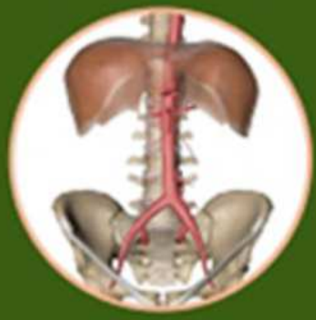
FOURTH EDITION

The ANATOMICAL BASIS of DENTISTRY



Bernard Liebgott

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The Anatomical Basis of Dentistry

Fourth Edition

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To Dorion, my wife and life companion,
who fully supported and encouraged my move to academia and teaching.
To all my students, who made my chosen career in teaching fulfilling and rewarding.

Preface

The fourth edition of *The Anatomical Basis of Dentistry* continues to fulfill the need for a textbook of gross anatomy specifically written for the dental profession. Yet another edition, however, begs the question, "How has the study of anatomy changed since the previous version of the book?" Human gross anatomy has not changed greatly over the centuries, but the methods of describing, illustrating, and presenting the material have changed considerably and continue to change. In addition, the introduction of clinical relevance has transformed the study of anatomy from an insufferable mandatory first-year hurdle to a meaningful experience on which to build a successful career in the practice of dentistry.

Another question posed to virtually all students of dentistry is, "Why are dentists required to study the complete body and not just the head and neck?" The answer is that, as dental professionals, we are licensed to write prescriptions, take and interpret radiographs, administer anesthesia (local and general), and perform orofacial surgical procedures. Treatment, however, cannot be administered until the patient's health is evaluated through a medical history, which may reveal existing medical conditions that may require modification or even preclude some procedures. Furthermore, despite medical histories and necessary precautions, complications can arise during routine treatment. Prevention and treatment of complications require sound background knowledge of the form and function of the human body beyond a basic knowledge of the dental arches.

Organization

As in previous editions of *The Anatomical Basis of Dentistry*, Chapter 1 introduces the reader to terminology and provides a general description of the body systems in preparation for the regional anatomy that follows. It is highly recommended that this chapter be read initially and then reread from time to time throughout the course. Chapters 2 through 5 deal with the regions of the trunk of the body (back, thorax, abdomen, and neck). Chapter 6 presents an in-depth study of the skull and the bones that comprise it as an introduction to a thorough study of the craniofacial complex. The head is presented in detail in Chapter 7 and then reviewed by systems in Chapter 8. Chapters 9 and 10 provide an overview of the upper and lower limbs to complete the study of the human body, and to familiarize the reader with sites of intravenous and intramuscular injections as well as surrounding anatomical structures that may affect these procedures.

Clinical applications are featured throughout the book, and Chapter 11 remains devoted to applied or clinical anatomy, which is fundamental to the practice of dentistry. These sections have been updated to reflect advances developed in the past decade. No pretense is made to teach clinical dentistry, but rather the applied anatomy is presented to instill a keener interest in the anatomical structures involved and lay the foundation for upcoming clinical courses and eventual dental practice.

New To This Edition

The fourth edition maintains the principles and scope of previous editions. The artwork, however, has been—for the most part—replaced. Anatomical illustrations are invaluable in large or small group teaching and student review of gross anatomy. Although simple line-art drawings proved satisfactory in past editions, they lacked realism and a sense of depth. Three-dimensional male and female digital models were used to render more realistic illustrations of the various regions of the body as viewed from various perspectives. The digital renderings are easily incorporated into computer-generated presentations for the teacher and interactive learning programs for the student. Incorporated in each illustration is an anatomical "compass" that indicates the orientation of the figure.

Objective

Much thought has been given to the scope and amount of material presented in this book. It is the culmination of many years spent in the classroom, in the laboratory, and in the clinical practice of general dentistry. The book certainly is not intended to be an exhaustive, all-inclusive anatomical work replete with long lists of references; several excellent reference books are available for further study or clarification. Conversely, this book is not intended as a brief synopsis or a basic textbook of anatomy. It contains ample material to meet the requirements of a gross anatomy course for undergraduate dental students. At the same time, it is hoped that this book will maintain its usefulness and prove valuable throughout the undergraduate clinical years and eventually take its place on the desk of the practicing dentist and dental specialist.

Bernard Liebgott

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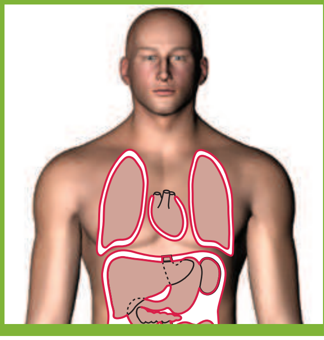
General Concepts



CHAPTER OUTLINE

THE STUDY OF ANATOMY

The word *anatomy* was coined from two Greek root words that mean "to cut up." This is precisely the way in which the early anatomists studied the structure of once-living things—by dissecting animal or human remains, observing structures, and then speculating as to what function these structures might perform. The scope of anatomy has broadened considerably. Human anatomy is now the study of the structure of the human body through a variety of approaches, and these approaches have given rise to specialized subfields of human anatomy.

Gross Anatomy

Gross anatomy is concerned with the study of human form and structure as seen with the naked eye. When applicable, **applied** or **clinical anatomy** is introduced to illustrate the connection with everyday clinical problems in the health sciences. There are two classic approaches to the study of gross anatomy, both of which are used in this book.

A **systemic approach** is one in which the various systems of the body are studied as separate entities. This system of study is favored by college anatomy courses that do not include laboratory dissections. The systems are discussed in later in this chapter and in Chapter 8.

A **regional approach** divides the body into a number of regions, which are then studied in turn. All the structures belonging to various systems are considered within the region being studied. This system of study follows the sequence of events encountered in a dissection and is favored in anatomy courses that include a dissecting laboratory component or a program that uses prosected specimens (specimens that were previously dissected).

This textbook largely follows a regional approach, because most dental school anatomy programs include a laboratory component. Bones, joints, muscles, blood vessels, nerves, fascia, and skin are found in every region of the body. For this reason a brief overview of the systems that give rise to these elements is presented in this chapter. The regions are covered in Chapters 2 (back), 3 (thorax), 4 (abdomen), 5 (neck), 7 (head), 9 (upper limb), and 10 (lower limb). A systemic review of the head is covered in Chapter 8, and applied anatomy for dental professionals is covered in the final Chapter 11.

Histology

Histology is the study of smaller details of structure as seen through a microscope. It is the study of human tissues and ranges from basic tissue and cell architecture, with use of light and confocal microscopes, to ultrastructural elements of tissues and cells, with use of the electron microscope. Biochemical techniques combined with histological techniques have given rise to applied disciplines of histochemistry and immunocytochemistry.

Neuroanatomy

Neuroanatomy is the study of the central nervous system (CNS), meaning the brain and spinal cord, as viewed in gross dissection and histological preparations, as well as the study of pathways through immunocytochemical tracers.

