve or vessel).
- **Fossa:** a "cuplike" depression in the bone, usually for articulation with another bone.
- **Groove:** a furrow in the bone.
- **Line:** a fine linear ridge of bone, but less prominent than a crest.
- **Malleolus:** a rounded eminence.
- **Meatus:** a passageway or canal in a bone.
- **Notch:** an indentation along the edge of a bone.
- **Process:** a bony prominence that may be sharp or blunt.
- **Protuberance:** a protruding eminence on an otherwise smooth surface.
- **Ramus:** a thin part of a bone that joins a thicker process of the same bone.
- **Spine:** a sharp process projecting from a bone.
- **Trochanter:** large, blunt process for muscle tendon or ligament attachment.
- **Tubercle:** a small, elevated process.
- **Tuberosity:** a large, rounded eminence that may be coarse or rough.

Bone Development

Bones develop in one of the following two ways:

- **Intramembranous formation:** most flat bones develop in this way by direct calcium deposition into a mesenchymal (primitive mesoderm) precursor or model of the bone.
- **Endochondral formation:** most long and irregularly shaped bones develop by calcium deposition into a cartilaginous model of the bone that provides a scaffold for the future bone.

The following sequence of events defines endochondral bone formation (Fig. 1.7, *A-F*):

- Formation of a thin collar of bone around a hyaline cartilage model.

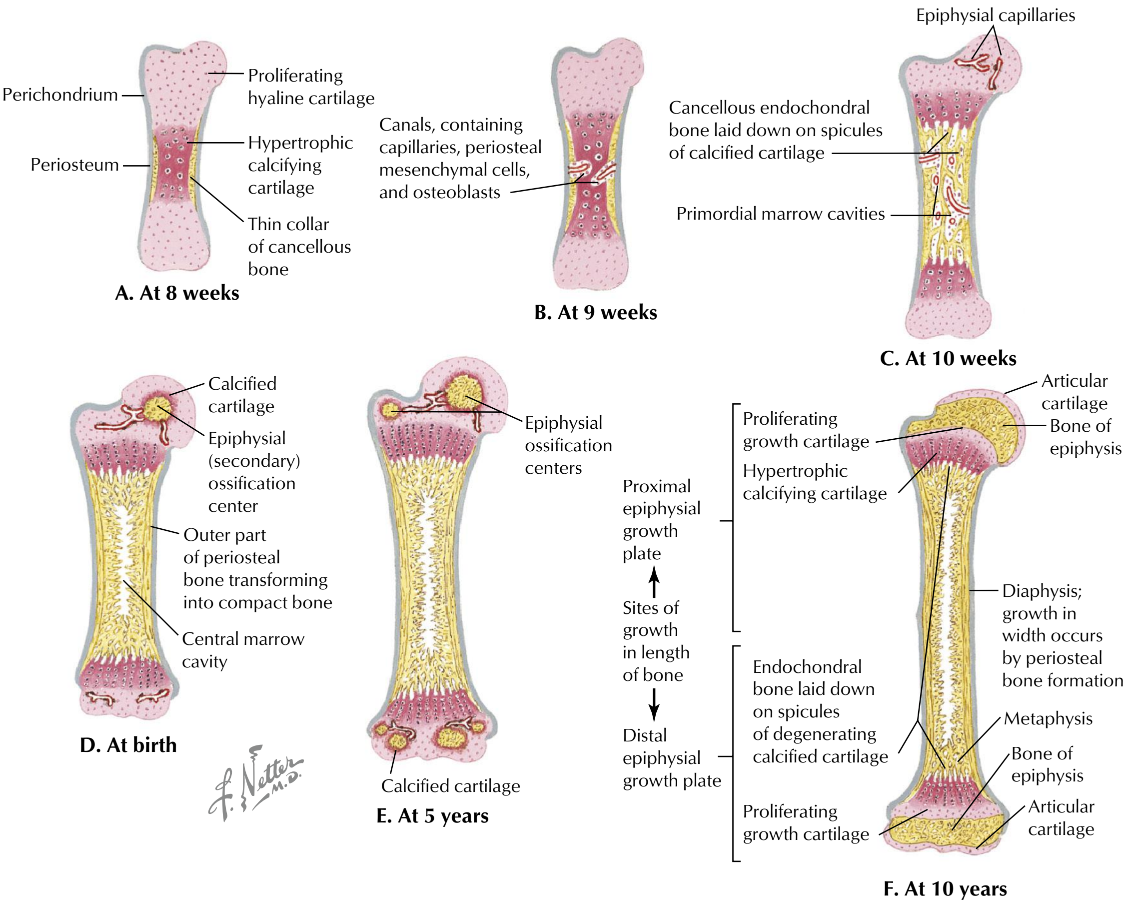


FIGURE 1.7 Growth and Ossification of Long Bones (Midfrontal Sections).

- Cavitation of the primary ossification center and invasion of vessels, nerves, lymphatics, red marrow elements, and osteoblasts.
- Formation of spongy (cancellous) endochondral bone on calcified spicules.
- Diaphysis elongation, formation of the central marrow cavity, and appearance of the secondary ossification centers in the epiphyses.
- Long bone growth during childhood.
- Epiphysial fusion occurring from puberty into maturity (early to mid-20s).

Types of Joints

Joints are the sites of union or articulation of two or more bones or cartilages, and are classified into one of the following three types (Fig. 1.8):

- **Fibrous** (synarthroses): bones joined by fibrous connective tissue.
- **Cartilaginous** (amphiarthroses): bones joined by cartilage, or by cartilage and fibrous tissue.
- **Synovial** (diarthroses): in this most common type of joint, the bones are joined by a joint cavity filled with a small amount of synovial fluid and surrounded by a capsule; the bony articular surfaces are covered with hyaline cartilage.

Fibrous joints include **sutures** (flat bones of the skull), **syndesmoses** (two bones connected by a fibrous membrane), and **gomphoses** (teeth fitting into fibrous tissue-lined sockets).

Cartilaginous joints include **primary** (synchondrosis) joints between surfaces lined by hyaline cartilage (epiphysial plate connecting the diaphysis with the epiphysis), and **secondary** (symphysis) joints between hyaline-lined articular surfaces and an intervening fibrocartilaginous disc. Primary joints allow for growth and some bending, whereas secondary joints allow for strength and some flexibility.

Synovial joints generally allow for considerable movement and are classified according to their shape and the type of movement that they permit (uniaxial, biaxial, or multiaxial movement) (Fig. 1.9), as follows:

- **Hinge** (ginglymus): are uniaxial joints for flexion and extension.
- **Pivot** (trochoid): are uniaxial joints for rotation.

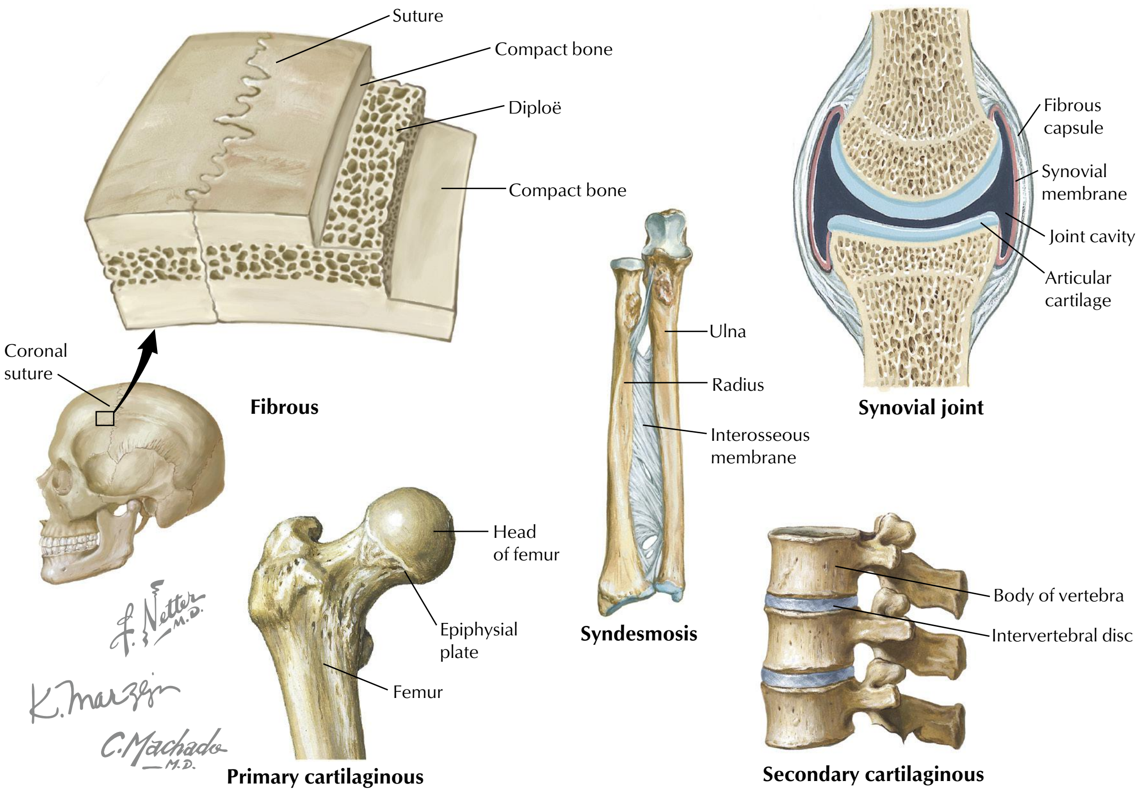


FIGURE 1.8 Types of Joints.

- **Saddle:** are biaxial joints for flexion, extension, abduction, adduction, and circumduction.
- **Condyloid** (ellipsoid; sometimes classified separately): are biaxial joints for flexion, extension, abduction, adduction, and circumduction.
- **Plane** (gliding): are joints that only allow simple gliding movements.
- **Ball-and-socket** (spheroid): are multiaxial joints for flexion, extension, abduction, adduction, mediolateral rotation, and circumduction.

4. MUSCULAR SYSTEM

Muscle cells (fibers) produce contractions (shortenings in length) that result in movement, maintenance of posture, changes in shape, or the propulsion of fluids through hollow tissues or organs. There are three different types of muscle:

- **Skeletal:** striated muscle fibers that are attached to bone and are responsible for movements of the skeleton (sometimes simplistically referred to as *voluntary muscle*).
- **Cardiac:** striated muscle fibers that make up the walls of the heart and proximal portions of the great veins where they enter the heart.
- **Smooth:** nonstriated muscle fibers that line various organ systems (gastrointestinal, urogenital, respiratory), attach to hair follicles, and line the walls of most blood vessels (sometimes simplistically referred to as *involuntary muscle*).

Skeletal muscle is divided into **fascicles** (bundles), which are composed of muscle fibers (muscle cells) (Fig. 1.10). The muscle fiber cells contain longitudinally oriented **myofibrils** that run the full length of the cell. Each myofibril is composed of many **myofilaments,** which are composed of individual **myosin** (thick filaments) and **actin** (thin filaments) that slide over one another during muscle contraction.

Skeletal muscle moves bones at their joints and possesses an **origin** (the muscle's fixed or proximal attachment) and an **insertion** (the muscle's movable or distal attachment). In a few instances, the muscle's origin moves more than its insertion. At the gross level, anatomists classify muscle on the basis of its shape:

- **Flat:** muscle that has parallel fibers, usually in a broad flat sheet with a broad tendon of attachment called an *aponeurosis.*
- **Quadrate:** muscle that has a four-sided appearance.

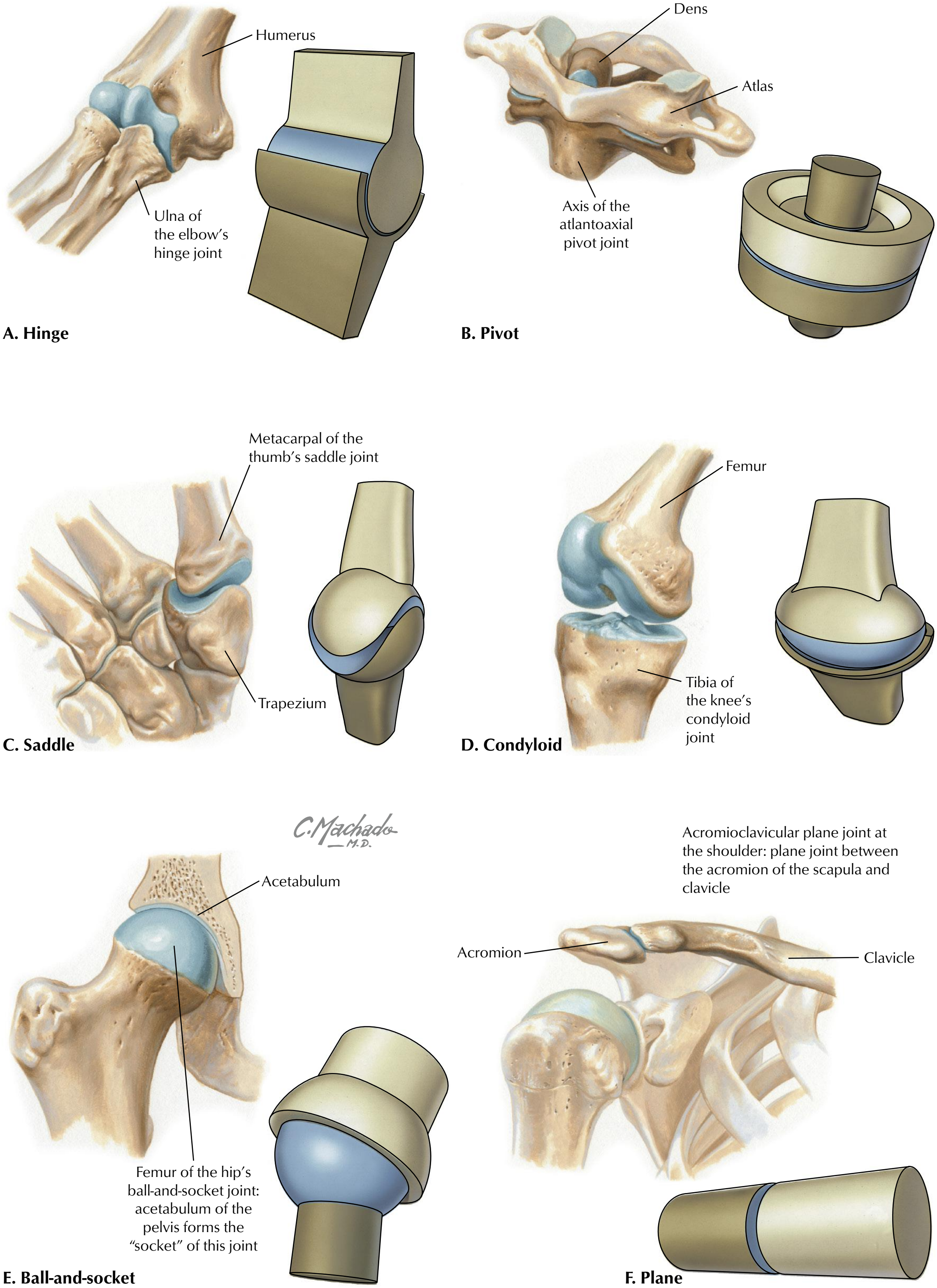
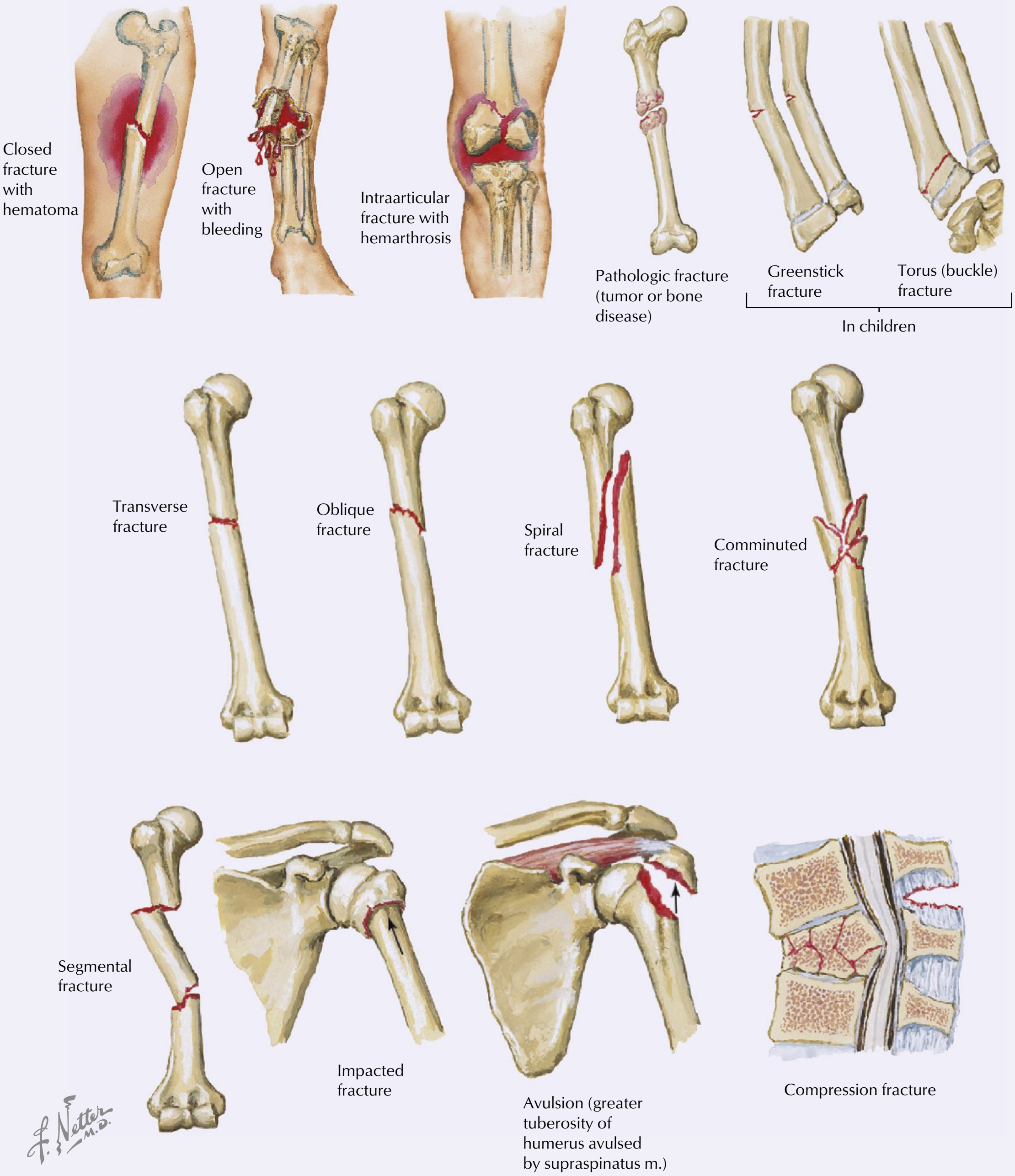


