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GROSS ANATOMY

6TH EDITION

Kyung Won Chung
Harold M. Chung

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knowledge of
anatomy and
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Dedication

Young Hee, my wife, sincere friend, and companion, for her love, care, and encouragement.

Kyung Won Chung

To Kathie, my wife, best friend, and soul partner, and to my daughter, Kira, for their love, support, and understanding.

Harold M. Chung

Preface

This concise review of human anatomy is designed for medical, dental, graduate, physician assistant/associate, physical therapy, and other health science students. It is intended primarily to help students prepare for the United States Medical Licensing Examination, the National Board Dental Examination, as well as other board examinations for students in health-related professions. It presents the essentials of human anatomy in the form of condensed descriptions and simple illustrations. The text is concisely outlined with related board-type questions following each section. An attempt has been made to include all board-relevant information without introducing a vast amount of material or entangling students in a web of details. Although this book is in summary form, it is equivalent to a standard textbook for a comprehensive study with more clinical information.

Organization

As with previous editions, the sixth edition begins with a brief introduction to the skeletal, muscular, nervous, circulatory, and organ systems. The introductory chapter is followed by chapters on regional anatomy. These include the introduction, upper limb, lower limb, thorax, abdomen, perineum and pelvis, back, and head and neck.

Anatomy forms a foundation of clinical medicine and surgery and is a visual science of human structures. Thus, the success of learning and understanding largely depends on the quality of dissection and on clear accurate illustrations. Many of the illustrations are simple schematic drawings, which are used to enhance the student's understanding of the descriptive text. A few of the illustrations are more complex, attempting to exhibit important anatomic relations. The considerable number of tables of muscles will prove particularly useful as a summary and review. In addition, the end-of-chapter summaries and summary charts for muscle innervation and action, cranial nerves, autonomic ganglia, and foramina of the skull are included in order to highlight pertinent aspects of the system.

Test questions at the end of each chapter emphasize important information and lead to a better understanding of the material. These questions also serve as a self-evaluation to help the student uncover areas of weakness. Answers and explanations are provided after the questions.

Features of the New Edition

- **Expanded and Updated Clinical Correlations**

Clinical correlations emphasize the clinical importance of anatomic knowledge by relating basic anatomy to actual clinical practice. They are designed to challenge the student, enhance genuine understanding of anatomy, and encourage

assimilation of information. The clinical correlations are set in boxes and placed at relevant locations in the text. They are designated by two *Cs* (cc), followed by the box number. Many cc boxes have been combined or regrouped.

- **End-of-Chapter Summaries**

These summaries help students review essential information quickly and reinforce key concepts.

- **Development Checks [check mark]**

These highlight the most important embryologic concepts in an effective, logical, and understandable way.

- **Review Test**

The chapter review tests consist of questions and answers that reflect the guidelines set forth by the National Board of Medical Examiners. The questions reinforce the key information and test basic anatomic knowledge and the students' ability to interpret their observations and solve clinical problems. Therefore, clinically oriented questions and applications have been significantly increased because their fundamental utility is based on the relationship of anatomy to clinical medicine. Many test questions have been rewritten. They are centered around a clinical situation that requires in-depth anatomic knowledge and problem-solving skills. Rationales are provided for correct and incorrect answers.

- **The Comprehensive Examination**

The examination is placed at the end of the book. It can be used for review of a particular topic or as a self-assessment tool in preparation for the actual Board examination.

- **The Illustration Program**

Illustrations play a critical role in helping students visualize anatomic structures and help identify their functional and clinical characteristics. Some illustrations have been rearranged or redrawn, and new ones have been added. In addition, a second color was added. The new two-color art program promotes recall, clarifies difficult concepts, and enhances understanding. More radiograms, angiograms, computed tomograms, and magnetic resonance images are included in the text and in the review test section to aid in the study of anatomic structures and their relationships.

It is the authors' intention to invite feedback, constructive criticisms, and valuable suggestions from students and colleagues who choose this book as an aid to learning and teaching basic and clinical anatomy.