Developmental Anatomy

Developmental anatomy is the study of age-related changes in size, complexity, shape, and ability to function. **Prenatal development** follows the development of the individual from the time of conception to birth. *Embryology* is particularly concerned with the first 2 months of life in utero, during which the organ systems are formed. **Postnatal development** traces the various changes in form and function after birth; and through infancy, childhood, adolescence, and adulthood.

Surface Anatomy

Surface anatomy (living anatomy) deals with the surface or topography of the living person. Superficial structures can be readily located, and deeper structures can be located and envisioned based on surface landmarks.

Imaging Anatomy

Imaging anatomy is the noninvasive study of living or dead subjects as revealed by conventional radiography, magnetic resonance imaging (MRI), and ultrasonography. The use of serialized radiographs taken at ever-increasing depths through the body (computed tomography [CT]) and MRI has rekindled interest in sectional anatomy (i.e., the study of structures as they appear on the surface of cross-sectional or longitudinal sections through a cadaver).

TERMINOLOGY

The basis for all communication in human gross anatomy and related basic and clinical sciences is standardized and universally accepted. A precise terminology enables us to name structures to distinguish them from all other structures and to relate the position of these named structures to the rest of the body so they can be located with consistency and precision.

The Anatomical Position

In the dissecting laboratory, we assume, by convention, that our subject is standing in the anatomical position (Fig. 1.1): that is, standing erect with (1) the toes pointed forward, (2) the eyes directed to the horizon, (3) the arms by the sides, and (4) the palms of the hands facing forward.

From this basic position, we can divide the subject according to four different planes and introduce terminology that relates to these planes.

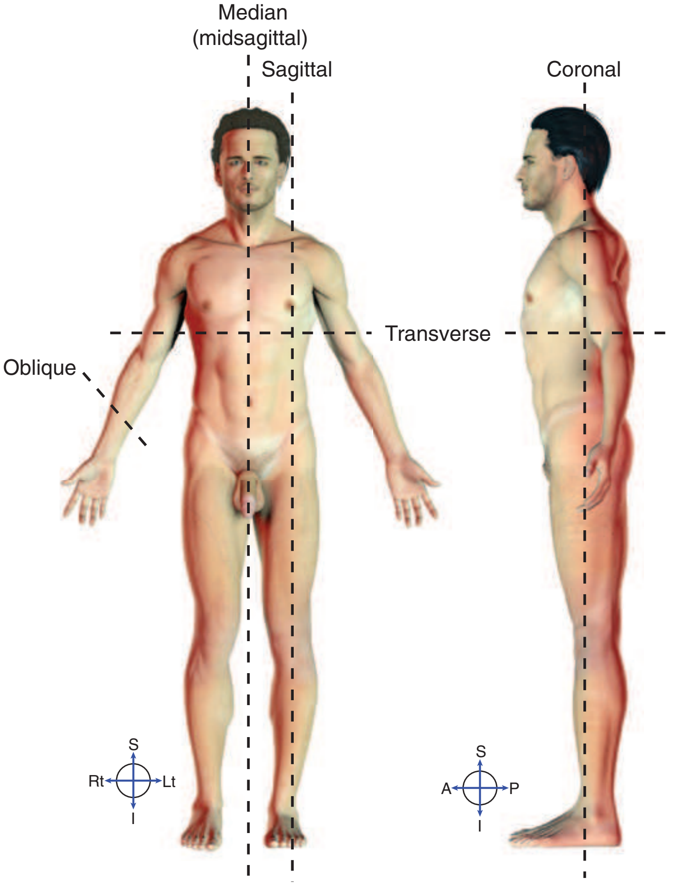
Anatomical Cuts and Planes

There are two basic ways to visualize deep structures of the human body. One is to dissect down to the area of interest; the other is to cut through the cadaver in defined planes (see Fig. 1.1). Sections also can be obtained from a living patient with CT or MRI.

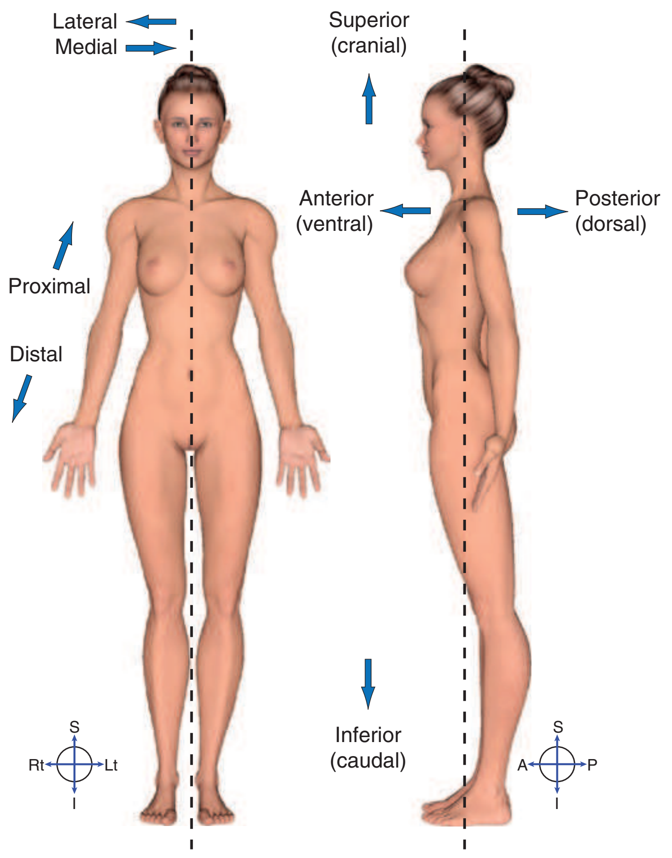
1. A cut through the **median** or **midsagittal plane** divides the body into equal right and left halves.
2. A **sagittal plane** is any one of an infinite number of planes parallel to the midsagittal plane that divide the body into unequal right and left parts.
3. The **coronal plane** is any one of an infinite number of planes that are at right angles to the midsagittal plane. A coronal cut will divide the body into anterior and posterior parts.
4. The **transverse, or horizontal, plane** is a plane that cuts across the body at right angles to the coronal and median planes, dividing the body into superior and inferior parts.
5. An **oblique plane** is, by default, any plane that deviates from the four aforementioned planes.
6. A **cross section** is any one of an infinite number of possible cuts across the body or one of its limbs at right angles to its long axis.
7. A **longitudinal section** is any one of an infinite number of possible cuts that parallel the long axis of the body or its components.

Terms of Relationship

The following terms are presented in pairs because each term has an opposite (Fig. 1.2). Again, the assumption is that our subject is in the anatomical position.



• **Fig. 1.1** Anatomical position and planes of section.



• **Fig. 1.2** Terms of relationship.