FIGURE 1.9 Types of Synovial Joints. (From *Netter's atlas of human anatomy*, ed 8, Plate 9; S-121.)

Clinical Focus 1.4

Fractures

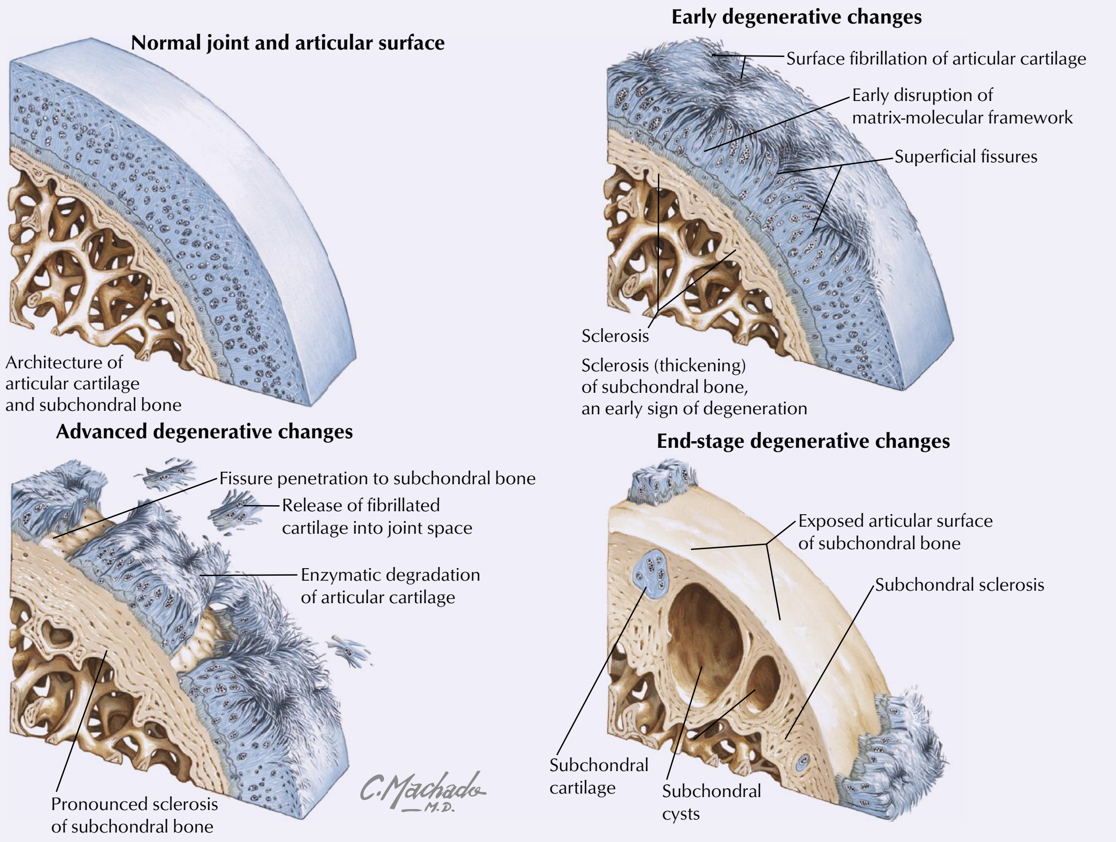
Fractures are classified as either **closed** (the skin is intact) or **open** (the skin is perforated; often referred to as a *compound fracture*). Additionally, the fracture may be classified with respect to its anatomical appearance (e.g., transverse, spiral).



Clinical Focus 1.5

Degenerative Joint Disease

Degenerative joint disease is a catch-all term for osteoarthritis, degenerative arthritis, osteoarthrosis, or hypertrophic arthritis; it is characterized by progressive loss of articular cartilage and failure of repair. **Osteoarthritis** can affect any synovial joint but most often involves the foot, knee, hip, spine, and hand. As the articular cartilage is lost, the joint space (the space between the two articulating bones) becomes narrowed, and the exposed bony surfaces rub against each other, causing significant pain.



- **Circular:** muscle that forms sphincters that close off tubes or openings.
- **Digastric:** two muscles in series and connected by a common tendon.
- **Fusiform:** muscle that has a wide center and tapered ends.
- **Pennate:** muscle that has a feathered appearance (unipennate, bipennate, or multipennate forms).

Muscle contraction shortens the muscle. Generally, skeletal muscle contracts in one of three ways:

- *Reflexive:* involuntary or through automatic contraction; seen in the diaphragm during respiration or in the reflex contraction elicited by tapping a muscle's tendon with a reflex hammer.
- *Tonic:* maintains "muscle tone," a slight contraction that may not cause movement but allows the muscle to maintain firmness necessary for stability of a joint and important in maintaining posture.
- *Phasic:* includes two types of contraction: **isometric contraction**, where no movement occurs but the muscle maintains tension to hold a position (stronger than tonic contraction); and **isotonic contraction**, where the muscle shortens to produce movement.

Muscle contraction that produces movements can act in several ways, depending on the conditions:

- **Agonist:** the main muscle responsible for a specific movement (the "prime mover").

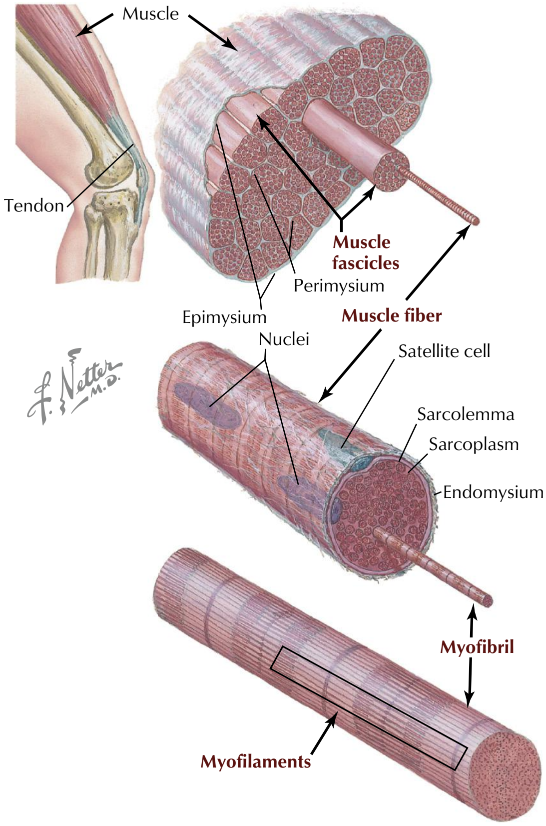


FIGURE 1.10 Structure of Skeletal Muscle.

- **Antagonist:** the muscle that opposes the action of the agonist; as an agonist muscle contracts, the antagonistic muscle relaxes.
- **Fixator:** one or more muscles that steady the proximal part of a limb when a more distal part is being moved.
- **Synergist:** a muscle, or muscles, that complements (works synergistically with) the contraction of the agonist, either by assisting with the movement generated by the agonist or by reducing unnecessary movements that would occur as the agonist contracts.

5. CARDIOVASCULAR SYSTEM

The cardiovascular system consists of (1) the **heart**, which pumps blood into the *pulmonary circulation* for gas exchange and into the *systemic circulation* to supply the body tissues; and (2) the **vessels** that carry the blood, including the arteries, arterioles, capillaries, venules, and veins. The blood passing through the cardiovascular system consists of the following formed elements (Fig. 1.11):

- Platelets.
- White blood cells (WBCs).
- Red blood cells (RBCs).
- Plasma.

Blood is a fluid connective tissue that circulates through the arteries to reach the body's tissues and then returns to the heart through the veins. When blood is "spun down" in a centrifuge tube, the RBCs precipitate to the bottom of the tube, where they account for about 45% of the blood volume. This is called the **hematocrit** and normally ranges from 40% to 50% in males and 35% to 45% in females. The next layer is a **"buffy coat,"** which makes up slightly less than 1% of the blood volume and includes WBCs (leukocytes) and platelets. The remaining 55% of the blood volume is the **plasma** and includes water, plasma proteins, clotting factors, and various solutes (**serum** is plasma with the clotting factors removed). The functions of blood include:

- Transport of dissolved gases, nutrients, metabolic waste products, and hormones to and from tissues.
- Prevention of fluid loss via clotting mechanisms.
- Immune defense.
- Regulation of pH and electrolyte balance.
- Thermoregulation through blood vessel constriction and dilation.

Blood Vessels

Blood circulates through the blood vessels (Fig. 1.12). **Arteries** carry blood away from the heart, and **veins** carry blood back to the heart. Arteries generally have more smooth muscle in their walls than veins and are responsible for most of the vascular resistance, especially the small muscular arteries and arterioles. **Capillaries** are simple microscopic tubes with very thin walls connecting arteries to veins; they constitute more that 90% of all the blood vessels in the human body. At any point in time, most of the blood resides in the veins (about 64%) and is returned to the right side of the heart; thus veins are the capacitance vessels, capable of holding most of the blood, and are far more variable and numerous than their corresponding arteries.

The major arteries are illustrated in Fig. 1.13. At certain points along the pathway of the systemic arterial circulation, large and medium-sized arteries lie near the body's surface and can be used to take a **pulse** by compressing the artery against a hard underlying structure (usually a bone). The most distal pulse from the heart is usually taken over the dorsalis pedis artery on the dorsum of the foot or by the posterior tibial artery pulse, at the medial aspect of the ankle.

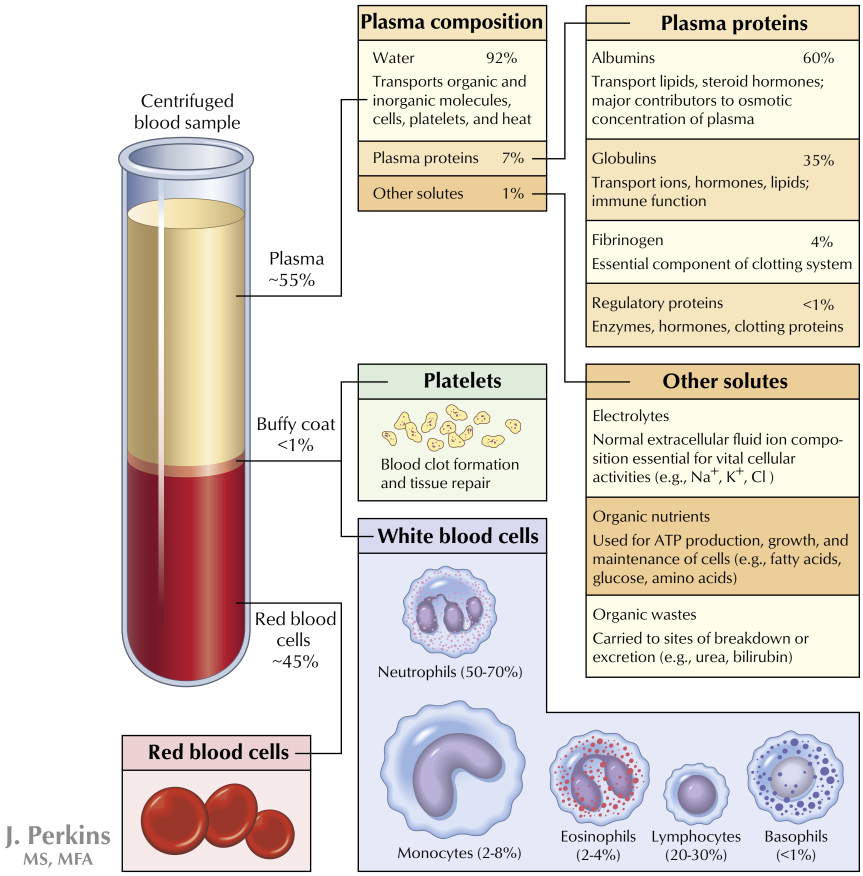


FIGURE 1.11
Composition of Blood.

The major veins are illustrated in Fig. 1.14. Veins are capacitance vessels because they are distensible and numerous and can serve as reservoirs for the blood. Because veins carry blood at low pressure and often against gravity, larger veins of the limbs and lower neck region have numerous valves that aid in venous return to the heart (several other veins throughout the body may also contain valves). Both the presence of valves and the contractions of adjacent skeletal muscles help to "pump" the venous blood against gravity and toward the heart. In most of the body, the veins occur as a superficial set of veins in the subcutaneous tissue that connects with a deeper set of veins that parallel the arteries. Types of veins include:

- *Venules:* these are very small veins that collect blood from the capillary beds.
- *Veins:* these are small, medium, and large veins that contain some smooth muscle in their walls, but not as much as their corresponding arteries.
- *Portal venous systems:* these are veins that transport blood between two capillary beds (e.g., the hepatic portal system draining the GI tract).

Heart

The heart is a hollow muscular (cardiac muscle) organ that is divided into four chambers (Figs. 1.12, 1.15):

- **Right atrium:** receives the blood from the systemic circulation via the superior and inferior venae cavae.
- **Right ventricle:** receives the blood from the right atrium and pumps it into the pulmonary circulation via the pulmonary trunk and pulmonary arteries.
- **Left atrium:** receives the blood from the lungs via pulmonary veins.
- **Left ventricle:** receives the blood from the left atrium and pumps it into the systemic circulation via the aorta.