Kyung Won Chung

Harold M. Chung

Acknowledgments

We wish to express our sincere thanks to the many students, colleagues, and friends who have made valuable suggestions that have led to the improvement of the 6th edition. We are also indebted to John M. Chung, M.D., for providing his invaluable criticism of the text and clinically oriented test questions as well as for his copyediting during the preparation phase of this edition. Finally, we greatly appreciate and enjoy the privilege of working with the Lippincott Williams & Wilkins staff, including Crystal Taylor, acquisitions editor; Kelly Horvath, managing editor; and Emilie Moyer, marketing manager; we thank the staff for their constant guidance, enthusiasm, and unfailing support throughout the preparation, production, and completion of this new edition.

Chapter 1

Introduction

Studies of gross anatomy can be approached in several different ways including systemic, regional, or clinical anatomy. **Systemic anatomy** is an approach to anatomic study organized by organ systems, such as the respiratory, digestive, or reproductive systems, which relates structure to function. **Regional anatomy** is an approach to anatomic study based on regions and deals with structural relationships among the parts of the body such as the thorax and abdomen, emphasizing the relationships among various systemic structures such as muscles, nerves, and blood vessels. Anatomy is best learned by emphasizing its connection to clinical medicine, and thus **clinical anatomy** emphasizes the practical application of anatomic knowledge to the solution of clinical problems that are important in and have real pertinence to the practice of medicine. In this introductory chapter, the systemic approach to the study of anatomy is used. In subsequent chapters, the clinical and regional approaches to the study of anatomy are used because many injuries and diseases involve specific body regions, and dissections and surgical procedures are performed region by region. In addition, clinical correlations are presented throughout the text.

Skeletal System

I. Bones

- Are calcified connective tissue consisting of cells (**osteocytes**) in a matrix of ground substance and collagen fibers.
- Serve as a **reservoir** for **calcium** and **phosphorus** and act as **levers** on which muscles act to produce the movements permitted by joints.
- Contain internal soft tissue, the **marrow**, where blood cells are formed.
- Are classified, according to shape, into long, short, flat, irregular, and sesamoid bones; and according to their developmental history into endochondral and membranous bones.

A. Long bones

- Include the humerus, radius, ulna, femur, tibia, fibula, metacarpals, and phalanges.
- Develop by replacement of hyaline cartilage plate (**endochondral ossification**).

- Have a shaft (**diaphysis**) and two ends (**epiphyses**). The **metaphysis** is a part of the diaphysis adjacent to the epiphyses.

1. *Diaphysis*

- Forms the **shaft** (central region) and is composed of a thick tube of **compact bone** that encloses the **marrow cavity**.

2. *Metaphysis*

- Is a part of the diaphysis, the growth zone between the diaphysis and epiphysis during bone development.

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3. *Epiphyses*

- Are **expanded articular ends** , separated from the shaft by the epiphyseal plate during bone growth, and composed of a **spongy bone** surrounded by a thin layer of compact bone.

B. Short bones

- Include the carpal and tarsal bones and are approximately cuboid shaped.
- Are composed of **spongy bone** and **marrow** surrounded by a thin outer layer of **compact bone**.

C. Flat bones

- Include the ribs, sternum, scapulae, and bones in the vault of the skull.
- Consist of **two layers of compact bone** enclosing **spongy bone** and **marrow space** (**diploë**).
- Have articular surfaces that are covered with fibrocartilage.
- Grow by replacement of connective tissue.

D. Irregular bones

- Include bones of mixed shapes such as bones of the skull, vertebrae, and coxa.
- Contain mostly **spongy bone** enveloped by a thin outer layer of **compact bone**.

E. Sesamoid bones

- **Develop in** certain **tendons** and reduce friction on the tendon, thus protecting it from excessive wear.
- Are commonly found where tendons cross the ends of long bones in the limbs, as in the wrist and the knee (i.e., patella).

cc 1.1

Osteoblast synthesizes new bone and **osteoclast** functions in the resorption (break down bone matrix and release calcium and minerals) and remodeling of bone. Parathyroid hormone causes mobilization of calcium by promoting bone resorption, while calcitonin suppresses mobilization of calcium from bone. Osteoid is the organic matrix of bone prior to calcification.