Terms of Relationship

Term	Definition
Anterior (ventral)	Toward the front of the body
Posterior (dorsal)	Toward the back of the body
Superior (cranial)	Toward the top of the head
Inferior (caudal)	Toward the soles of the feet
Medial	Toward the median plane
Lateral	Away from the median plane
Proximal (central)	Toward the trunk
Distal (peripheral)	Away from the trunk
Superficial	Toward the skin or body surface
Deep	Toward the interior of the body
Ipsilateral (homolateral)	On the same side
Contralateral	On the opposite side
Palmar surface of hand	Anterior surface of hand
Dorsal surface of hand	Posterior surface of hand
Plantar surface of foot	Inferior surface of foot
Dorsal surface of foot	Superior surface of foot

SKELETON (CARTILAGE AND BONES)

Cartilage

Cartilage is a specialized, supporting connective tissue. It consists of cells **(chondroblasts,** which give rise to **chondrocytes)** contained within a ground substance in the form of a rigid gel. There are no neurovascular elements within cartilage; instead, nutrients diffuse through the ground substance to the enclosed chondrocytes. No calcium salts are present; therefore cartilage does not appear on radiographs.

During early development, most of the fetal skeleton is present as cartilage, and most of this cartilage is subsequently replaced by bone during fetal and postnatal development.

Types

Hyaline (from the Greek word *hyalos,* meaning "glass") **cartilage** is a bluish-white, translucent structure. Nearly all of the fetal skeleton is hyaline cartilage. In the adult, its remnants are:

1. Articular cartilage, which is smooth and slippery and persists at the ends of cartilaginous bones to line articular surfaces of movable joints
2. Costal cartilages, which persist at the sternal ends of the ribs
3. Respiratory cartilages, consisting of the movable external nose and septum, larynx, trachea, and bronchial tree
4. Auditory cartilages, which include the external auditory meatus and the cartilaginous portion of the auditory (pharyngotympanic) tube

Elastic cartilage is pliable and yellowish in color because of the presence of elastin fibers. It is found in the external ear and in the epiglottis.

Fibrocartilage contains proportionately more collagen fibers, which are arranged in a parallel fashion for high tensile strength. It is found in tendon insertions and intervertebral discs (not including the pulpal nucleus).

Growth

Although cartilage is a rigid tissue, its unique structure allows it to grow as most soft tissues do. Cartilage can increase in size in two ways: (1) by *internal growth,* in which young chondrocytes proliferate within the cartilage, and (2) by *appositional growth,* in which a surface perichondrium consisting of a fibrous outer layer and a chondroblastic inner layer lays down surface cartilage.

Bone (Osteology)

Bone, like cartilage, is a living tissue consisting of cells or osteoblasts, which give rise to osteocytes within an organic framework or matrix.

Bone is unlike cartilage in that the intercellular matrix becomes calcified for greater rigidity and strength. Calcification, however, prevents diffusion of nutrients, and each cell within the matrix must therefore have a direct vascular supply.

Because of its rigid structure, interstitial growth is not possible. Appositional growth takes place only below the covering periosteal layer of bone. Periosteum consists of a fibrous outer layer and a cellular inner layer of osteoblasts, which form the bony matrix.

Functions

Bone has the following functions:

1. Support. Bones provide a rigid framework for the body.
2. Movement. Bones act as levers for muscles. Muscle usually attaches to approximating bones, and these attachments are able to move one bone in relation to another.
3. Protection. The brain and the thoracic viscera are protected by bone.
4. Hemopoiesis. The principal blood cells are formed in the marrow space of bone.
5. Storage. Calcium and phosphorus are stored in bone as body reserves.

Classification

By Region. The adult skeleton is divided into an axial and an appendicular skeleton. The **axial skeleton** comprises the skull, the vertebral or spinal column, the ribs, and the sternum. The **appendicular skeleton** includes the bones of the upper and lower limbs. The individual bones are illustrated in Fig. 1.3.

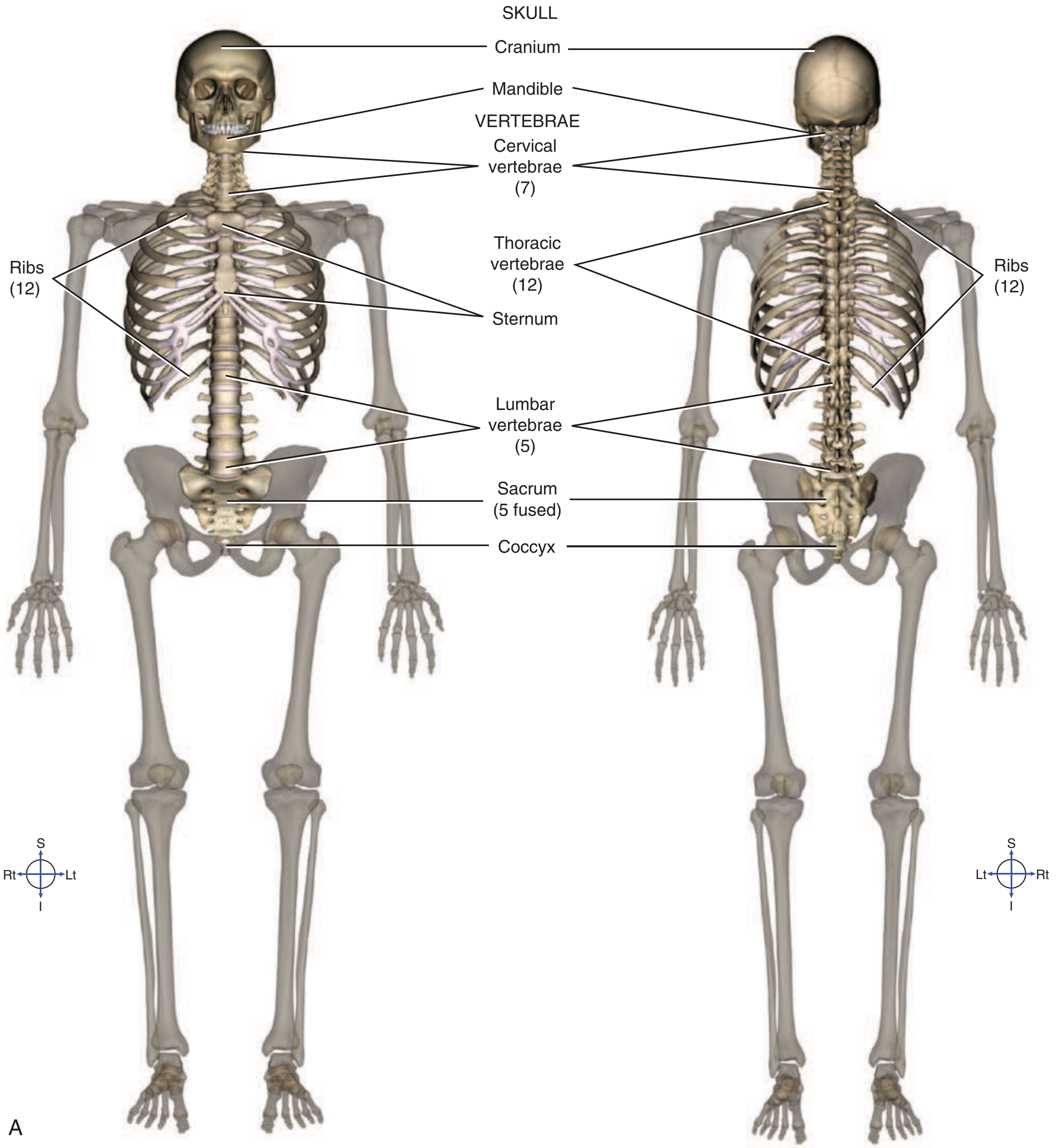
By Shape. **Long bones** are hollow tubes, shafts, or *diaphyses* that are capped at both ends by knoblike *epiphyses.* A section through a long bone (Fig. 1.4) reveals (1) an outer compact layer for rigidity, (2) an inner cancellous or spongy layer consisting of trabeculated bone for inner support, and (3) a marrow space containing blood cell–forming tissues in active red marrow or just plain fat in inactive yellow marrow.