The atria and ventricles are separated by atrioventricular valves (**tricuspid** on the right side and **mitral** on the left side) that prevent the blood from refluxing into the atria when the ventricles contract. Likewise, the two major outflow vessels, the pulmonary trunk from the right ventricle and the ascending aorta from the left ventricle, possess the

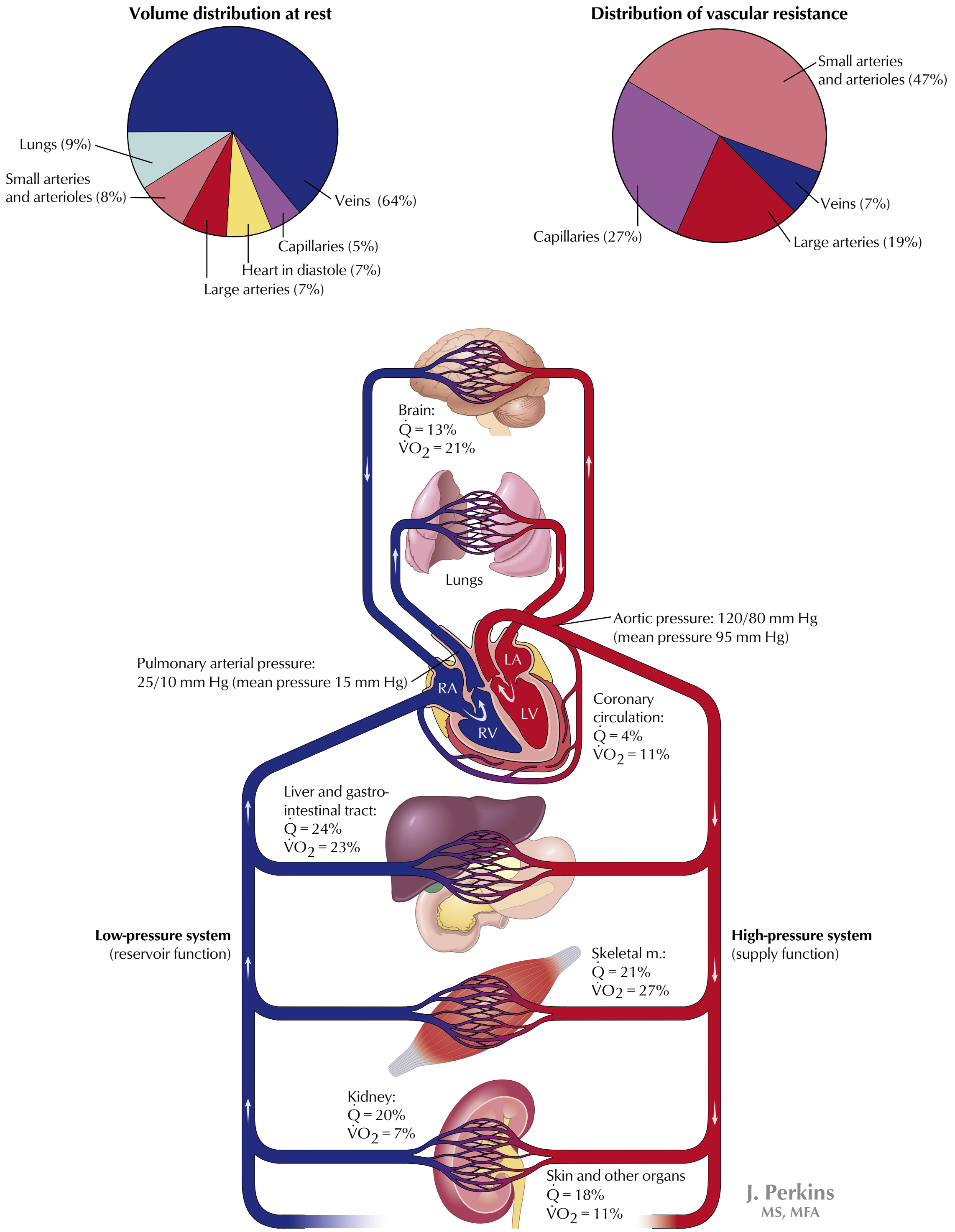


FIGURE 1.12 General Organization of Cardiovascular System. The amount of blood flow per minute ($\dot{Q}$), as a percentage of the cardiac output, and the relative percentage of oxygen used per minute ($\dot{V}O_2$) by the various organ systems are noted.

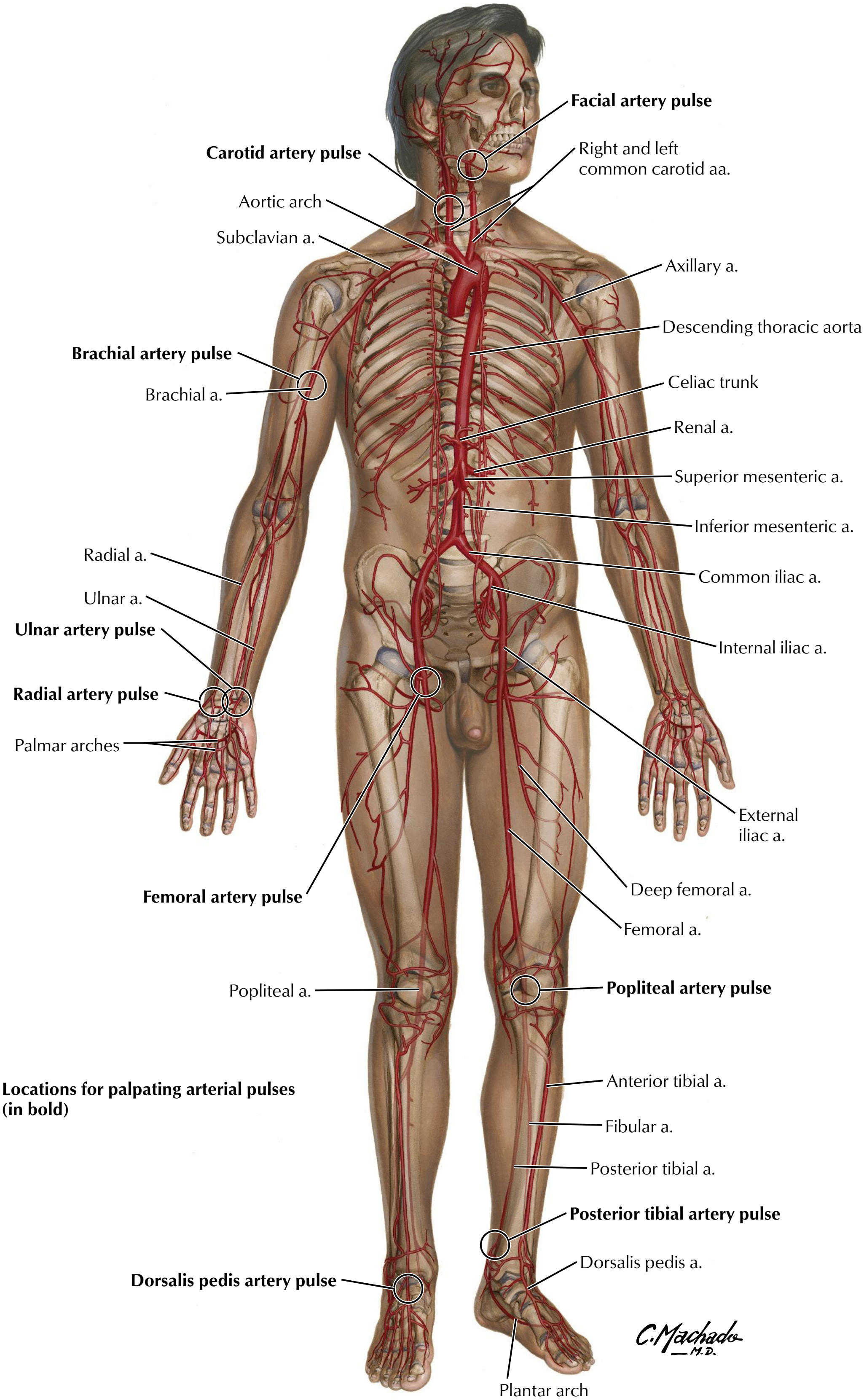


FIGURE 1.13 Major Arteries and Pulse Points. (From *Netter's atlas of human anatomy*, ed 8, Plate 14; S-303.)

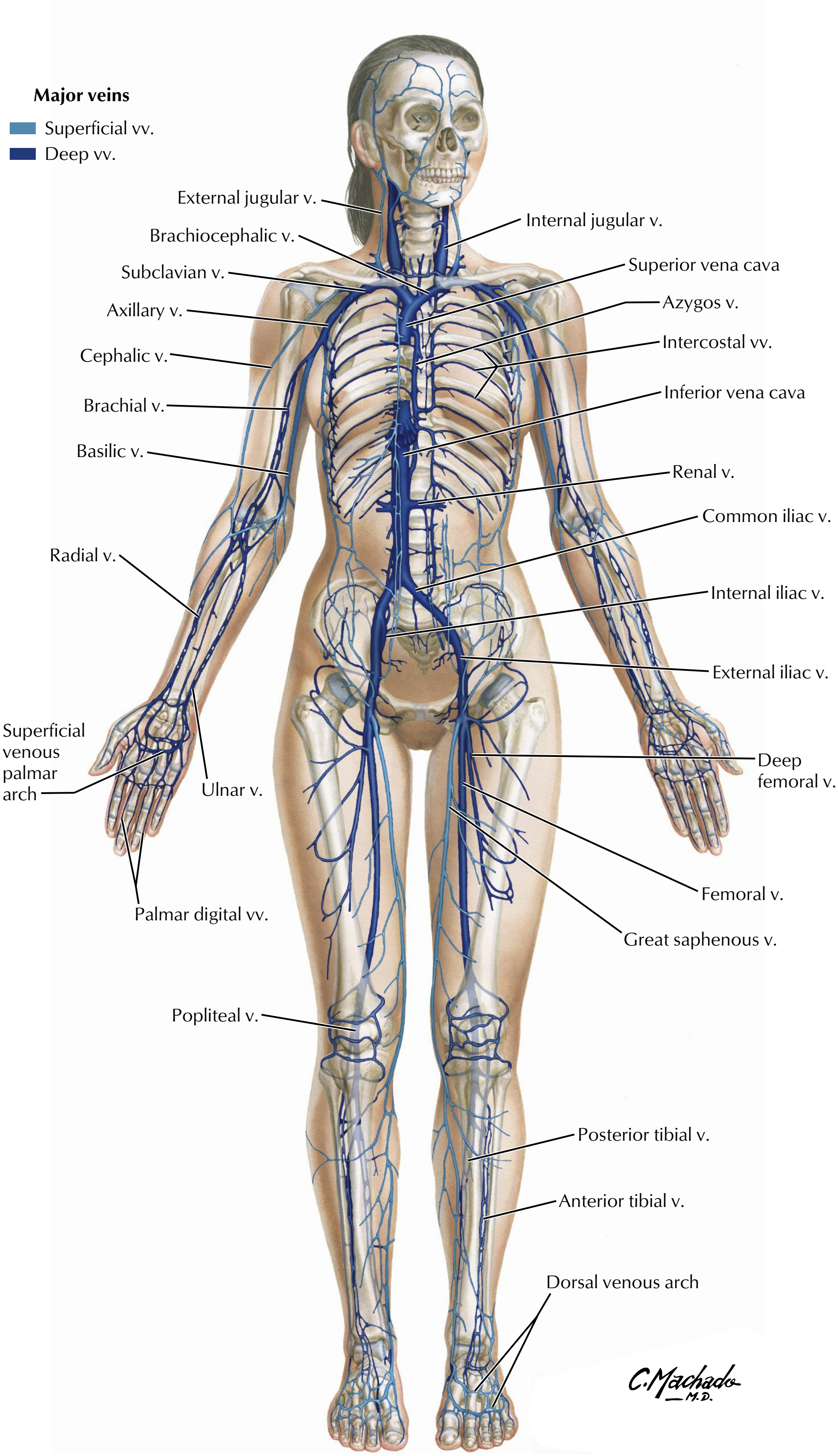
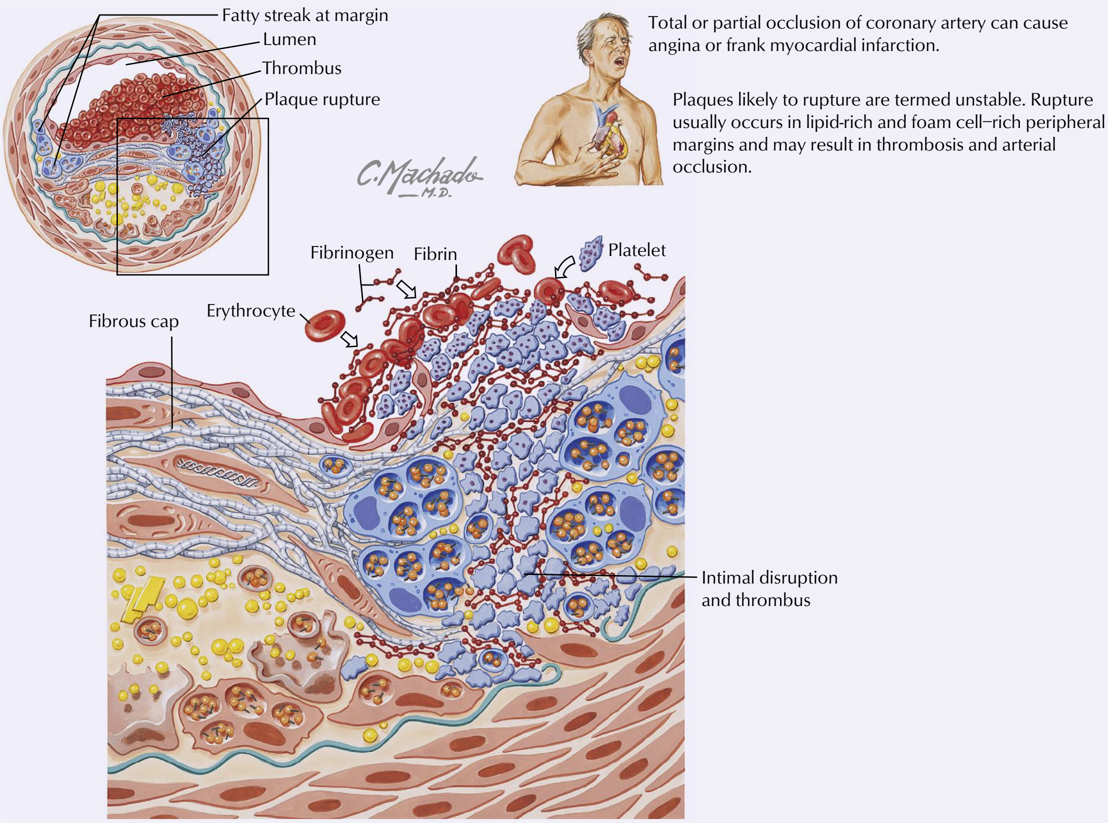


FIGURE 1.14 Major Veins. (From *Netter's atlas of human anatomy*, ed 8, Plate 15; S-304.)

Clinical Focus 1.6

Atherogenesis

Thickening and narrowing of the arterial wall and eventual deposition of lipid into the wall can lead to one form of **atherosclerosis.** The narrowed artery may not be able to meet the metabolic needs of the adjacent tissues, which may become ischemic. Multiple factors, including focal inflammation of the arterial wall, may result in this condition. When development of a plaque is such that it is likely to rupture and lead to thrombosis and arterial occlusion, the atherogenic process is termed **unstable plaque formation.**



pulmonary (pulmonic) valve and the **aortic** valve (both semilunar valves), respectively.

6. LYMPHATIC SYSTEM

General Organization

The lymphatic system is intimately associated with the cardiovascular system, both in the development of its lymphatic vessels and in its immune function. The lymphatic system functions to:

- Protect the body against infection by activating defense mechanisms of the immune system.
- Collect tissue fluids, solutes, hormones, and plasma proteins and return them to the circulatory system (bloodstream).
- Absorb fat (chylomicrons) from the small intestine.