Osteomalacia is a gradual softening of the bone due to failure of bone to calcify because of lack of vitamin D or renal tubular dysfunction. **Osteopenia** is a decreased calcification of bone or a reduced bone mass due to an inadequate osteoid synthesis. **Osteoporosis** is an age-related disorder characterized by decreased bone mass and increased susceptibility to fractures of the hip, vertebra, and wrist. It occurs when bone resorption outpaces bone formation, since bone constantly undergoes cycles of resorption and formation (remodeling) to maintain the concentration of calcium and phosphate in the extracellular fluid. Signs of osteoporosis are vertebral compression, loss of body height, development of kyphosis, and hip fracture. **Osteopetrosis** is an abnormally dense bone, obliterating the marrow cavity, due to defective resorption of immature bone.

II. Joints

- Are places of union between two or more bones.
- Are innervated as follows: The nerve supplying a joint also supplies the muscles that move the joint and the skin covering the insertion of such muscles (**Hilton's law**).

- Are classified on the basis of their structural features into fibrous, cartilaginous, and synovial types.

A. Fibrous joints (synarthroses)

- Are joined by fibrous tissue, have **no joint cavities** , and permit little movement.

1. Sutures

- Are connected by fibrous connective tissue (i.e., like uniting a wound with stitches).
- Are found between the flat bones of the skull.

2. Syndesmoses

- Are connected by fibrous connective tissue.
- Occur as the inferior tibiofibular and tympanostapedial syndesmoses.

B. Cartilaginous joints

- Are united by **cartilage** and have **no joint cavity**.

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1. Primary cartilaginous joints (synchondroses)

- Are united by **hyaline cartilage**.
- Permit **no movement** but growth in the length of the bone.
- Include epiphyseal cartilage plates (the union between the epiphysis and the diaphysis of a growing bone) and spheno-occipital and manubriosternal synchondroses.

2. Secondary cartilaginous joints (symphyses)

- Are joined by **fibrocartilage** and are slightly movable joints.

- Include the pubic symphysis and the intervertebral disks.

C. Synovial (diarthrodial) joints

- Permit a great degree of free movement and are classified according to the shape of the articulation and/or type of movement.
- Are characterized by four features: **joint cavity**, **articular (hyaline) cartilage**, **synovial membrane** (which produces synovial fluid), and **articular capsule**.

1. Plane (gliding) joints

- Are united by two flat articular surfaces and allow a simple **gliding** or sliding of one bone over the other.
- Occur in the proximal tibiofibular, intertarsal, intercarpal, intermetacarpal, carpometacarpal, sternoclavicular, and acromioclavicular joints.

2. Hinge (ginglymus) joints

- Resemble **door hinges** and allow only flexion and extension.
- Occur in the elbow, ankle, and interphalangeal joints.

3. Pivot (trochoid) joints

- Are formed by a central bony pivot turning within a bony ring.
- Allow **only rotation** (movement around a single longitudinal axis).
- Occur in the superior and inferior radioulnar joints and in the atlantoaxial joint.

4. Condylar (ellipsoidal) joints

- Have two convex condyles articulating with two concave condyles. The shape of the articulation is **ellipsoidal**.
- Allow flexion and extension and occur in the wrist (radiocarpal), metacarpophalangeal, knee (tibiofemoral), and atlanto-occipital joints.

5. *Saddle (sellar) joints*

- Resemble a **saddle** on a horse's back and allow flexion and extension, abduction and adduction, and circumduction but no axial rotation.
- Occur in the carpometacarpal joint of the thumb and between the femur and patella.

6. *Ball-and-socket (spheroidal) joints*

- Are formed by the reception of a globular (ball-like) head into a cup-shaped cavity and allow movement in many directions.
- Allow flexion and extension, abduction and adduction, medial and lateral rotations, and circumduction and occur in the shoulder and hip joints.

cc 2.1

Osteoarthritis is a noninflammatory degenerative joint disease characterized by degeneration of the articular cartilage and osseous outgrowths at the margins. It results from wear and tear of the joints; commonly affects the hands, fingers, hips, knees, feet, and spine; and is accompanied by pain and stiffness. **Rheumatoid arthritis** is an inflammatory disease primarily of the joints. It is an autoimmune disease in which the immune system attacks the synovial membranes and articular structures, leading to deformities and disability. There is no cure for rheumatoid arthritis, and its most common symptoms are joint swelling, stiffness, and pain.