The blood supply to long bones (Fig. 1.5) is from the following three different sources: (1) nutrient arteries pierce the shaft and supply all layers to the marrow cavity within, (2) periosteal arteries supply periosteum and some adjacent compact bone, and (3) epiphyseal arteries supply the epiphyses and the adjacent joint structures.

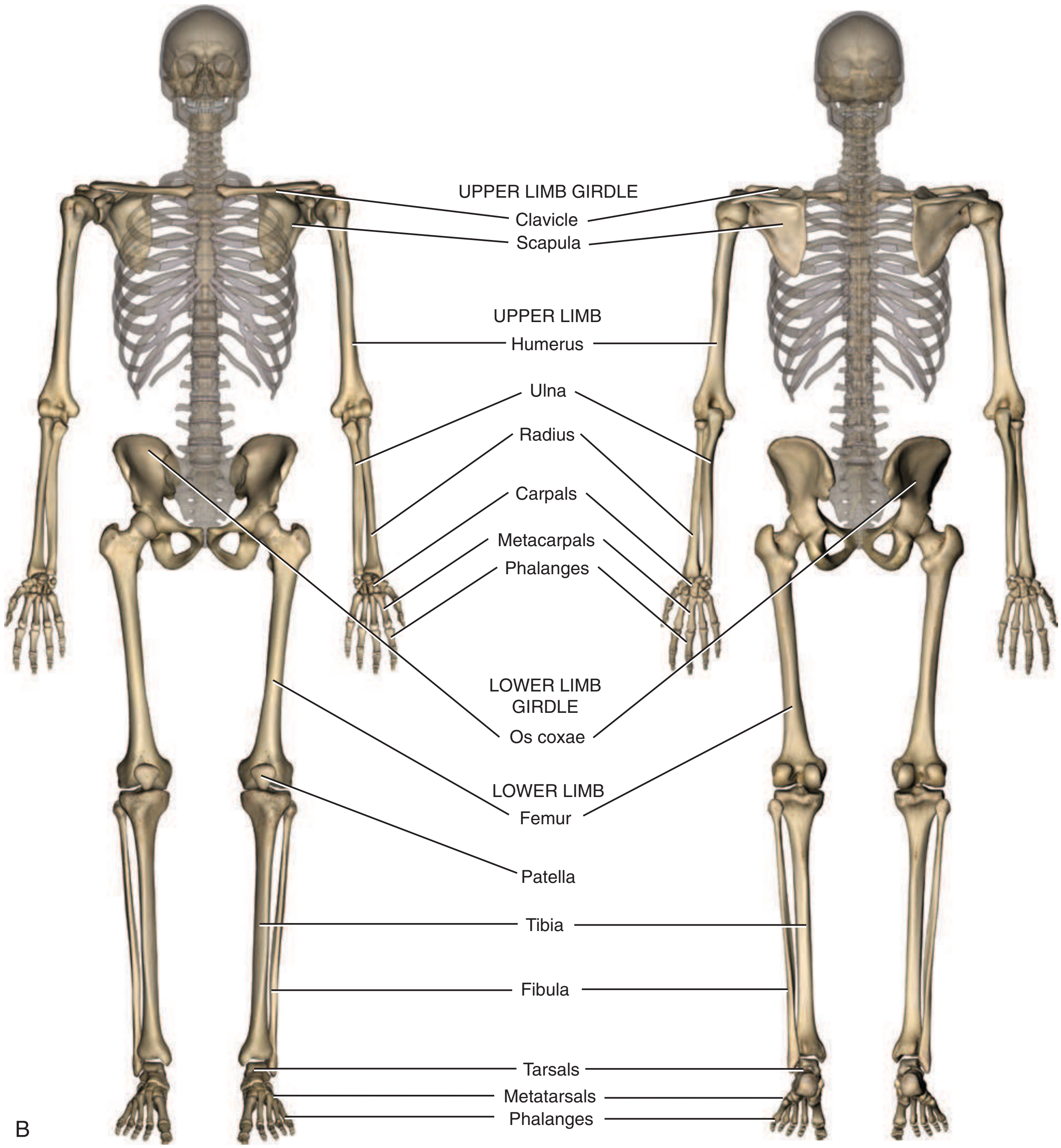
Short bones are similar to long bones, except they are cuboidal rather than tubular in shape and lack the shaft of long bones. They are usually six-sided, with cartilage covering the articular surfaces. Short bones consist of the same layered structures as long bones but have no epiphyses. The carpal bones of the wrist and the tarsal bones of the ankle are short bones.

Flat bones are thin and flat and are found in the vault of the skull and the scapula. They consist of a sandwich: two layers of compact bone encasing a cancellous layer called the *diploë*. The diploic layer contains red bone marrow.

Irregular bones are bones that fit none of the previous descriptions. Some irregular bones are mainly cancellous bone covered with only thin layers of compact bone. Others, such as the lacrimal bone (a small delicate bone of the orbit), consist only of a single compact layer. Still others, such as the maxilla (upper jaw), are invaded and hollowed by nasal mucosa during development, resulting in pneumatic bones. Pneumatic bones consist of thin compact bone surrounding an air-filled cavity or sinus.



• **Fig. 1.3** Skeleton. **A,** Anterior and posterior views of **axial skeleton.**



• **Fig. 1.3, cont'd B,** Anterior and posterior views of **appendicular skeleton.**

Sesamoid bones (from the Greek word *sesamon,* meaning "like a seed") are not actually part of the skeleton. They occur rather in some tendons of the hands, feet, and knee where the tendon rubs against bone. The patella (knee cap) is a smooth, rounded, sesamoid bone found within the tendon of the quadriceps femoris muscle. Articular cartilage covers the areas in contact with bone (see Chapter 10).