Components of the lymphatic system include the following:

- **Lymph:** a watery fluid that resembles plasma but contains fewer proteins and may contain fat, together with cells (mainly lymphocytes and a few RBCs).
- **Lymphocytes:** the cellular components of lymph, including T cells, B cells, and NK cells ("natural killer" cells).
- **Lymph vessels:** an extensive network of vessels and capillaries in the peripheral tissues that transport lymph and lymphocytes.
- **Lymphoid organs:** these are collections of lymphoid tissue, including lymph nodes, aggregates

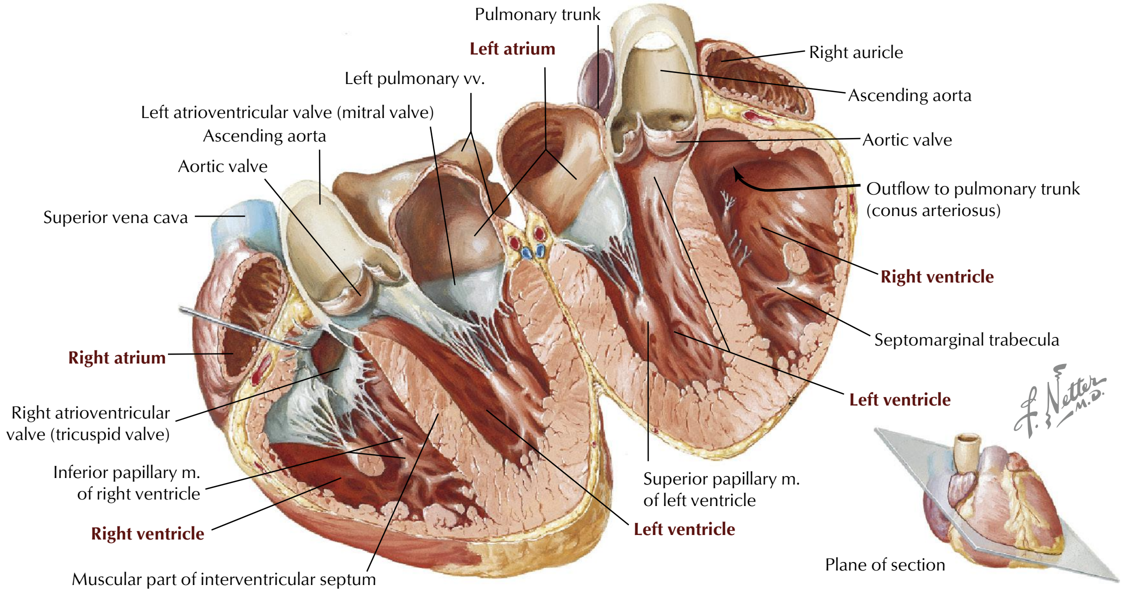


FIGURE 1.15 Chambers of the Heart. (From *Netter's atlas of human anatomy*, ed 8, Plate 245; S-316.)

of lymphoid tissue along the respiratory and gastrointestinal passageways, tonsils, thymus, spleen, and bone marrow.

Lymphatic Drainage

The body is about 60% fluid by weight, with 40% located in the intracellular fluid (ICF) compartment (inside the cells) and the remaining 20% in the extracellular fluid (ECF) compartment. The lymphatics are essential for returning ECF, solutes, and protein (lost via the capillaries into the ECF compartment) back to the bloodstream, thus helping to maintain a normal blood volume. On average, the lymphatics return about 3.5 to 4.0 liters of fluid per day back to the bloodstream. The lymphatics also distribute various hormones, nutrients (fats from the bowel and proteins from the interstitium), and waste products from the ECF to the bloodstream.

Lymphatic vessels transport lymph from everywhere in the body via major lymphatic channels. The majority of lymph (about 75-80%) ultimately collects in the **thoracic duct** for delivery back to the venous system (joins the veins at the union of the left internal jugular and left subclavian veins) (Fig. 1.16). A much smaller **right lymphatic duct** drains the right upper quadrant of the body lymphatics to a similar site on the right side. Along the route of these lymphatic vessels, encapsulated **lymph nodes** are strategically placed to "filter" the lymph as it moves toward the venous system. Lymph nodes form a key site for phagocytosis of microorganisms and other particulate matter, and they can initiate the body's immune responses.

Immune Response

When a foreign microorganism, virus-infected cell, or cancer cell is detected within the body, the lymphatic system mounts what is called an *immune response.* The detected pathogens are distinguished from the body's own normal cells, and then a response is initiated to neutralize the pathogen. The human body has evolved three major responses to protect against foreign invaders:

- **Nonspecific barriers:** this first line of defense is composed of physical barriers to invasion. These include the skin and mucous membranes that line the body's exterior (skin) or its respiratory, gastrointestinal, urinary, and reproductive systems (mucosa and its secretions, which may include enzymes, acidic secretions, flushing mechanisms such as tear secretion or the voiding of urine, sticky mucus to sequester pathogens, and physical coughing and sneezing to remove pathogens and irritants).
- **Innate immunity:** this second line of defense (if the nonspecific barrier is breached) is composed of a variety of cells and antimicrobial secretions, and manifests itself by producing inflammation and fever.
- **Adaptive immunity:** this third line of defense is characterized by specific pathogen recognition,

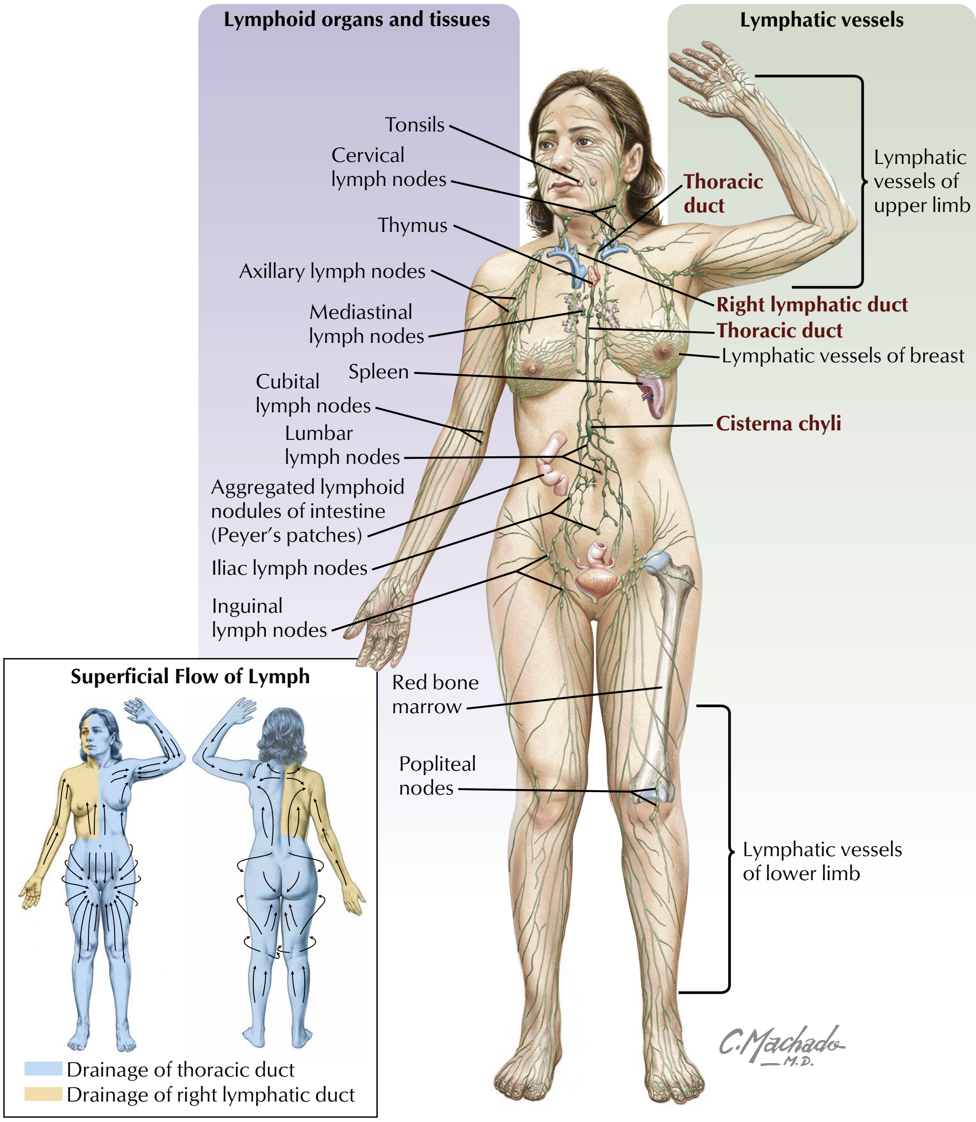


FIGURE 1.16 Overview of Lymphatic System. (From *Netter's atlas of human anatomy*, ed 8, Plate 16; S-343.)

immunologic memory, amplification of immune responses, and rapid response against pathogens that reinvade the body.

7. RESPIRATORY SYSTEM

The respiratory system provides oxygen to the body for its metabolic needs and eliminates carbon dioxide. Structurally, the respiratory system includes the following (Fig. 1.17):

- **Nose and paranasal sinuses.**
- **Pharynx** and its subdivisions (nasopharynx, oropharynx, and laryngopharynx).
- **Larynx**, continuous with the trachea inferiorly.
- **Trachea.**
- **Lungs** (a right lung and a left lung) and their bronchi, bronchioles, alveolar ducts/sacs, and alveoli.

Functionally, the respiratory system performs five basic functions:

- Filters and humidifies the air and moves it in and out of the lungs.
- Provides a large surface area for gas exchange with the blood.
- Helps to regulate the pH of body fluids.
- Participates in vocalization.
- Assists the olfactory system with the detection of smells.

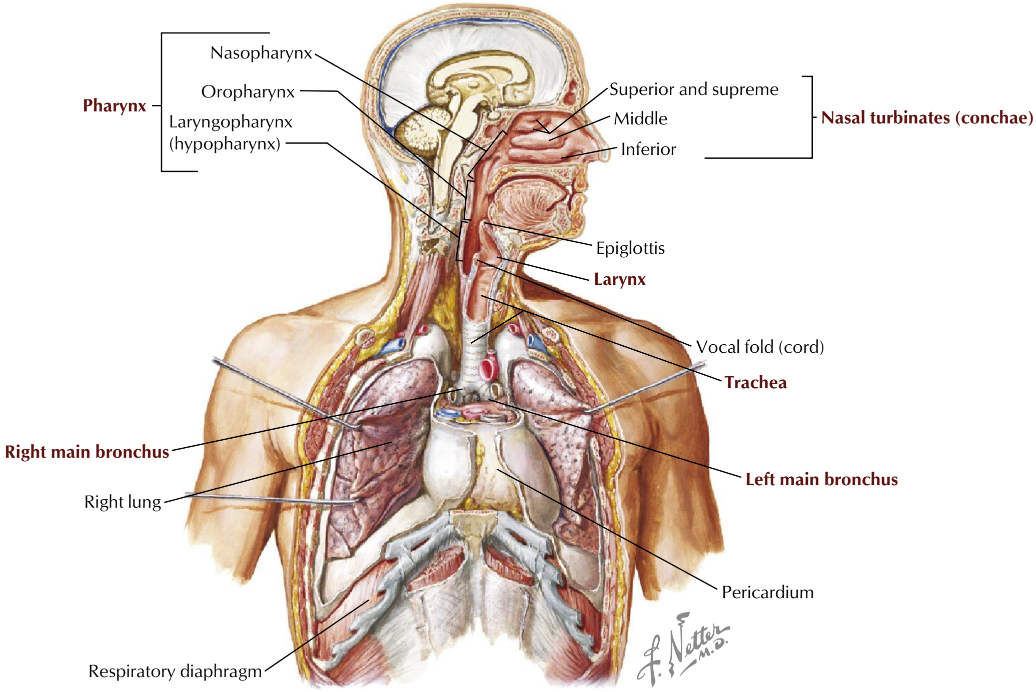


FIGURE 1.17 Respiratory System.

8. NERVOUS SYSTEM

General Organization

The nervous system integrates and regulates many body activities, sometimes at discrete locations (specific targets) and sometimes more globally. The nervous system usually acts quite rapidly and can also modulate effects of the endocrine and immune systems. The nervous system is separated into two structural divisions (Fig. 1.18):

- **Central nervous system** (CNS): includes the brain and spinal cord.
- **Peripheral nervous system** (PNS): includes the somatic, autonomic, and enteric nerves outside the CNS.

Neurons

Nerve cells are called **neurons,** and their structure reflects the functional characteristics of an individual neuron (Fig. 1.19). Information comes to the neuron largely through treelike processes called **axons**, which terminate on the neuron at specialized junctions called **synapses.** Synapses can occur on neuronal processes called **dendrites** or on the neuronal cell body, called a **soma** or *perikaryon.*

Neurons convey efferent (motor or output) information via action potentials that course along a *single axon* arising from the soma that then synapses on a selective target, usually another neuron or target cells, such as muscle cells. Common types of neurons include the following:

- *Unipolar* (often called *pseudounipolar*): a neuron with one axon that divides into two long processes (sensory neurons found in the spinal ganglia of a spinal nerve).
- *Bipolar:* a neuron that possesses one axon and one dendrite (rare but found in the retina and olfactory epithelium).
- *Multipolar:* a neuron that possesses one axon and two or more dendrites (the most common type).

Although the human nervous system contains billions of neurons, all neurons can be classified largely into one of three functional types:

- **Motor neurons:** they convey **efferent** impulses from the CNS or ganglia (collections of neurons outside the CNS) to target (effector) cells; *somatic* efferent axons target skeletal muscle, and *visceral* efferent axons target smooth muscle, cardiac muscle, and glands.
- **Sensory neurons:** they convey **afferent** impulses from peripheral receptors to the CNS; *somatic afferent axons* convey pain, temperature, touch, pressure, and proprioception (nonconscious) sensations; *visceral afferent axons* convey pain and other sensations (e.g., nausea) from organs, glands, and blood vessels to the CNS.

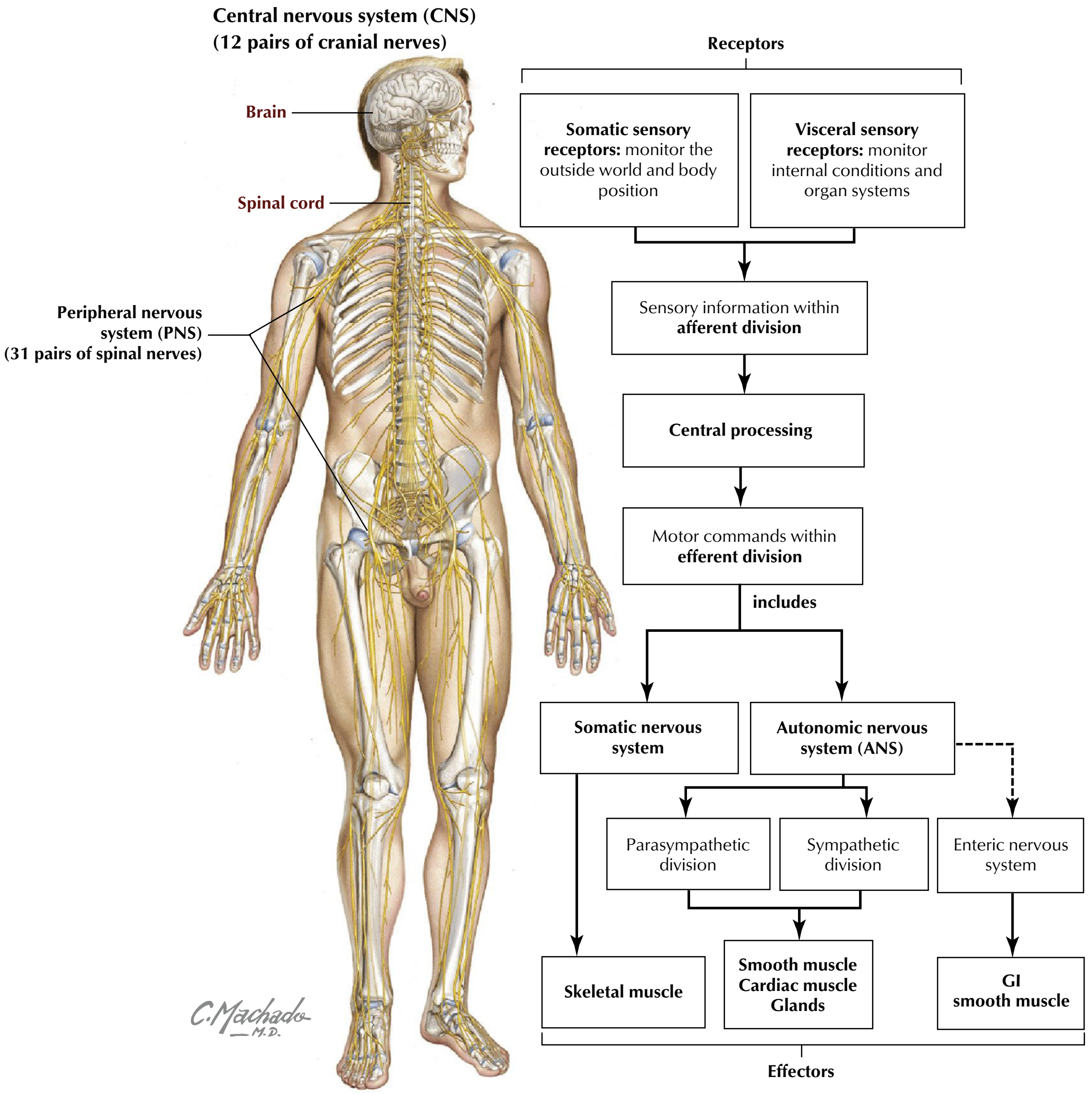


FIGURE 1.18 General Organization of Nervous System. (From *Netter's atlas of human anatomy*, ed 8, Plate 4; S-15.)