Muscular System

I. Muscle

- Consists predominantly of **contractile cells** and produces the **movements** of various parts of the body by contraction.
- Occurs in three types:

A. Skeletal muscle

- Is voluntary and striated; makes up about 40% of the total body mass; and functions

to produce movement of the body, generate body heat, and maintain body posture.

- Has two attachments, an **origin** (which is usually the more fixed and proximal attachment), and an **insertion** (which is the more movable and distal attachment).
- Is enclosed by **epimysium**, a thin layer of connective tissue. Smaller bundles of muscle fibers are surrounded by **perimysium**. Each muscle fiber is enclosed by **endomysium**.

cc 2.1

Lou Gehrig's disease (amyotrophic lateral sclerosis): is a fatal neurologic disease that attacks the neurons responsible for controlling voluntary muscles. The muscles gradually weaken and atrophy; the brain is unable to control voluntary movement of the arms, legs, and body; and patients lose the ability to breath, swallow, and speak. The earliest symptoms may include cramping, twitching, and muscle weakness.

B. Cardiac muscle

- Is involuntary and striated and forms the **myocardium**, the middle layer of the heart.
- Is innervated by the autonomic nervous system but contracts spontaneously without any nerve supply.
- Includes specialized myocardial fibers that form the cardiac **conducting system**.

C. Smooth muscle

- Is involuntary and nonstriated, and generally arranged in two layers, **circular** and **longitudinal**, in the walls of many visceral organs.
- Is innervated by the autonomic nervous system, regulating the size of the lumen of a tubular structure.
- Undergoes rhythmic contractions called **peristaltic waves** in the walls of the gastrointestinal (GI) tract, uterine tubes, ureters, and other organs.

II. Structures Associated with Muscles

A. Tendons

- Are **fibrous bands** of dense connective tissue that **connect muscles to bones** or cartilage.
- Are supplied by sensory fibers extending from muscle nerves.

B. Ligaments

- Are **fibrous bands** that **connect bones to bones** or cartilage, or are folds of peritoneum serving to support visceral structures.

C. Raphe

- Is the line of union of symmetrical structures by a fibrous or tendinous band such as the pterygomandibular, pharyngeal, and scrotal raphes.

D. Aponeuroses

- Are **flat fibrous sheets** or expanded broad tendons that attach to muscles and serve as the means of origin or insertion of a flat muscle.

E. Retinaculum

- Is a fibrous band that holds a structure in place in the region of joints.

F. Bursae

- Are **flattened sacs of synovial membrane** that contain a viscid fluid for moistening the bursa wall to facilitate movement by minimizing friction.
- Are found where a tendon rubs against a bone, ligament, or other tendon.
- Are prone to fill with fluid when infected, and may communicate with an adjacent joint cavity.

G. Synovial tendon sheaths

- Are **tubular sacs** filled with synovial fluid that wrap **around the tendons** .
- Occur where tendons pass under ligaments or retinacula and through osseofibrous tunnels, thus facilitating movement by reducing friction.
- Have linings, like synovial membrane, that respond to infection by forming more **fluid** and by proliferating more cells, causing adhesions and thus restriction of movement of the tendon.

H. Fascia

- Is a **fibrous sheet** that envelops the body under the skin and invests the muscles and may limit the spread of pus and extravasated fluids such as urine and blood.

1. *Superficial fascia*

- Is a **loose connective tissue** between the dermis and the deep (investing) fascia and has a fatty superficial layer and a membranous deep layer.
- Contains fat, cutaneous vessels, nerves, lymphatics, and glands.

2. *Deep fascia*

- Is a sheet of fibrous tissue that **invests the muscles** and helps support them by serving as an elastic sheath or stocking.
- Provides origins and insertions for muscles and forms retinacula and fibrous sheaths for tendons.
- Forms potential pathways for infection or extravasation of fluids.

Nervous System

1. *Divisions of the Nervous System*

- Is divided anatomically into the **central nervous system** (CNS), consisting of the brain and spinal cord, and the **peripheral nervous system** (PNS), consisting of 12 pairs of cranial nerves and 31 pairs of spinal nerves, and their associated ganglia.
- Is divided functionally into the **somatic** nervous system, which controls primarily voluntary activities, and the **visceral (autonomic)** nervous system, which controls

primarily involuntary activities.