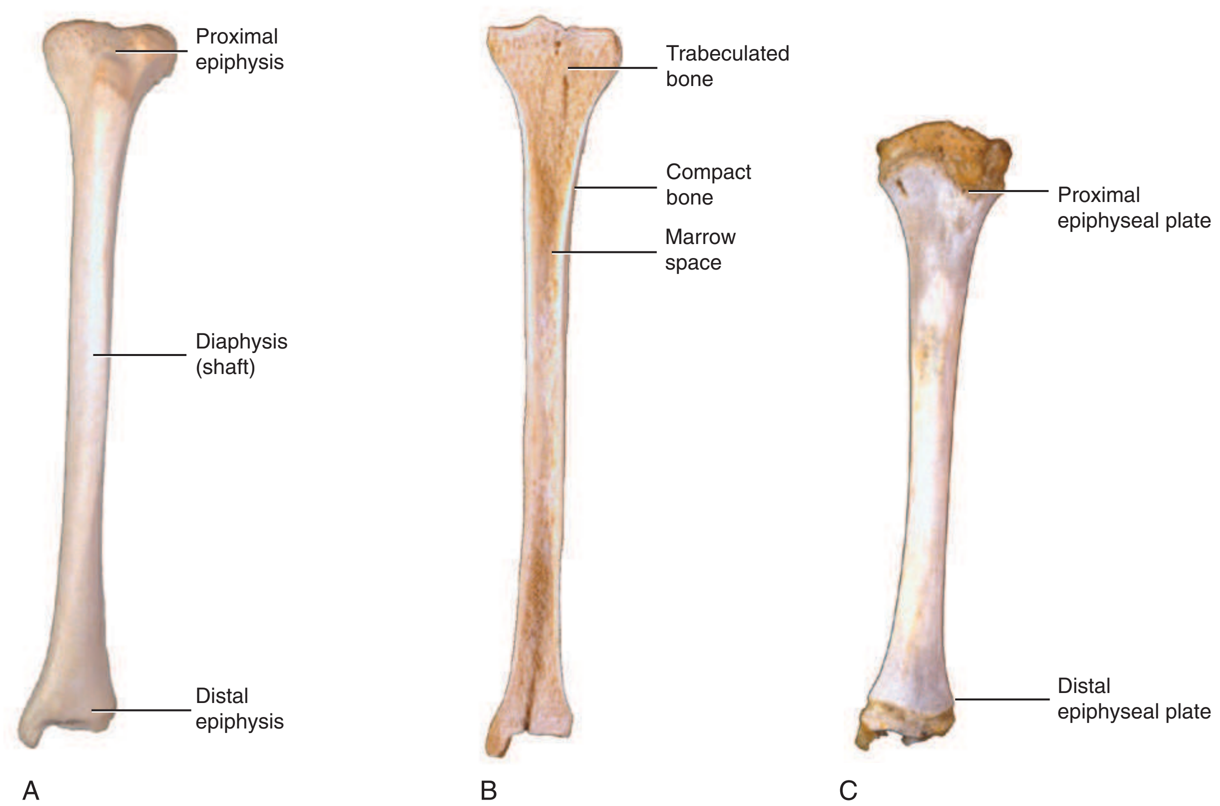
Surface Features

The surface of individual bones is marked by several features that reflect (1) attachments of muscles and ligaments, producing raised areas; (2) passage of nerves and vessels through or over the bone, producing openings and depressions; and (3) articulations with other bones, producing joint surfaces that are raised or depressed. Some terms are self-descriptive, but most are not intuitive without a background in Latin and Greek.

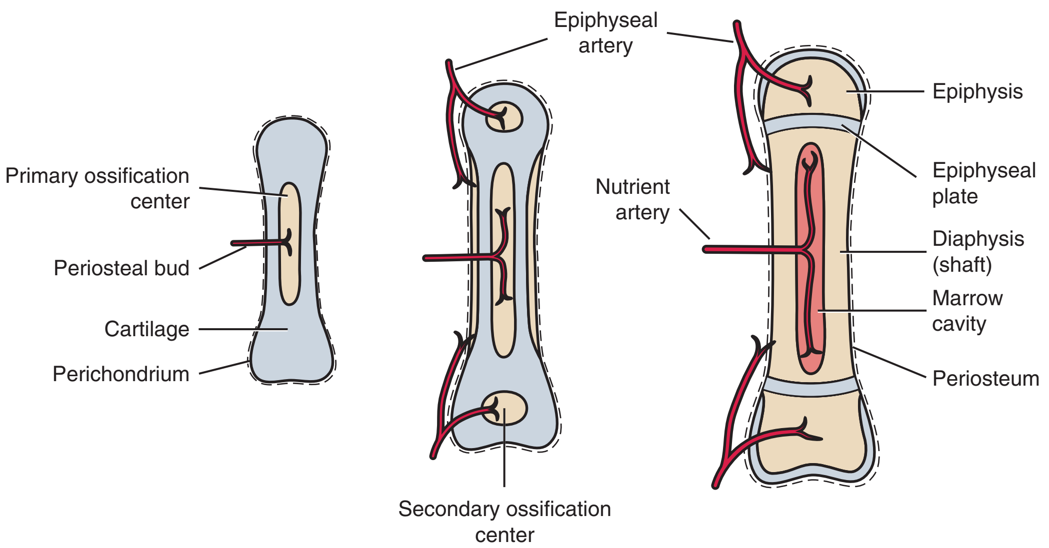
Following is a list of bony features that will be encountered in the study of bones as they are presented throughout the book.

Raised Markings or Elevations

Condyle. (From the Greek, meaning "knuckle") The rounded or widened end of a bone with a smooth articular surface covered



• **Fig. 1.4** Features of a long bone. **A,** Adult tibia. **B,** Longitudinal cut to show internal features. **C,** Tibia of a child.



• **Fig. 1.5** Three stages in development of a long bone.

by cartilage (e.g., medial and lateral condyles of the femur and the condyles of the mandible).

Epicondyle. A ridge of bone immediately above the condyle that provides muscle attachment (e.g., the medial and lateral epicondyles of the humerus).

Process. A projection of bone for the attachment of muscles (e.g., the spinous and transverse processes of vertebrae and the coronoid process of the mandible).

Plate. A flattened process that provides muscular attachment (e.g., the lateral pterygoid plate of the sphenoid bone of the skull).

Tubercle. A small rounded elevation on a bone for muscle attachment (e.g., the adductor tubercle of the femur and the pharyngeal tubercle at the base of the skull).

Tuberosity. A rounded prominence of bone (e.g., the ischial tuberosities of the os coxae on which we sit, and the maxillary tuberosity forming the rounded posterior wall of the maxilla).

Trochanter. Large bony traction processes found only on the superior end of the femur (e.g., the greater and lesser trochanter of the femur, which provide attachment for large, powerful muscles of the lower limb).

Malleolus. Two bony prominences found only on bones of the leg that serve to bind the lower leg to the ankle below (e.g., the medial malleolus on the inferior end of the tibia and the lateral malleolus on the inferior end of the fibula).