- **Interneurons:** they convey impulses between sensory and motor neurons in the CNS, thus forming integrated networks between cells; interneurons probably account for more than 99% of all neurons in the body.

Neurons can vary considerably in size, ranging from several micrometers to more than 100 µm in diameter. Neurons may possess numerous branching dendrites, studded with dendritic spines that increase the receptive area of the neuron many-fold. The neuron's axon may be quite short or over 1 meter long. The axonal diameter may vary. Axons that are larger than 1 to 2 µm in diameter are insulated by **myelin** sheaths. In the CNS, axons are myelinated by a special glial cell called an **oligodendrocyte,** whereas in the PNS they are surrounded by a glial cell called a **Schwann cell**, which often also myelinates the PNS axons. Some Schwann cells do not produce myelin and simply invest a group of nerve fibers separately within their cytoplasm, e.g. most cutaneous (sensory) nerves to the skin.

Glia

Glia are the cells that support neurons, within both the CNS (neuroglia) and the PNS. Glial cells far outnumber the neurons in the nervous system and contribute to most of the postnatal growth, along with axonal myelination, seen in the CNS. Functionally, glia:

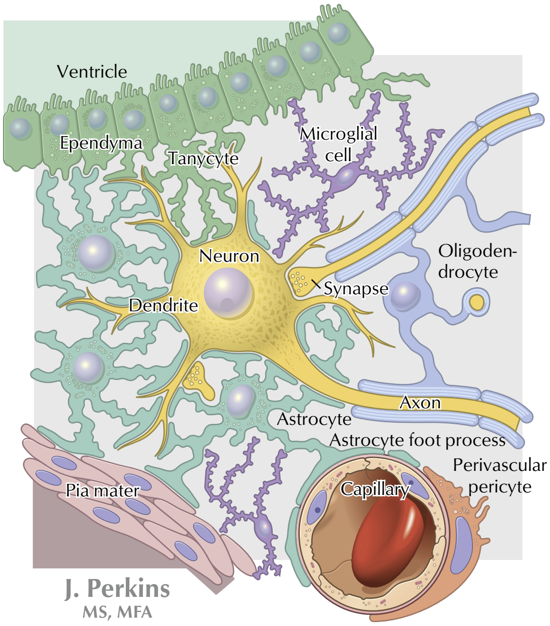


FIGURE 1.19 Cell Types Found in Central Nervous System.

- Provide structural isolation of neurons and their synapses.
- Sequester ions in the extracellular compartment.
- Provide trophic support to the neurons and their processes.
- Support growth and secrete growth factors.
- Support some of the signaling functions of neurons.
- Myelinate axons.
- Phagocytize debris and participate in inflammatory responses.
- Play a dynamic role in pruning or preserving neuronal connections.
- Rid the brain of metabolites and dump them into the CSF.
- Participate in the formation of the blood-brain barrier.

The different types of glial cells include the following (see Fig. 1.19):

- **Astrocytes:** these are the most numerous of the glial cells; provide physical and metabolic support for CNS neurons, can become reactive during CNS injury, release growth factors and other bioactive molecules, and contribute to the formation of the *blood-brain barrier*.
- **Oligodendrocytes:** these are smaller glial cells; responsible for the formation and maintenance of myelin in the CNS.
- **Microglia:** these are smallest and rarest of CNS glia, although more numerous than neurons in CNS; these phagocytic cells participate in inflammatory reactions, remodel and remove synapses, and respond to injury.
- **Ependymal cells:** these cells line the ventricles of the brain and the central canal of the spinal cord, which contains **cerebrospinal fluid (CSF)**.
- **Schwann cells:** these are the glial cells of the PNS; surround all axons (myelinating many of them) and provide trophic support, facilitate regrowth of PNS axons, and clean away cellular debris (Fig. 1.20).

Peripheral Nerves

The peripheral nerves observed grossly in the human body are composed of bundles of thousands of nerve fibers enclosed within a connective tissue covering and supplied by small blood vessels. The nerve "fibers" consist of axons (efferent and afferent) individually separated from each other by the cytoplasmic processes of Schwann cells or myelinated by a multilayered wrapping of continuous Schwann cell membrane (the *myelin sheath*).

The peripheral nerve resembles an electrical cable of axons that is further supported by three connective tissue sleeves or coverings (Fig. 1.20):

- **Endoneurium:** a thin connective tissue sleeve that surrounds the axons and Schwann cells.
- **Perineurium:** a dense layer of connective tissue that encircles a bundle (fascicle) of nerve fibers.
- **Epineurium:** an outer thick connective tissue sheath that encircles bundles of fascicles; this is the "nerve" typically seen grossly coursing throughout the human body.

Peripheral nerves include the 12 pairs of **cranial nerves** arising from the brain or brainstem and the 31 pairs of **spinal nerves** arising from the spinal cord.

Meninges

The brain and spinal cord are surrounded by three membranous connective tissue layers called the *meninges.* These three layers include the following (Fig. 1.21):

- **Dura mater:** the thick, outermost meningeal layer, richly innervated by sensory nerve fibers.
- **Arachnoid mater**: the fine, weblike avascular membrane directly beneath the dural surface.
- **Pia mater:** the delicate membrane of connective tissue that intimately envelops the brain and spinal cord.

The space between the arachnoid and the underlying pia is called the **subarachnoid space** and contains **cerebrospinal fluid** (CSF), which bathes and protects the CNS.

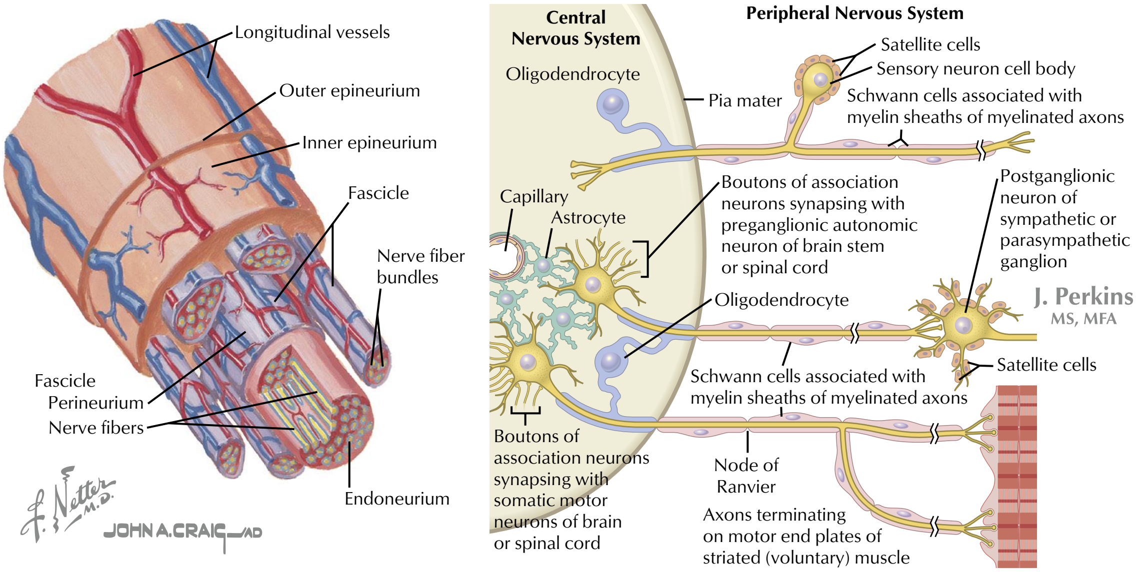


FIGURE 1.20 Features of Typical Peripheral Nerve.

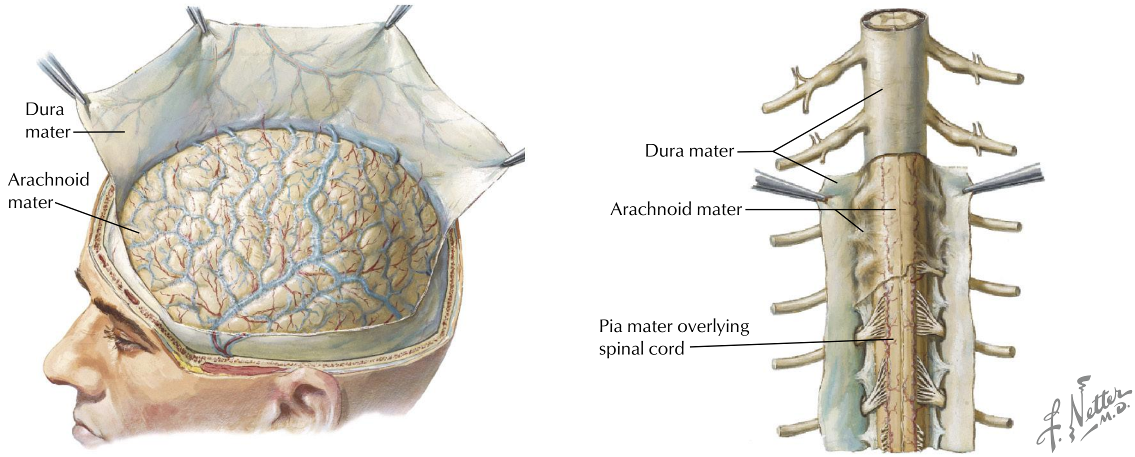


FIGURE 1.21 CNS Meninges. (From *Netter's atlas of human anatomy*, ed 8, Plates 129 and 189; S-28 and S-19.)

Cranial Nerves

Twelve pairs of cranial nerves arise from the brain, and they are identified both by their names and by Roman numerals I to XII (Fig. 1.22). The cranial nerves are somewhat unique and can contain multiple functional components:

- **General:** same general functions as spinal nerves.
- **Special:** functions found only in cranial nerves.
- **Afferent** and **efferent:** sensory and motor functions, respectively.
- **Somatic** and **visceral:** related to skin and skeletal muscle (somatic) or to smooth muscle, cardiac muscle, and glands (visceral).

Therefore, each cranial nerve (CN) may possess multiple functional components, such as the following:

- *General somatic afferents* (GSAs): they contain nerve fibers that are sensory from the skin, such as those of a spinal nerve.
- *General visceral efferents* (GVEs): they contain motor fibers to visceral structures (smooth muscle and/or glands), such as a parasympathetic fiber from the sacral spinal cord (spinal cord levels S2 to S4 give rise to parasympathetics).
- *Special somatic afferents* (SSAs): they contain special sensory fibers, such as those for vision and hearing.

In general, **CN I** and **CN II** arise from the forebrain and are really tracts of the brain for the special senses of smell and sight. The other cranial nerves arise from the brainstem. Cranial nerves **III**, **IV**, and **VI** move the extraocular skeletal muscles

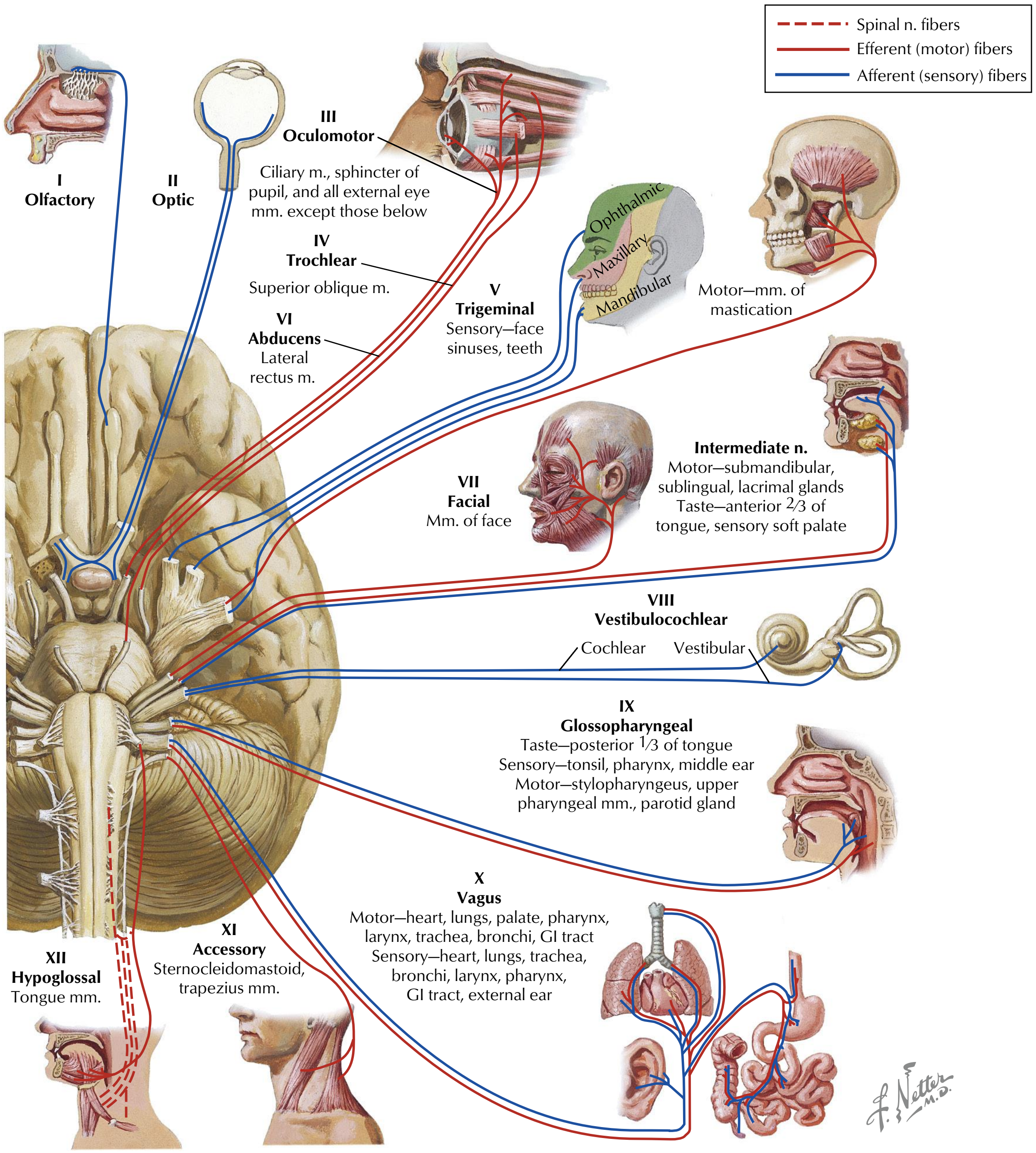


FIGURE 1.22 Overview of Cranial Nerves. (From *Netter's atlas of human anatomy*, ed 8, Plate 145; S-53.)

of the eyeball. **CN V** has three divisions: V_1 and V_2 are sensory, and V_3 is both motor to skeletal muscle and sensory. Cranial nerves **VII, IX,** and **X** are both motor and sensory. **CN VIII** is the special sense of hearing and balance. **CN XI** and **CN XII** are motor to skeletal muscle. Cranial nerves **III, VII, IX,** and **X** also contain parasympathetic fibers of origin (visceral), although many of the autonomic fibers will "jump" onto the branches of **CN V** to reach their targets. Table 1.2 summarizes the types of fibers in each cranial nerve.

Spinal Nerves

The spinal cord gives rise to 31 pairs of spinal nerves (Figs. 1.23, 1.24, 2.13, and Chapter 2 – Section 5. Spinal Cord), which then form two major branches (rami):

- **Posterior (dorsal) ramus:** a small ramus that courses dorsally to the back; it conveys motor and sensory information to and from the skin, intrinsic back skeletal muscles (erector spinae, transversospinales), and synovial joints of the vertebral column.
- **Anterior (ventral) ramus:** a much larger ramus that courses laterally and ventrally; it innervates

TABLE 1.2 Cranial Nerve Fibers

CRANIAL NERVE		FUNCTIONAL COMPONENT*
I	Olfactory	SVA (Special sense of smell)
II	Optic	SSA (Special sense of sight)
III	Oculomotor	GSE (Motor to extraocular muscles)
		GVE (Parasympathetic to smooth muscle in eye)
IV	Trochlear	GSE (Motor to one extraocular muscle)
V	Trigeminal	GSA (Sensory to face, orbit, nose, anterior tongue)
		SVE (Motor to skeletal muscles)
VI	Abducens	GSE (Motor to one extraocular muscle)
VII	Facial	GSA (Sensory to skin of ear)
		SVA (Special sense of taste to anterior tongue)
		GVE (Motor to glands—salivary, nasal, lacrimal)
		SVE (Motor to facial muscles)
VIII	Vestibulocochlear	SSA (Special sense of hearing and balance)
IX	Glossopharyngeal	GSA (Sensory to posterior tongue)
		SVA (Special sense of taste—posterior tongue)
		GVA (Sensory from middle ear, pharynx, carotid body, sinus)
		GVE (Motor to parotid gland)
		SVE (Motor to one muscle of pharynx)
X	Vagus	GSA (Sensory external ear)
		SVA (Special sense of taste—epiglottis)
		GVA (Sensory from pharynx, larynx, thoracoabdominal organs)
		GVE (Motor to thoracoabdominal organs)
		SVE (Motor to muscles of pharynx/larynx)
XI	Accessory	GSE (Motor to two muscles)
XII	Hypoglossal	GSE (Motor to tongue muscles)

**GSA*, General somatic afferent; *GSE*, general somatic efferent; *GVA*, general visceral afferent; *GVE*, general visceral efferent; *SSA*, special somatic afferent; *SVA*, special visceral afferent; *SVE*, special visceral efferent.