- Is composed of **neurons** and **neuroglia** , which are nonneuronal cells such as astrocytes, oligodendrocytes, and microglia.
- Controls and integrates the activity of various parts of the body.

II. Neurons

- Are the structural and functional units of the nervous system (neuron doctrine).
- Are specialized for the reception, integration, transformation, and transmission of information.

A. Components of neurons

- Consist of cell bodies (perikaryon or soma) and their processes, dendrites and axons.
 - **Cell bodies** are located in the gray matter of the CNS, and their collections are called **ganglia** in the PNS and **nuclei** in the CNS.
 - **Dendrites** (dendron means "tree") are usually short and highly branched and **carry impulses toward the cell body**.
 - **Axons** are usually single and long, have fewer branches (collaterals), and **carry impulses away from the cell body**.

B. Classification of neurons

1. Unipolar (pseudounipolar) neurons

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- Have **one process** , which divides into a central branch that functions as an axon and a peripheral branch that serves as a dendrite.
- Are called pseudounipolar because they were originally bipolar. The two processes fuse during development to form a single process that bifurcates at a distance from the cell body.
- Are sensory neurons of the PNS and found in spinal and cranial nerve ganglia.

2. *Bipolar neurons*

- Have **two processes** (one dendrite and one axon); are sensory; and are found in the olfactory epithelium, the retina, and the inner ear.

3. *Multipolar neurons*

- Have **several dendrites** and **one axon** and are most common in the CNS (e.g., motor cells in anterior and lateral horns of the spinal cord, autonomic ganglion cells).

C. **Ganglion**

- Is a collection of neuron cell bodies **outside the CNS**, and a **nucleus** is a collection of neuron cell bodies **within the CNS**.

D. **Other components of the nervous system**

1. *Cells that support neurons*

- Include **Schwann cells** and **satellite cells** in the PNS.
- Are called **neuroglia** in the CNS and are composed mainly of three types: **astrocytes**; **oligodendrocytes**, which play a role in myelin formation and transport of material to neurons; and **microglia**, which phagocytose waste products of nerve tissue.

2. *Myelin*

- Is the fat-like substance forming a sheath around certain nerve fibers.
- Is formed by **Schwann cells in the PNS** and **oligodendrocytes in the CNS**.

3. *Synapses*

- Are the **sites of functional contact** of a neuron with another neuron, an effector (muscle, gland) cell, or a sensory receptor cell.

- Are classified by the site of contact as axodendritic, axoaxonic, or axosomatic (between axon and cell body).
- Subserve the transmission of nerve impulses, commonly from the axon terminals (presynaptic elements) to the plasma membranes (postsynaptic elements) of the receiving cell.

III. Central Nervous System (CNS)

A. Brain

- Is enclosed within the cranium, or brain case.
- Has a **cortex** , which is the **outer part** of the cerebral hemispheres, and is composed of **gray matter**. This matter consists largely of the **nerve cell bodies** , dendrites, and neuroglia.
- Has an interior part composed of **white matter** , which consists largely of **axons** forming tracts or pathways, and ventricles, which are filled with cerebrospinal fluid (CSF).

B. Spinal cord

- Is **cylindrical** , occupies approximately the upper two thirds of the vertebral canal, and is enveloped by the meninges.
- Has cervical and lumbar enlargements for the nerve supply of the upper and lower limbs, respectively.
- Has centrally located **gray matter** , in contrast to the cerebral hemispheres, and peripherally located **white matter**.
- Grows more slowly than the vertebral column during fetal development, and hence, its terminal end gradually shifts to a higher level.
- Has a conical end known as the **conus medullaris** and ends at the level of L2 (or between L1 and L2) in the adult and at the level of L3 in the newborn.

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C. Meninges

- Consist of three layers of connective tissue membranes (**pia**, **arachnoid** , and **dura mater**) that surround and protect the brain and spinal cord.

- Contain the **subarachnoid space** , which is the interval between the arachnoid and pia mater, filled with CSF.