Crest. An elongated raised process or ridge of bone produced by muscle attachment (e.g., the iliac crest of the os coxae and the infratemporal crest at the base of the skull).

Linea, or Line. A slightly raised ridge of bone produced by muscle attachment (e.g., the linea aspera of the femur and the superior nuchal line of the skull).

Spine. Yet another raised area of bone (e.g., the spine of the scapula, which is an elongated extension providing attachment for muscles; and the spine of the sphenoid bone in the skull, which provides attachment for a ligament).

Depressions and Openings

Fossa. A gently rounded depression that in some cases provides space for the muscles (e.g., supraspinous and infraspinous fossae of the scapula) and in other cases denotes the smooth concave area for joint surfaces (e.g., the glenoid fossa of the scapula and the mandibular fossa of the skull).

Groove, or Sulcus. Linear bony depressions that accommodate cylindrical or tubular structures (e.g., the bicipital or intertubercular groove of the humerus accommodates a tendon of the biceps muscle, and the superior sagittal sulcus accommodates the superior sagittal venous sinus within the skull).

Foramen. A hole that allows structures (usually nerves and vessels) to pass through the bone (e.g., the foramen ovale [round hole] and the foramen magnum [large hole] in the skull).

Canal. An opening that has length through bone; when a canal emerges onto the surface of the bone, that surface opening is sometimes referred to as a *foramen* (e.g., the infraorbital canal exits onto the face as the infraorbital foramen).

Notch. A "bite" from the edge of the bone that transmits vessels and nerves, like an incomplete foramen (e.g., the suprascapular notch of the scapula and the mandibular notch of the mandible).

Fissure. An elongated space between two bones of the skull (e.g., the superior and inferior orbital fissures).

Development

Bone develops from embryonic mesenchyme by one of two mechanisms—intramembranous ossification or endochondral ossification. Once bone is formed, however, there is no difference in appearance or properties between intramembranous and endochondral bone. The former replaces membrane; the latter replaces cartilage.

Intramembranous Ossification. During embryonic skeletal development, mesenchymal cells condense as a membrane in the area of the future bone. Osteoblasts differentiate from the mesenchymal cells and lay down a bone matrix at multiple sites that gradually coalesce to form a single bone. Bones of the skull vault and face develop in this fashion and are separated by fibrous sutures that are remnants of the bone precursor membrane. The clavicle develops in this fashion.

Endochondral Ossification. The remainder of the skeleton undergoes a slightly more complicated process of endochondral ossification (see Fig. 1.5). Each of these bones is preformed in cartilage during early embryonic development. During the sixth to eighth weeks of embryonic development, cartilage within the center of the future bone shaft dies and is replaced by invading osteoblasts that form the **primary center of ossification.** The perichondrium surrounding the shaft becomes periosteum, and it lays down an intramembranous collar of bone around the primary center. All the primary centers develop before birth. Invading vascular tissue hollows the shaft to form the medullary cavity that contains red bone marrow.

Postnatally, **secondary centers of ossification** develop in the epiphyses, or ends, of the long bones and increase in size until they ultimately fuse with the primary centers to form a complete bone. Up until maturation after puberty, a plate of remaining cartilage, the **epiphyseal plate,** separates the epiphyses from the shaft. Short bones do not have a shaft and develop in the same manner as secondary centers of ossification (see Figs. 1.4 and 1.5).

Postnatal Growth. The cartilage of the epiphyseal plate continues to proliferate at these sites and contributes to the increase in length of the entire bone. The shape of the bone is maintained by selective apposition and resorption (**bone remodeling**). During adolescence, two competing phenomena occur. The growth rate of long bones accelerates, and at the same time, sex hormone changes cause gradual ossification of the epiphyseal plates (**synostosis**). Thus, complete ossification of long bones results in cessation of growth in the adult. Cartilage remains at both ends, covering the epiphyses as articular cartilage.

Mineralized bone appears on radiographs, but cartilage does not. Secondary centers and short bones begin to ossify and mineralize after birth in a more or less predictable sequence as the child grows. Knowing when these various centers ossify enables us to determine **bone** or **skeletal ages** of children which, in turn, is an indicator of biological age.

JOINTS (ARTHROLOGY)

A joint is an articulation or union between two or more bones. Joints may be classified according to the degree of possible movement and by the tissues that bind the bones together.

By Degree of Movement

Synarthrodial joints allow no movement between the bones they unite. A good example is the flat bones of the skull, which are bound together as a rigid entity. **Amphiarthrodial joints** are partially movable, and **diarthrodial joints** are freely movable.

By Joint Tissues

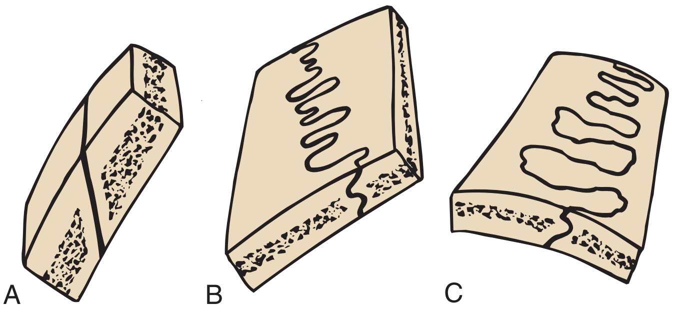
Joints between bones may be composed of fibrous connective tissue, cartilage, a combination of connective tissue and cartilage, or cartilage and a joint cavity.

Fibrous Joints

There are three types of fibrous joints: (1) suture, (2) syndesmosis, and (3) gomphosis.

Sutures are found only between the flat bones of the skull (Fig. 1.6). In the fetal skull the sutures are wide; and the bones present smooth, opposing surfaces. This spacing between the flat bones of the skull allows a slight degree of movement between the skull bones during passage of the head through the birth canal (birth molding).

After birth the sutures become quite rigid (synarthrodial) during infancy and early childhood, allowing no movement between skull bones. The developing sutures differentiate into one of three types (see Fig. 1.6): (1) a *squamous suture* in which the bones simply overlap obliquely but are rendered immobile by intervening tough fibrous tissue; (2) a *serrated suture,* which develops sawtoothed interdigitating projections from the opposing bones; and (3) a *denticulate suture,* which features interlocking dovetailed surfaces.