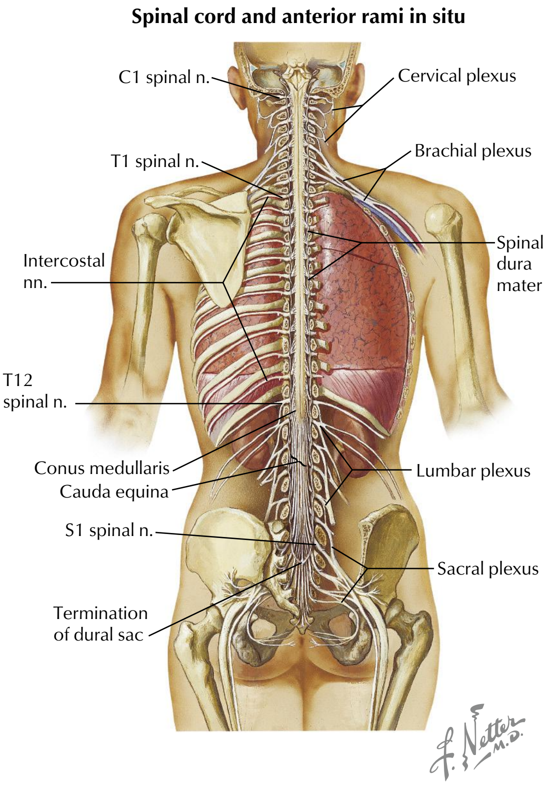


FIGURE 1.23 Overview of Spinal Cord and Spinal Nerves. (From *Netter's atlas of human anatomy*, ed 8, Plate 186; S-16.)

all the remaining skin and skeletal muscles of the neck, limbs, and trunk.

Once nerve fibers (sensory or motor) are beyond, or peripheral to, the spinal cord proper, the fibers (axons) then reside in nerves of the PNS. Components of the PNS include the following (Fig. 1.24):

- **Somatic nervous system:** sensory and motor fibers to skin, skeletal muscle, and joints (Fig. 1.24, left side).
- **Autonomic nervous system** (ANS): sensory and motor fibers to all smooth muscle (viscera, vasculature), cardiac muscle (heart), and glands (Fig. 1.24, right side).
- **Enteric nervous system:** plexuses and ganglia of the GI tract that regulate bowel secretion, absorption, and motility (originally considered part of ANS); they are linked to the ANS for optimal regulation.

Features of the *somatic nervous system* include the following:

- It is a one-neuron motor system.
- The motor (efferent) neuron is in the CNS, and an axon projects to a peripheral target (e.g., skeletal muscle).
- The sensory (afferent) neuron (pseudounipolar) resides in a peripheral ganglion called a *spinal ganglion* and conveys sensory information from

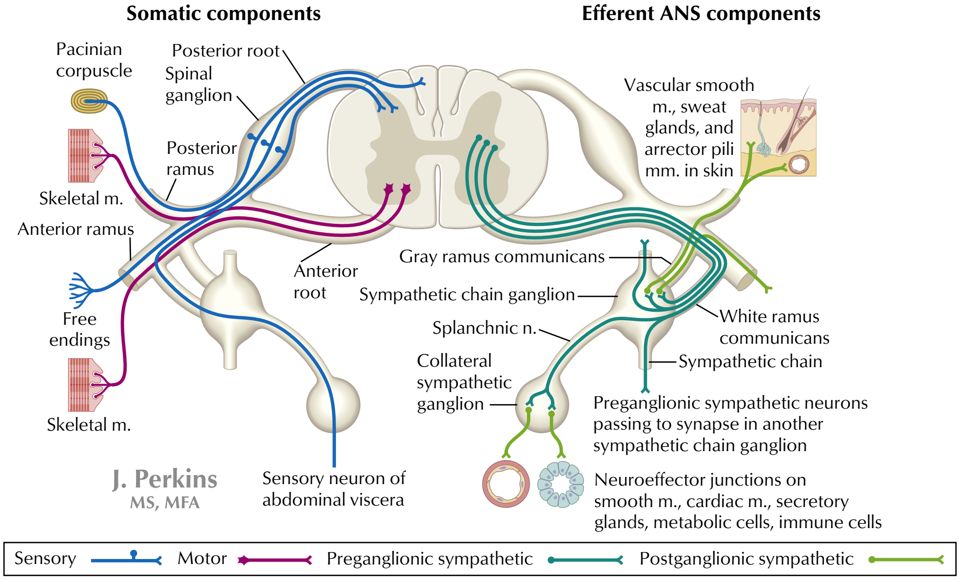


FIGURE 1.24 Elements of Peripheral Nervous System. For clarity, this schematic shows the arrangement of the efferent and afferent somatic nerve components of a typical spinal nerve on the left side and the efferent components of the ANS of a typical spinal nerve on the right side.

the skin, muscle, or joint to the CNS (in this case the spinal cord).

The unilateral area of skin innervated by the somatic sensory fibers from a single spinal nerve root is called a **dermatome**. The nerve roots to neighboring dermatomes overlap. Therefore, damage to a single dorsal root would produce *hypoesthesia* (diminished sensation), not anesthesia (complete loss of sensation), to the region supplied predominately by that dermatome level. Complete dermatomal anesthesia would result if three contiguous dorsal roots were damaged. Clinically, dermatome maps of the body can be helpful in localizing spinal cord or peripheral nerve lesions (see Chapter 2).

Features of the *ANS division of the PNS* include the following:

- It is a two-neuron motor system; the first neuron resides in the CNS and the second neuron in a peripheral autonomic ganglion.
- The axon of the first neuron is termed *preganglionic* and of the second neuron, *postganglionic*.
- The ANS has two divisions, sympathetic and parasympathetic.
- The *sensory neuron* (pseudounipolar) resides in a spinal ganglion (similar to the somatic system) and conveys sensory information from the viscera to the CNS (not shown in Fig. 1.24).

Autonomic Nervous System

The ANS is divided into sympathetic and parasympathetic divisions. In contrast to the somatic division of the PNS, the ANS is a *two-neuron system* with a **preganglionic neuron** in the CNS that sends its axon into a peripheral nerve to synapse on a **postganglionic neuron** in a peripheral autonomic ganglion (Fig. 1.25). The postganglionic neuron then sends its axon to the target (*smooth muscle, cardiac muscle, and glands*). The ANS is a visceral system, since many of the body's organs are composed of smooth muscle walls or contain secretory glandular tissue.

Sympathetic Division

The **sympathetic division** of the ANS is also known as the *thoracolumbar division* because:

- Its preganglionic neurons are found only within the intermediolateral gray matter of the T1-L2 spinal cord levels.

Preganglionic axons exit the T1-L2 spinal cord in an anterior root, then enter a spinal nerve, and then via a white **ramus communicans** enter the **sympathetic chain.** The sympathetic chain is a bilateral chain of ganglia just lateral to the vertebral bodies that runs from the base of the skull to the coccyx. Once in the sympathetic chain, the preganglionic axon may take one of three synaptic routes (Fig. 1.25):

1. Synapse on a postganglionic sympathetic neuron at the T1-L2 level, or ascend or descend to synapse on a **sympathetic chain neuron** at any of the 31 spinal nerve levels.
2. Pass through the sympathetic chain, enter a **splanchnic (visceral) nerve**, and synapse in a **collateral (prevertebral) ganglion** in the abdominopelvic

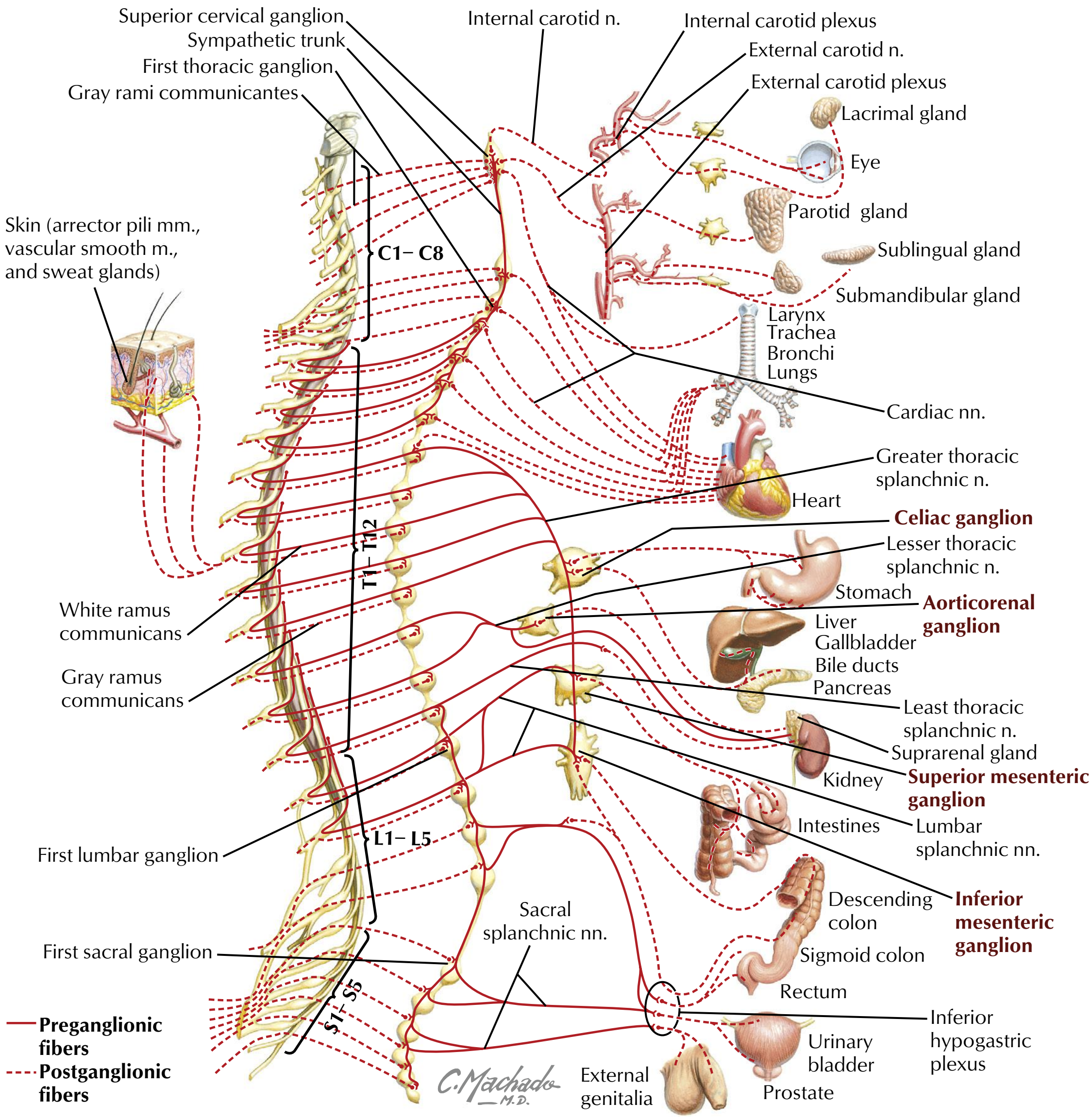


FIGURE 1.25 Sympathetic Division of Autonomic Nervous System. (From *Netter's atlas of human anatomy*, ed 8, Plate 6; S-21.)

cavity (celiac, aorticorenal, superior mesenteric or inferior mesenteric ganglia).

3. Pass through the sympathetic chain, enter a splanchnic nerve, pass through a collateral ganglion (aorticorenal), and synapse on the cells of the **adrenal medulla** (the central portion of the adrenal gland).

Axons of the postganglionic sympathetic neurons (which greatly outnumber preganglionic neurons) may act in one of four ways (Fig. 1.25):

1. Reenter the spinal nerve via a **gray ramus communicans** and join any one of the 31 spinal nerves (anterior and posterior rami) as they distribute widely throughout the body. These fibers innervate sweat glands (sudomotor), arrector pili muscles of hair (pilomotor resulting in "goose bumps"), and blood vessels (vasomotor).
2. Reenter the spinal nerve but course along blood vessels in the head, or join cardiopulmonary or hypogastric plexuses of nerves to distribute to the head, thorax, and pelvic viscera.
3. Arise from postganglionic neurons in abdominopelvic **collateral ganglia** and course with blood vessels to abdominopelvic viscera.
4. Cells of the **adrenal medulla** are differentiated neuroendocrine cells **(paraneurons)** that do not

TABLE 1.3 Effects of Sympathetic Stimulation on Various Structures

STRUCTURE	EFFECTS	STRUCTURE	EFFECTS
Eye	Dilates the pupil	Liver	Causes glycogen breakdown, glucose synthesis and release
Lacrimal glands	Reduces secretion slightly (vasoconstriction)	Salivary glands	Reduces and thickens secretion via vasoconstriction
Skin	Causes goose bumps (arrector pili muscle contraction)	Genital system	Causes ejaculation and orgasm, and remission of erection
Sweat glands	Increases secretion		Constricts male internal urethral sphincter muscle
Peripheral vessels	Causes vasoconstriction		
Heart	Increases heart rate and force of contraction	Urinary system	Decreases urine production via vasoconstriction
Coronary arteries	Vasoconstriction (metabolic vasodilation overrides this effect)		Constricts male internal urethral sphincter muscle
Lungs	Assists in bronchodilation and reduced secretion	Adrenal medulla	Increases secretion of epinephrine or norepinephrine
Digestive tract	Decreases peristalsis, contracts internal anal sphincter muscle, causes vasoconstriction to shunt blood elsewhere		

have axons but release hormones directly into the bloodstream. They are innervated directly by preganglionic sympathetic fibers.

Preganglionic axons release acetylcholine (ACh) at their synapses, and norepinephrine (NE) is the transmitter released by postganglionic axons (except ACh is released on *sweat glands*). The cells of the adrenal medulla (modified postganglionic sympathetic neurons) release epinephrine and some NE into the blood, not as neurotransmitters but as *hormones*. The sympathetic system acts globally throughout the body to mobilize it in "fright-flight-fight" situations (Table 1.3).

Parasympathetic Division

The parasympathetic division of the ANS also is a two-neuron system with its preganglionic neuron in the CNS and postganglionic neuron in a peripheral ganglion (Fig. 1.26). The **parasympathetic division** also is known as the *craniosacral division* because:

- Its preganglionic neurons are found in cranial nerves III, VII, IX, and X and in the sacral spinal cord at levels S2-S4.
- Its preganglionic neurons reside in the four cranial nuclei associated with the four cranial nerves listed earlier or in the lateral gray matter of the sacral spinal cord at levels S2-S4.

Preganglionic parasympathetic axons exit the CNS in one of three ways:

1. Exit the brainstem in the **cranial nerve** (except CN X) and pass to a **peripheral ganglion** in the head (ciliary, pterygopalatine, submandibular, or otic ganglia) to synapse on the parasympathetic postganglionic neurons residing in these ganglia.
2. *CN X preganglionic fibers* exit the brainstem and provide preganglionic parasympathetic fibers **to terminal ganglia** (microscopically small post-ganglionic neurons) in the neck, thorax, and proximal two-thirds of the abdominal viscera.
3. Exit the sacral spinal cord via an anterior root and then enter the **pelvic splanchnic nerves**, to synapse on postganglionic neurons in **terminal ganglia** located in or near the viscera to be innervated.

Axons of the postganglionic parasympathetic neurons take one of two courses:

1. Pass from the **parasympathetic ganglion in the head** (ciliary, pterygopalatine, otic, and submandibular) on existing nerves or blood vessels, to innervate smooth muscle and glands of the head.
2. Pass from terminal ganglia in or near the viscera innervated and then synapse on smooth muscle, cardiac muscle, or glands in the neck, thorax, and abdominopelvic cavity.