IV. Peripheral Nervous System (PNS)

A. Cranial nerves

- Consist of **12 pairs** and are connected to the brain rather than to the spinal cord.
- Have motor fibers with cell bodies located within the CNS and sensory fibers with cell bodies that form sensory ganglia located outside the CNS.
- Emerge from the ventral aspect of the brain (except for the trochlear nerve, cranial nerve IV).
- Contain all four functional components of the spinal nerves and three additional components (see Nervous System: IVC ; Nerves of the Head and Neck: Chapter 8).

B. Spinal nerves (Figure 1-1)

- Consist of **31 pairs** : 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal.
- Are formed from dorsal and ventral roots; each dorsal root has a ganglion that is within the intervertebral foramen.
- Are connected with the sympathetic chain ganglia by **rami communicantes**.
- Contain sensory fibers with cell bodies in the dorsal root ganglion (general somatic afferent [GSA] and general visceral afferent [GVA] fibers), motor fibers with cell bodies in the anterior horn of the spinal cord (general somatic efferent [GSE] fibers), and motor fibers with cell bodies in the lateral horn of the spinal cord (general visceral efferent [GVE] fibers) between T1 and L2.

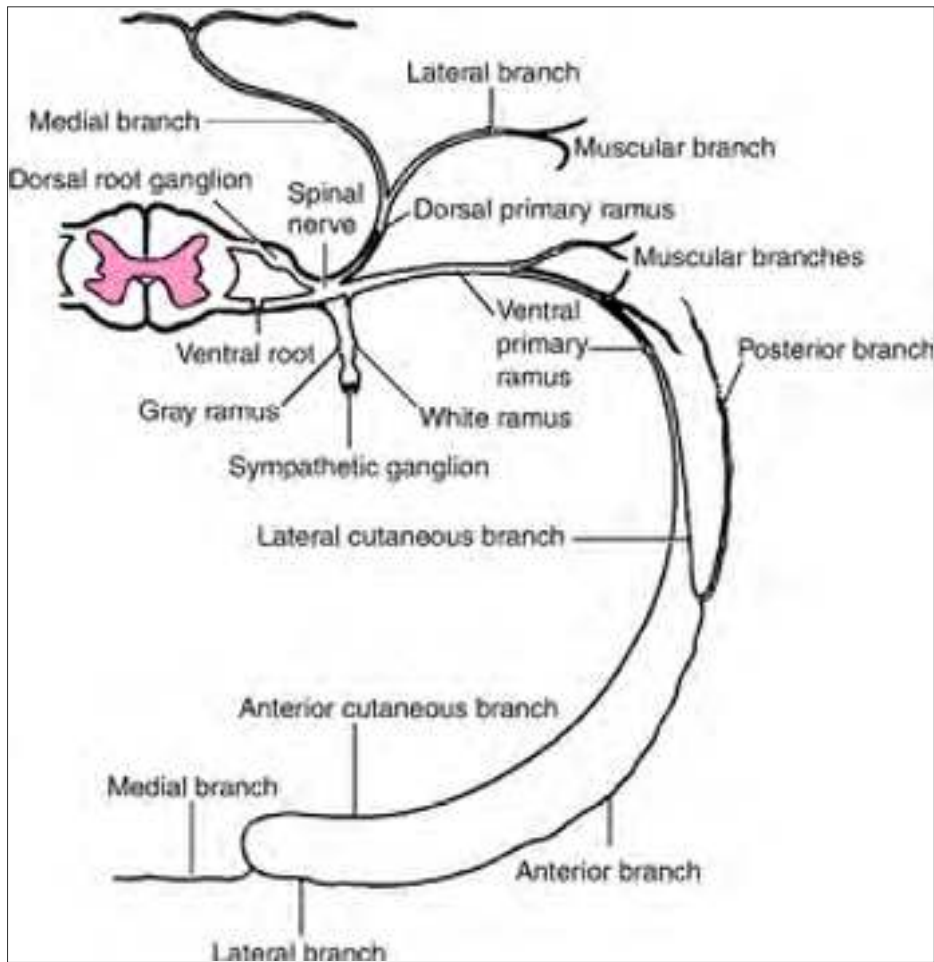


Figure 1-1 Typical spinal nerve (anterior = ventral; posterior = dorsal).