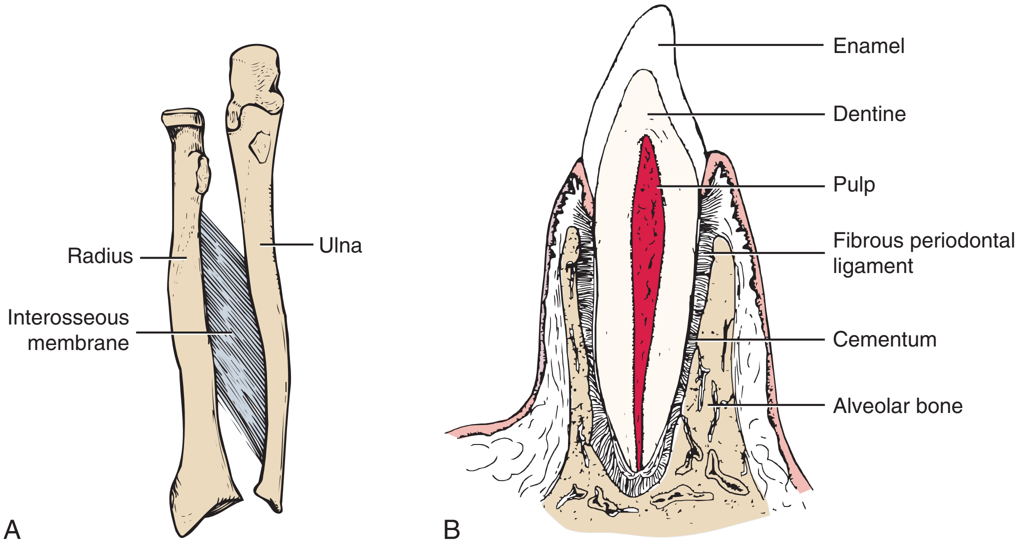
• **Fig. 1.6** Sutures. **A,** Squamous. **B,** Serrated. **C,** Denticulate.

A **syndesmosis,** unlike other fibrous joints, is partially movable (amphiarthrodial) and is a joint in which the two bony components are farther apart, united by a fibrous interosseous membrane (Fig. 1.7A). Examples are the joint between the two bones of the forearm (radius and ulna) and the joint between the bones of the leg (fibula and tibia). Syndesmoses also are found between the spines and laminae of the vertebrae.

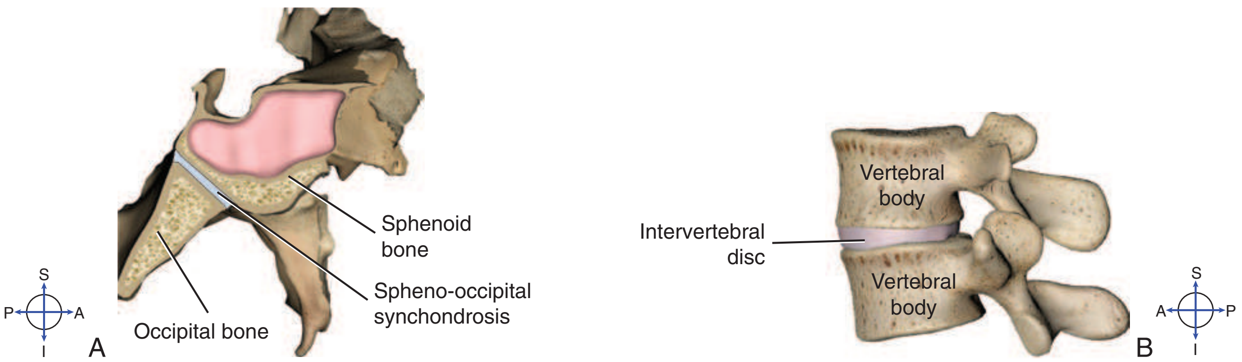
A **gomphosis** is a unique joint in the form of a peg-and-socket articulation between the roots of the teeth and the maxillary and mandibular alveolar processes (Fig. 1.7B). Fibrous tissue organized as the periodontal ligament anchors the tooth securely in the socket. Mobility of this joint indicates a pathological state affecting the supporting structures of the tooth.

Primary Cartilaginous Joints (Synchondroses)

Primary cartilaginous joints develop between two bones of **endochondral** origin. They are characterized by a solid plate of hyaline cartilage between apposing surfaces (Fig. 1.8A). The



• **Fig. 1.7** Other examples of fibrous joints. **A,** Syndesmosis. **B,** Gomphosis.



• **Fig. 1.8** Cartilaginous joints. **A,** Primary cartilaginous joint (synchondrosis). **B,** Secondary cartilaginous joint (symphysis).

cartilage plate functions in exactly the same manner as the epiphyseal plate between primary and secondary centers of long bones and provides an area of growth between bones. An example is the spheno-occipital synchondrosis in the young skull between the sphenoid bone and the occipital bone of the skull. This joint starts to fuse during adolescence and is not present in the adult skull.

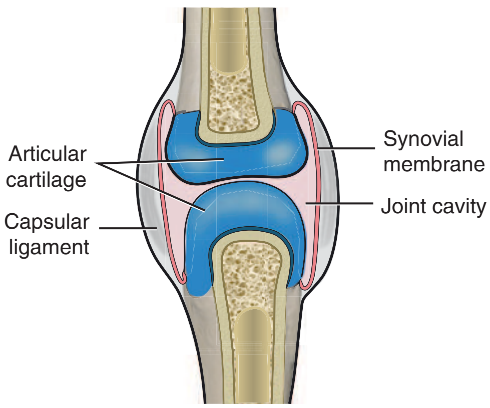
Secondary Cartilaginous Joints (Symphyses)

A secondary cartilaginous joint, or **symphysis,** is a partially movable (amphiarthrodial) joint in which the apposing bony surfaces are covered with cartilage but separated by intervening fibrous tissue or fibrocartilage (Fig. 1.8B). Symphyses are found in the midline of the body and include the joints between vertebral bodies (intervertebral discs), between right and left pubic bones (symphysis pubis), and in the newborn skull between the right and left halves of the mandible (symphysis menti). The symphysis menti starts to fuse during the first year of life to form a single bone, the mandible.

Synovial Joints

A synovial joint is freely movable (diarthrodial) and is typical of nearly all the joints of the upper and lower limbs. Synovial joints have a number of characteristic features (Fig. 1.9).

Articular cartilage coats the surfaces of the apposing bones. The cartilage may be hyaline (where bones of endochondral origin articulate) or may be *fibrocartilage* (where bones of intramembranous origin articulate). Typical of cartilage, this layer contains no blood vessels or nerves but must instead be nourished from the epiphyseal vessels of the bone and derives nourishment from the synovial lubricating fluid within the joint. A joint cavity exists between the articular surfaces of the apposing bones. The **joint cavity** is not large but contains enough space to allow a thin intervening film of synovial fluid. A **capsular ligament** surrounds the joint like a fibrous sleeve and attaches to the circumference of both bones to completely enclose the joint cavity. A synovial membrane consisting of loose areolar tissue contains a rich supply of capillaries. This membrane lines the inner aspect of the capsular ligament but does not line the articular surfaces of the cartilage. The **synovial membrane** secretes a lubricating synovial fluid, or synovium, into the joint cavity. Some synovial joints contain **discs** interposed between the articular surfaces. A disc or meniscus is a fibrocartilaginous or sometimes condensed fibrous structure found within some joint cavities. These padlike structures divide the joint cavity into two compartments allowing for two types of movements, one for each subdivided joint compartment. The temporomandibular, or jaw, joint is an example of a synovial joint containing a disc (see Chapter 7).