As noted above, the vagus nerve (CN X) is unique. Its preganglionic axons exit the brainstem and synapse on terminal ganglia in or near the targets in the neck, thorax (heart, lungs, glands, smooth muscle), and abdominal cavity (proximal two thirds of the GI tract and its accessory organs). Short axons of the terminal ganglia neurons then synapse on their targets.

Parasympathetic axons *do not pass* into the limbs as do sympathetic axons. Therefore, the vascular smooth muscle, arrector pili muscles of the skin (attached to hair follicles), and sweat glands are all innervated only by the sympathetic system. ACh is the *neurotransmitter* at all parasympathetic

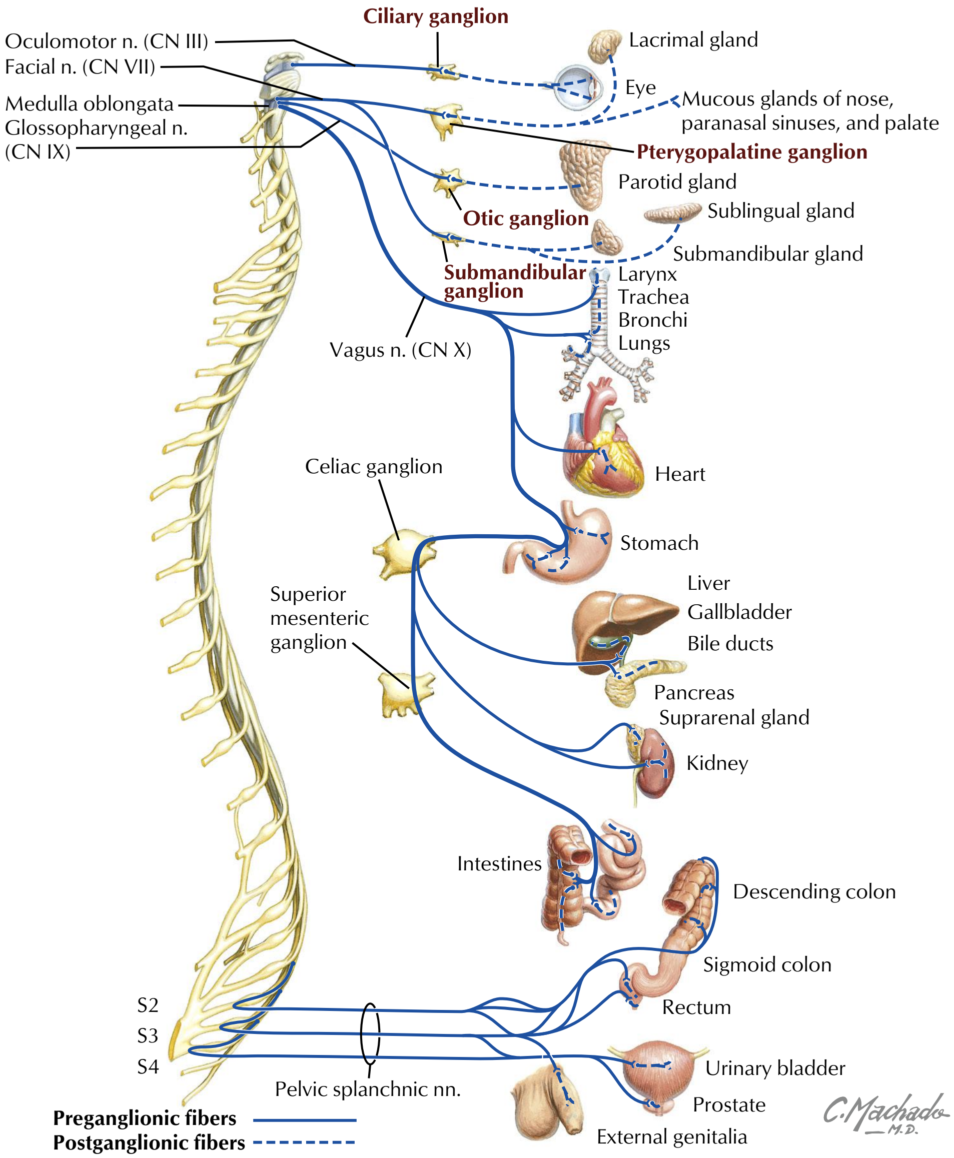


FIGURE 1.26 Parasympathetic Division of Autonomic Nervous System. (From *Netter's atlas of human anatomy*, ed 8, Plate 7; S-22.)

synapses, both preganglionic and postganglionic synapses.

The parasympathetic system is involved in feeding and sexual arousal functions and acts more slowly and focally than the sympathetic system. For example, CN X can slow the heart rate without affecting input to the stomach. In general, the sympathetic and parasympathetic systems maintain homeostasis, although as a protective measure, the body maintains a low level of "sympathetic tone" and can activate this division on a moment's notice. ANS function is regulated ultimately by the hypothalamus. Most presynaptic parasympathetic axons are long, extending to their peripheral targets, while the postsynaptic fibers are short because the parasympathetic ganglia often reside near or in the organs they innervate. Table 1.4 summarizes the specific functions of the parasympathetic division of the ANS.

Although the ANS uses classic neurotransmitters such as NE and ACh at its synapses, its neurons also co-release a wide variety of neuroactive peptides and other neuromodulators that "fine-tune" their functions at the level of their respective targets.

Enteric Nervous System

The enteric nervous system was formally considered the third division of the ANS. The word *enteric* refers to the bowel. This component of the PNS consists

TABLE 1.4 Effects of Parasympathetic Stimulation on Various Structures

STRUCTURE	EFFECTS	STRUCTURE	EFFECTS
Eye	Constricts pupil	Digestive tract	Increases peristalsis, increases secretion, inhibits internal anal sphincter for defecation
Ciliary body	Constricts muscle for accommodation (near vision)		
Lacrimal glands	Increase secretion	Liver	Aids glycogen synthesis and storage
Heart	Decreases heart rate and force of contraction	Salivary glands	Increase secretion
		Genital system	Promotes engorgement of erectile tissues
Coronary arteries	Vasodilation (of little importance)		
Lungs	Cause bronchoconstriction and increased secretion	Urinary system	Contracts bladder (detrusor muscle) for urination, inhibits contraction of male internal urethral sphincter, increases urine production

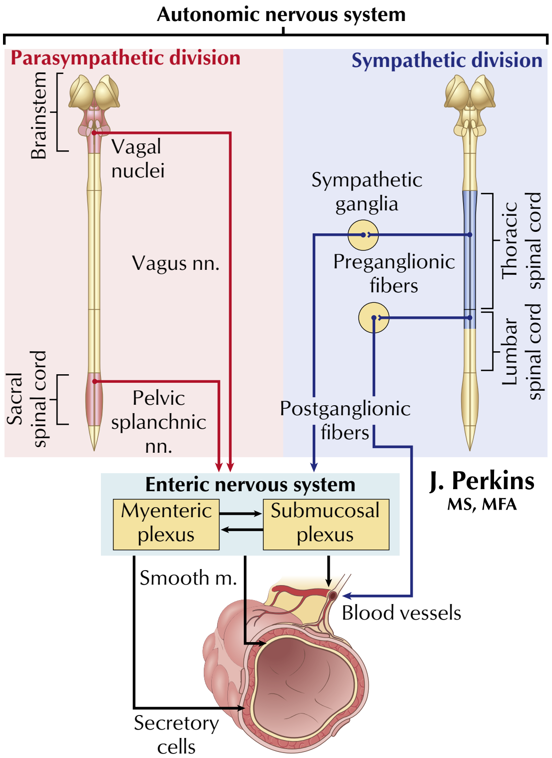


FIGURE 1.27 Relationship of Enteric Nervous System to Sympathetic and Parasympathetic ANS Divisions.

of ganglia and nerve plexuses in the walls and mesenteries of the GI tract. These ganglia and their neural networks include the following (Fig. 1.27):

- **Myenteric (Auerbach's) plexuses:** ganglia and nerves located between the circular and longitudinal smooth muscle layers of the muscularis externa of the bowel wall.
- **Submucosal (Meissner's) plexuses:** ganglia and nerves located in the submucosa of the bowel wall.

The enteric nervous system has important links to both divisions of the ANS, which are critical for optimal regulation of bowel secretion, absorption, and motility. More than 20 different transmitter substances have been identified in the intrinsic neurons of the enteric nervous system, pointing to the fine degree of regulation that occurs at the level of the bowel wall. Optimal GI functioning requires coordinated interactions of the ANS, the enteric nervous system, and the endocrine system.

9. ENDOCRINE SYSTEM

The endocrine system, along with the nervous and immune systems, facilitates communication, integration, and regulation of many of the body's functions (Fig. 1.28). Specifically, the endocrine system interacts with target sites (cells and tissues), some that are quite a distance from a gland, by releasing hormones into the bloodstream. Generally, endocrine glands and hormones also share the following features:

- Secretion is controlled by feedback mechanisms.
- Hormones bind target receptors on cell membranes or within the cells (cytoplasmic or nuclear).
- Hormone action may be slow to appear but may have long-lasting effects.
- Hormones are chemically diverse molecules (amines, peptides/proteins, steroids).

Hormones can communicate through a variety of cell-to-cell interactions, including:

- *Autocrine:* interacts on another cell as well as on itself.
- *Paracrine:* interacts directly on an adjacent or nearby cell.
- *Endocrine:* interacts at a great distance by traveling in the bloodstream.
- *Neurocrine:* interacts similar to a neurotransmitter, except released into the bloodstream.

Table 1.5 summarizes the major hormones and the tissues responsible for their release.

Additionally, other organs have paracrine or endocrine functions. For example, the **placenta** releases human chorionic gonadotropin (hCG), estrogens, progesterone, and human placental lactogen

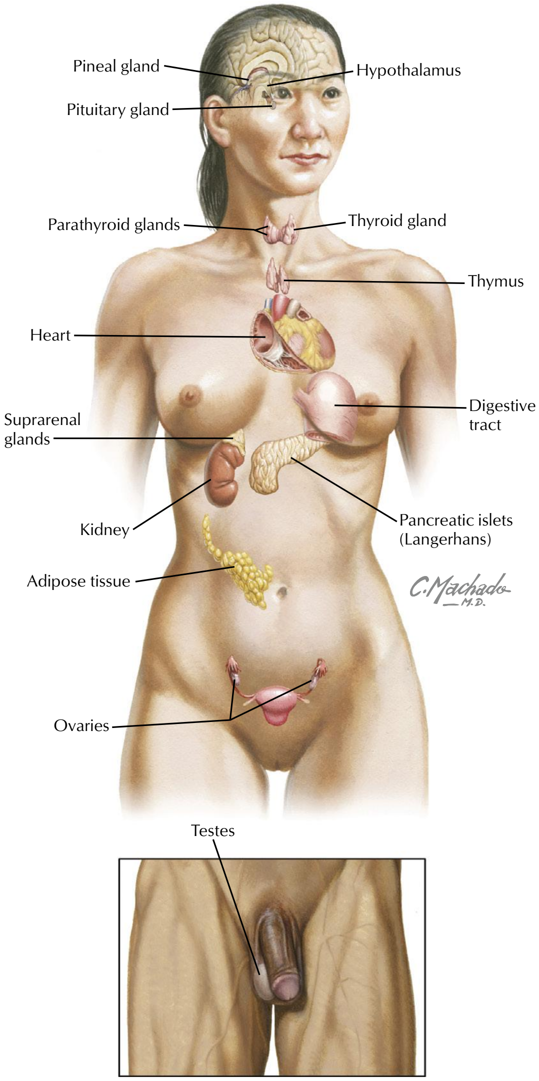


FIGURE 1.28 Major Endocrine Organs. (From *Netter's atlas of human anatomy*, ed 8, Plate 21; S-522.)

(hPL), whereas other cells release a variety of growth factors. The mesenteries of the GI tract also release various substances, and they contain a variable amount of fat, which itself releases the hormone leptin. Again, the endocrine system is widespread and critically important in regulating bodily functions. Each year, researchers find additional paracrine and endocrine substances, and many of their regulatory functions continue to be elucidated.

10. GASTROINTESTINAL SYSTEM

The GI system includes the epithelial-lined tube that begins with the oral cavity and extends to the anal canal, as well as GI-associated glands, including the following:

TABLE 1.5 Major Hormones*

TISSUE/ ORGAN	HORMONE
Hypothalamus	Antidiuretic hormone (ADH), oxytocin, thyrotropin-releasing hormone (TRH), corticotropin-releasing hormone (CRH), growth hormone–releasing hormone (GHRH), gonadotropin-releasing hormone (GnRH), somatostatin (SS), dopamine (DA)
Pineal gland	Melatonin
Anterior pituitary gland	Adrenocorticotropic hormone (ACTH), thyroid-stimulating hormone (TSH), growth hormone (GH), prolactin, follicle-stimulating hormone (FSH), luteinizing hormone (LH), melanocyte-stimulating hormone (MSH)
Posterior pituitary gland	Oxytocin, vasopressin (ADH)
Thyroid gland	Thyroxine (T_4), triiodothyronine (T_3), calcitonin
Parathyroid glands	Parathyroid hormone (PTH, parathormone)
Thymus gland	Thymopoietin, thymulin, thymosin, thymic humoral factor, interleukins, interferons
Heart	Atrial natriuretic peptide (ANP)
Digestive tract	Gastrin, secretin, cholecystokinin (CCK), motilin, gastric inhibitory peptide (GIP), glucagon, SS, vasoactive intestinal peptide (VIP), ghrelin, leptin, and many more
Liver	Insulin-like growth factors (IGFs)
Suprarenal (adrenal) glands	Cortisol, aldosterone, androgens, epinephrine (E), norepinephrine (NE)
Pancreatic islets	Insulin, glucagon, SS, VIP, pancreatic polypeptide
Kidneys	Erythropoietin (EPO), calcitriol, renin, urodilatin
Fat	Leptin
Ovaries	Estrogens, progestins, inhibin, relaxin
Testes	Testosterone, inhibin
White blood cells and some connective tissue cells	Various cytokines; interleukins, colony-stimulating factors, interferons, tumor necrosis factor (TNF)

*This list is not comprehensive; only the more commonly found hormones are listed.

- **Salivary glands:** three major glands and hundreds of microscopic minor salivary glands scattered throughout the oral mucosa.
- **Liver:** the largest solid gland in the body
- **Gallbladder:** functions to store and concentrate bile needed for fat digestion.
- **Pancreas:** crucial exocrine (digestive enzymes) and endocrine organ.

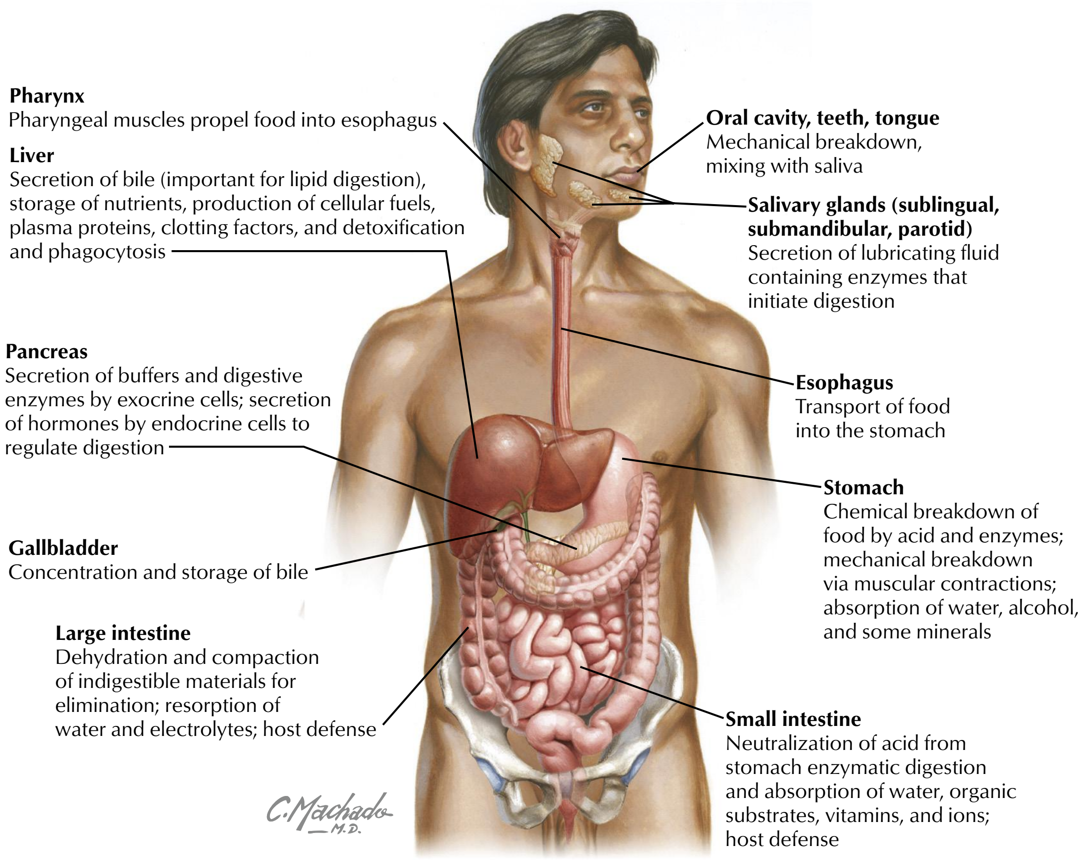


FIGURE 1.29 Overview of Gastrointestinal System. (From *Netter's atlas of human anatomy*, ed 8, Plate 18; S-394.)