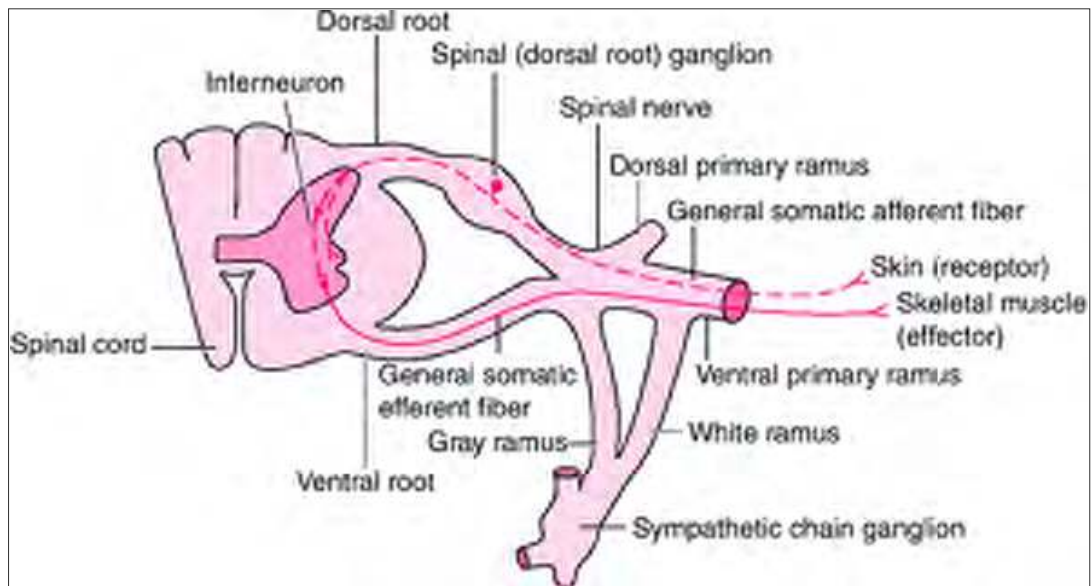


Figure 1-2 General somatic afferent and efferent nerves.

- Are divided into the **ventral and dorsal primary rami**. The ventral primary rami enter into the formation of plexuses (i.e., cervical, brachial, and lumbosacral); the dorsal primary rami innervate the skin and deep muscles of the back.

C. Functional components in peripheral nerves (Figures 1-2 and 1-3)

1. General somatic afferent (GSA) fibers

- Transmit pain, temperature, touch, and proprioception from the body to the CNS.

2. General somatic efferent (GSE) fibers

- Carry motor impulses to skeletal muscles of the body.

3. General visceral afferent (GVA) fibers

- Convey sensory impulses from visceral organs to the CNS.

4. General visceral efferent (GVE) fibers (autonomic nerves)

- Transmit motor impulses to smooth muscle, cardiac muscle, and glandular tissues.

5. Special somatic afferent (SSA) fibers

- Convey special sensory impulses of vision, hearing, and equilibration to the CNS.

6. Special visceral afferent (SVA) fibers

- Transmit smell and taste sensations to the CNS.