The epithelial-lined tube that is the GI tract measures about 28 feet (8 m) in length (from mouth to anal canal) and includes the following cavities and visceral structures (Fig. 1.29):

- **Oral cavity:** tongue, teeth, and salivary glands.
- **Pharynx:** throat, subdivided into the nasopharynx, oropharynx, and laryngopharynx.
- **Esophagus:** passing from the pharynx to the stomach.
- **Stomach:** the expandable saclike portion of the GI tract.
- **Small intestine:** subdivided into the duodenum, jejunum, and ileum.
- **Large intestine:** subdivided into the cecum, ascending colon, transverse colon, descending colon, sigmoid colon, rectum, and anal canal.

11. URINARY SYSTEM

The urinary system includes the following components (Fig. 1.30):

- **Kidneys:** paired retroperitoneal organs that filter the plasma and produce urine; located high in the posterior abdominal wall just anterior to the muscles of the posterior wall.
- **Ureters:** course retroperitoneally from the kidneys to the pelvis and convey urine from the kidneys to the urinary bladder.
- **Urinary bladder:** lies subperitoneally in the anterior pelvis, stores urine, and, when appropriate, discharges the urine through the urethra.
- **Urethra:** courses from the urinary bladder to the exterior.

The **kidneys** function to:

- Filter the plasma and begin the process of urine formation.
- Reabsorb important electrolytes, organic molecules, vitamins, and water from the filtrate.
- Excrete metabolic wastes, metabolites, and foreign chemicals (e.g., drugs).
- Regulate fluid volume, composition, and pH.
- Secrete hormones that regulate blood pressure, erythropoiesis, and calcium metabolism.
- Convey urine to the ureters, which then pass the urine to the bladder.

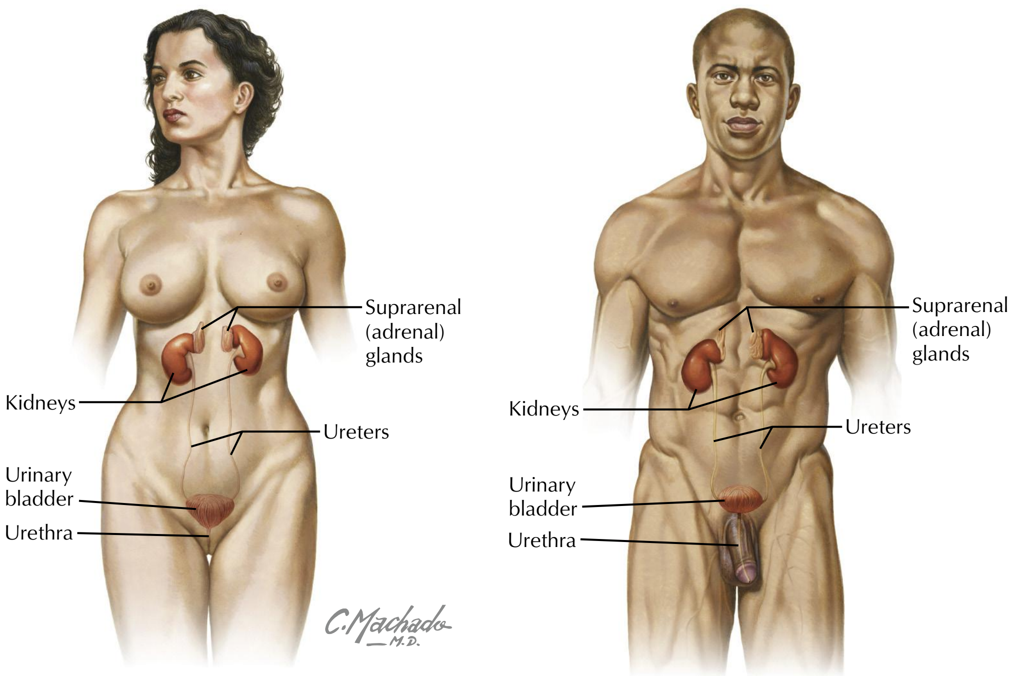


FIGURE 1.30 Urinary System. (From *Netter's atlas of human anatomy*, ed 8, Plate 19; S-458.)

The *kidneys* filter about 180 liters of fluid each day. Grossly, each kidney measures about 12 cm long × 6 cm wide × 3 cm thick and weighs about 150 grams, although variability is common. Approximately 20% of the blood pumped by the heart passes to the kidney each minute for plasma filtration, although most of the fluid and important plasma constituents are returned to the blood as the filtrate courses down the tubules of the *kidney's nephrons* (the nephrons are the kidney's filtration units; they are microscopically small and number about 1 million in each kidney).

Each ureter is about 24 to 34 cm long, lies in a retroperitoneal position, and contains a thick smooth muscle wall. The *urinary bladder* serves as a reservoir for the urine and is a smooth muscle "bag" that expels the urine when appropriate. The *female urethra* is short (3-4 cm), whereas the *male urethra* is long (~20 cm), coursing through the prostate gland, external urethral sphincter, and corpus spongiosum of the penis.

12. REPRODUCTIVE SYSTEM

Female Reproductive System

The female reproductive system is composed of the following structures (Fig. 1.31):

- **Ovaries:** the paired gonads of the female reproductive system; produce the female germ cells called *ova* (oocytes, eggs) and secrete the hormones estrogen and progesterone.
- **Uterine tubes** (fallopian tubes): paired tubes that extend from the superolateral walls of the uterus and open as fimbriated funnels into the pelvic cavity adjacent to the ovary, to "capture" the oocyte as it is ovulated.
- **Uterus:** hollow, pear-shaped muscular (smooth muscle) organ that protects and nourishes a developing fetus.
- **Vagina:** distensible fibromuscular tube (also called *birth canal*) approximately 8 to 9 cm long that extends from the uterine cervix (neck) to the vestibule.

Male Reproductive System

The male reproductive system is composed of the following structures (see Fig. 1.31):

- **Testes:** the paired gonads of the male reproductive system, egg shaped and about the size of a chestnut; produce the male germ cells, *spermatozoa,* and reside in the scrotum (externalized from the abdominopelvic cavity).
- **Epididymis:** a convoluted tubule that receives the spermatozoa and stores them as they mature.
- **Ductus (vas) deferens:** a muscular (smooth muscle) tube about 40 to 45 cm long that conveys sperm from the epididymis to the ejaculatory duct (seminal vesicle).

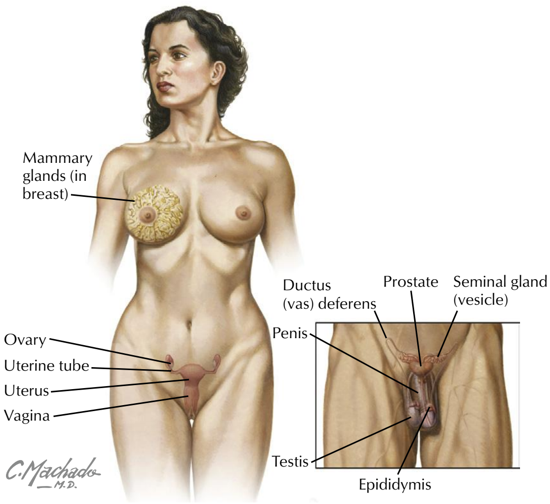


FIGURE 1.31 Reproductive System. (From *Netter's atlas of human anatomy*, ed 8, Plate 20; S-472.)

- **Seminal vesicles:** paired tubular glands that lie posterior to the prostate gland, about 15 cm long; produce seminal fluid and join the ductus deferens at the ejaculatory duct.
- **Prostate gland:** a walnut-sized gland that surrounds the urethra as it leaves the urinary bladder; produces prostatic fluid, which is added to semen (sperm are suspended in glandular secretions).
- **Urethra:** a canal that passes through the prostate gland, enters the penis, and conveys the semen for expulsion from the body during ejaculation.

13. BODY CAVITIES

Organ systems and other visceral structures are often segregated into body cavities. These cavities can protect the viscera and also may allow for some expansion and contraction in size. Two major collections of body cavities are recognized (Fig. 1.32):

- **Posterior cavities:** include the brain, surrounded by the meninges and bony cranium, and the spinal cord, surrounded by the same meninges as the brain and the bony vertebral column.
- **Anterior cavities:** include the thoracic and abdominopelvic cavities, separated by the respiratory diaphragm (a skeletal muscle important in respiration).

The CNS (brain and spinal cord) is surrounded by three membranes (see Fig. 1.21):

- Pia mater.
- Arachnoid mater.
- Dura mater.

The thoracic cavity contains two **pleural cavities** (right and left) and a single midline space called the **mediastinum** (middle space) that contains the heart and structures lying posterior to it, including the thoracic descending aorta and esophagus. The heart itself resides in the **pericardial sac,** which has a parietal and a visceral layer.

The abdominopelvic cavity also is lined by a serous membrane, the **peritoneum,** which has a parietal layer (which lines the interior abdominopelvic walls) and a visceral layer (which envelopes the viscera).

14. OVERVIEW OF EARLY DEVELOPMENT

Week 1: Fertilization and Implantation

Fertilization occurs in the ampulla of the uterine tube (fallopian tube) usually within 24 hours after ovulation (Fig. 1.33). The fertilized ovum (the union of sperm and egg nuclei, with a diploid number of chromosomes) is termed a **zygote.** Subsequent cell division (cleavage) occurs at the two-, four-, eight-, and 16-cell stages and results in formation of a ball of cells that travels down the uterine tube toward the uterine cavity. When the cell mass reaches days 3 to 4 of development, it resembles a mulberry and is called a **morula** (16-cell stage). As the growing morula enters the uterine cavity at about day 5, it contains hundreds of cells and it develops a fluid-filled cyst in its interior; it is now known as a **blastocyst**. At about days 5 to 6, implantation occurs as the blastocyst literally erodes or burrows its way into the uterine wall (endometrium) (see Fig. 1.33).

Week 2: Formation of the Bilaminar Embryonic Disc

As the blastocyst implants, it forms an inner cell mass (future embryo, **embryoblast**) and a larger fluid-filled cavity surrounded by an outer cell layer called the **trophoblast** (Figs. 1.33 and 1.34). The trophoblast undergoes differentiation and complex cellular interactions with maternal tissues to initiate formation of the primitive

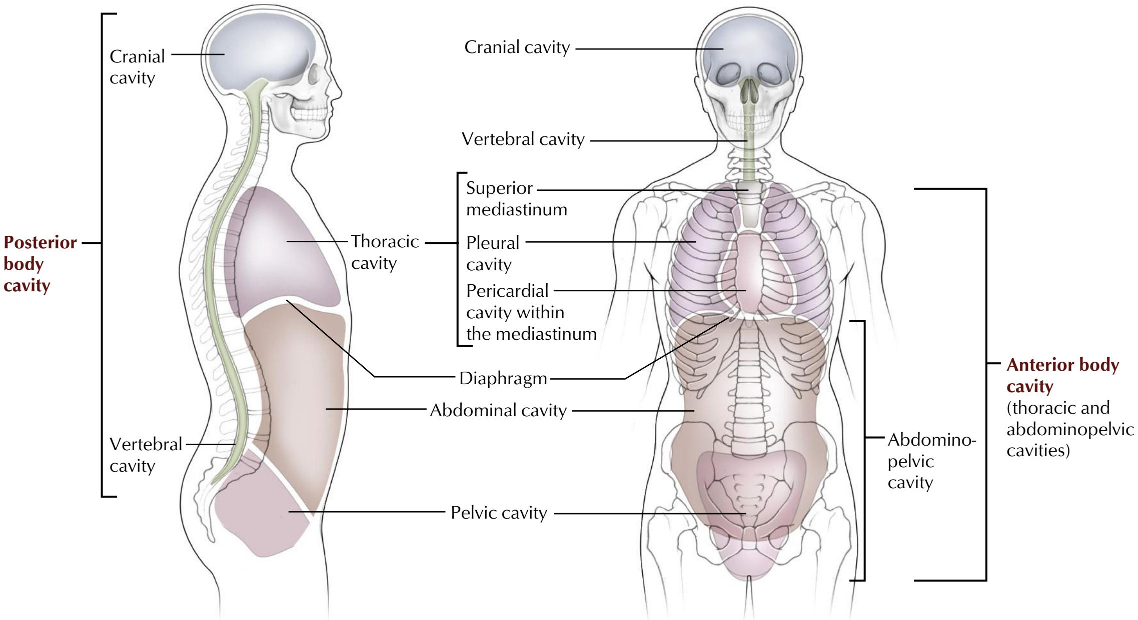


FIGURE 1.32 Major Body Cavities. (From *Netter's atlas of human anatomy*, ed 8, Plate BP 2; S-BP 2.)

uteroplacental circulation. Simultaneously, the inner cell mass develops into the following two cell types (bilaminar disc formation):

- **Epiblast:** formation of a sheet of columnar cells on the dorsal surface of the embryoblast.
- **Hypoblast:** a sheet of cuboidal cells on the ventral surface of the embryoblast.

The epiblast forms a cavity on the dorsal side that gives rise to the *amniotic cavity*. The blastocyst cavity on the ventral side becomes the *primitive yolk sac*, which is lined by simple squamous epithelium derived from the hypoblast. About day 12, further hypoblast cell migration forms the true yolk sac, and the old blastocyst cavity becomes coated with extraembryonic mesoderm.

Week 3: Gastrulation

Gastrulation (development of a trilaminar embryonic disc) begins with the appearance of the **primitive streak** on the dorsal surface of the epiblast (Fig. 1.35). This streak forms a groove demarcated at its cephalic end (head) by the **primitive node**. The node forms a midline cord of mesoderm that becomes the **notochord**. Migrating epiblast cells

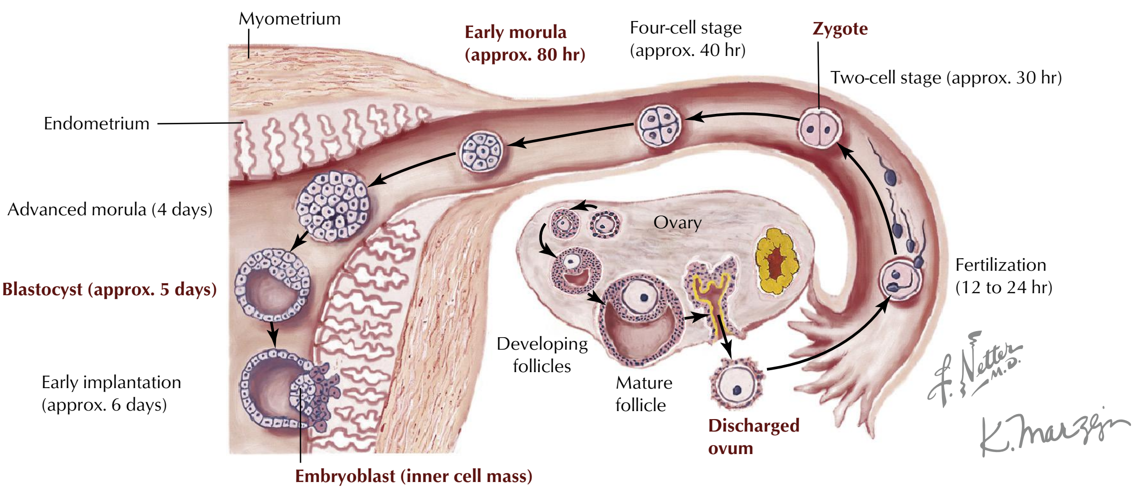


FIGURE 1.33 Schematic of Key Events: Week 1 of Human Development.