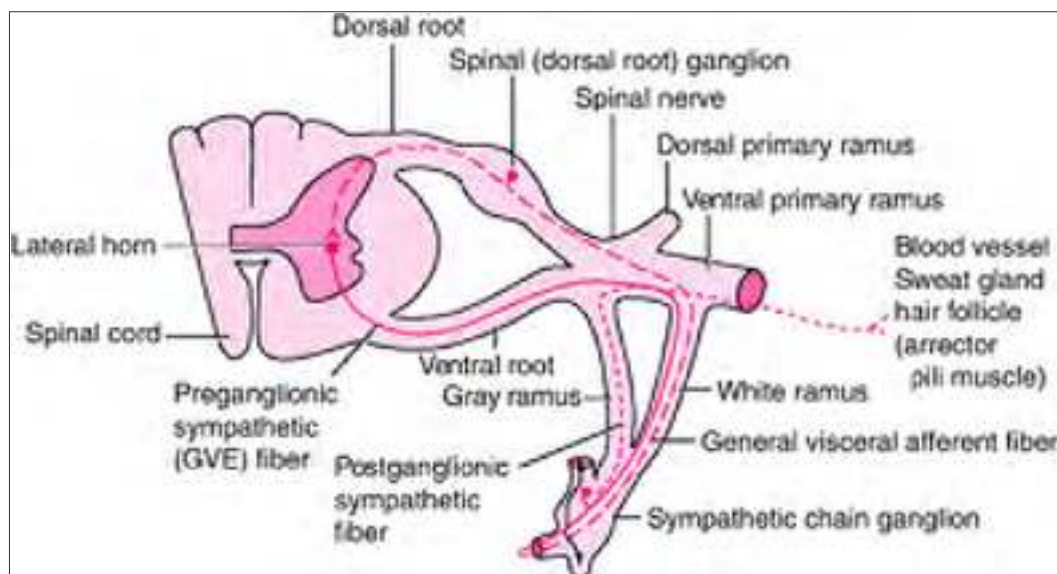


Figure 1-3 General visceral efferent (autonomic) and afferent nerves.

7. Special visceral efferent (SVE) fibers

- Conduct motor impulses to the muscles of the head and neck.
- Arise from branchiomeric structures such as muscles for mastication, muscles for facial expression, and muscles for elevation of the pharynx and movement of the larynx.

V. **Autonomic Nervous System**

- Is divided into the **sympathetic** (thoracolumbar outflow), **parasympathetic** (craniosacral outflow), and **enteric divisions**.
- Is composed of two neurons, preganglionic and postganglionic, which are GVE neurons.

A. **Sympathetic nerve fibers** (see Figure 1-3)

- Have preganglionic nerve cell bodies that are located in the lateral horn of the thoracic and upper lumbar levels (L2 or L1-L3) of the spinal cord.
- Have **preganglionic fibers** that pass through ventral roots, spinal nerves, and white rami communicantes. These fibers enter adjacent sympathetic chain ganglia, where they synapse or travel up or down the chain to synapse in remote ganglia or run further through the splanchnic nerves to synapse in collateral ganglia, located along the major abdominal blood vessels.
- Have **postganglionic fibers** from the chain ganglia that return to spinal nerves by way of gray rami communicantes and supply the skin with secretory fibers to sweat glands, motor fibers to smooth muscles of the hair follicles (arrectores pilorum), and vasomotor fibers to the blood vessels.
- Function primarily in **emergencies**, preparing individuals for **fight or flight**, and thus increase heart rate, inhibit GI motility and secretion, and dilate pupils and bronchial lumen.

B. **Parasympathetic nerve fibers**

- Comprise the preganglionic fibers that arise from the brainstem (cranial nerves III, VII, IX, and X) and sacral part of the spinal cord (second, third, and fourth sacral segments).
- Are, with few exceptions, characterized by **long preganglionic fibers** and **short postganglionic fibers**.
- Are distributed to the walls of the visceral organs and glands of the digestive system but not to the skin or to the periphery.
- Decrease heart rate, increase GI peristalsis, and stimulate secretory activity.
- Function primarily in **homeostasis**, tending to promote quiet and orderly processes of the body.

C. Enteric division

- Consists of enteric ganglia and plexus of the GI tract, including the myenteric (Auerbach's) and submucosal (Meissner's) plexuses.
- Plays an important role in the control of GI motility and secretion.

Circulatory System

I. Vascular System

- Functions to transport vital materials between the external environment and the internal fluid environment of the body. It carries **oxygen; nutrients; waste products**, including carbon dioxide; hormones; defense elements; and cells involved in wound healing.
- Consists of the **heart** and **vessels** (arteries, capillaries, veins) that transport blood through all parts of the body.
- Includes the **lymphatic vessels**, a set of channels that begin in the tissue spaces and return excess tissue fluid to the bloodstream.

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A. Circulatory loops

1. Pulmonary circulation

- Transports blood from the right ventricle through the pulmonary arteries to the lungs for the exchange of oxygen and carbon dioxide and returns it to the left atrium of the heart through the pulmonary veins.

2. Systemic circulation

- Transports blood from the left ventricle through the aorta to all parts of the body and returns it to the right atrium through the superior and inferior venae cavae and the cardiac veins.

B. Heart

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