• **Fig. 1.9** Typical synovial joint.

Blood and Nerve Supply

Epiphyseal arteries that supply the epiphyses of long bones also supply the synovial joints between the long bones. Hilton's law states that the nerves that supply the muscles that move a synovial joint send sensory branches to supply the joint. There are two types of sensory nerve endings that convey two kinds of messages to the CNS. **Proprioceptive endings,** or *Ruffini corpuscles,* in the capsular ligament convey a sense of position and degree of movement of a joint. **Pain receptors** in the synovial membrane indicate whether the allowable degree of movement is being overtaxed.

Classification

Freely movable synovial joints may be classified in different ways (Fig. 1.10). One classification is based on the number of axes in which a joint can be moved (i.e., uniaxial, biaxial, or multiaxial). The shape or form of the opposing bony surfaces determines the degree of movement.

Multiaxial Joints. Multiaxial joints provide the greatest degree of movement in three planes. There are two types of multiaxial joints.

Ball-and-Socket Joint. One apposing bony surface is ball-shaped, and the other is a reciprocal socket allowing movement in all planes (multiaxial). An example is the freely movable shoulder joint.

Saddle or Ellipsoid Joint. The apposing bony surfaces are reciprocally saddle-shaped, allowing a fair degree of movement in two planes and limited movement in the third plane. An example is the carpometacarpal joint of the thumb.

Biaxial Joints. A biaxial joint allows movement in two planes. The shape of the joint surfaces prevents rotation around a vertical axis (the third plane of movement). There is only one type of biaxial joint.

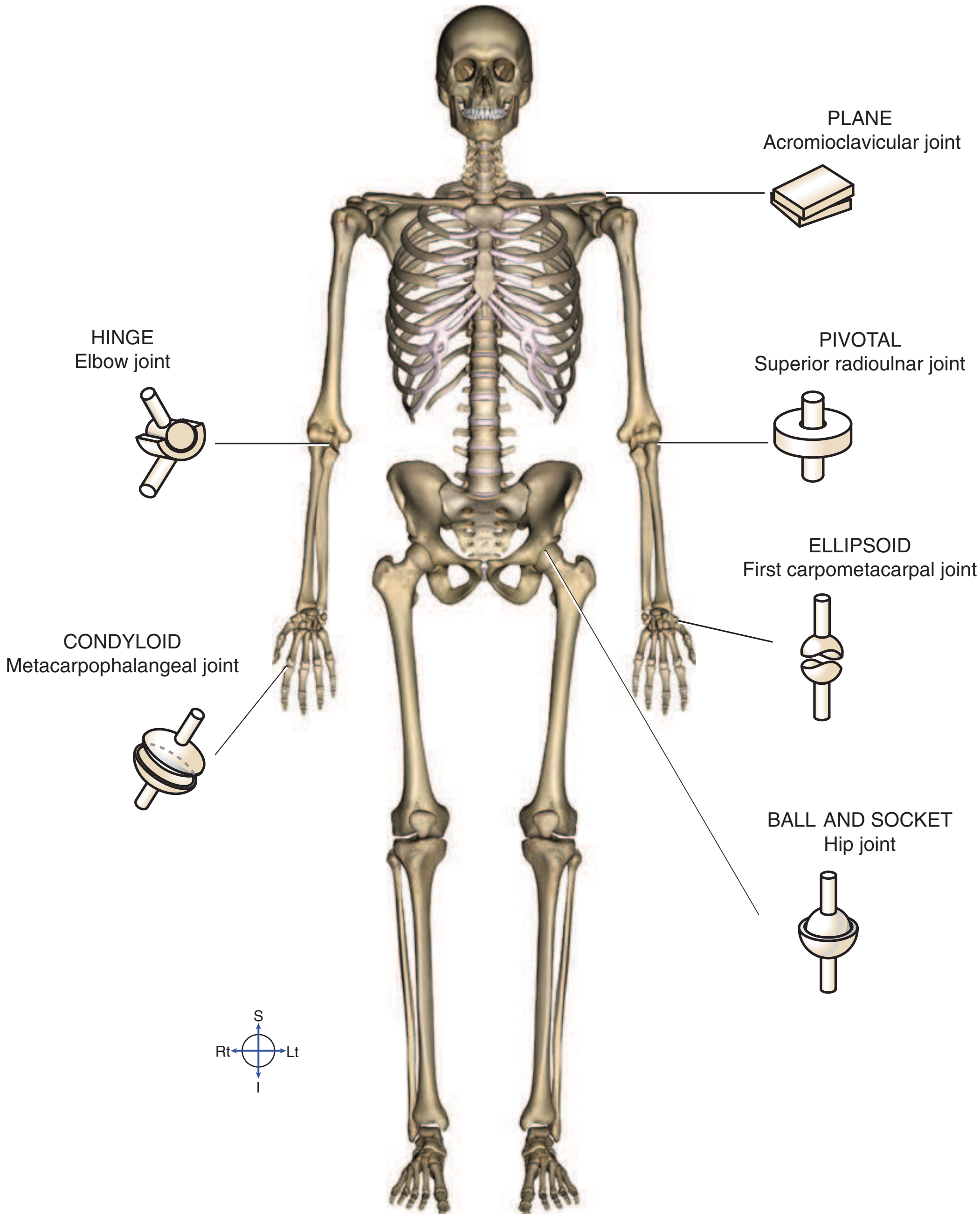
Condyloid Joint. One apposing bony surface is an ellipse; the other is an elliptical socket. Movements are in two planes at mutual right angles. Examples are the metacarpophalangeal joints of the fingers.

Uniaxial Joints. Uniaxial joints allow movements in one plane only. There are three types of uniaxial joints.

Plane Joint. The apposing surfaces of bone are almost flat and generally allow movement in one plane only. Examples are the intercarpal, intertarsal, and acromioclavicular joints.

Hinge (Ginglymus) Joint. One apposing bony surface is cylindrical, the other is reciprocally concave, and the joint allows movement in one plane. An example is the humeroulnar (elbow) joint, which allows only flexion and extension.

Pivot Joint. One of the apposing bones is encircled at the joint end by a fibrous ring or cuff, enabling the bone within the cuff to rotate about the vertical axis. An example is the head of the radius rotating as the forearm is pronated and supinated (see Chapter 9).



• **Fig. 1.10** Classification of synovial joints.

MUSCULAR SYSTEM (MYOLOGY)

Muscle is a specialized tissue that has the ability to contract and produce movement. The three kinds of muscle tissue within the body differ from each other in their histological appearances and in their ability to be controlled voluntarily. These tissues are (1) *skeletal muscle,* (2) *smooth muscle,* and (3) *cardiac muscle.*

Skeletal Muscle

Skeletal muscle is so named because of its attachment to bones. Because muscles span joints, they have the ability to move one bone in relation to another; for example, the brachialis muscle flexes the elbow, or the masseter muscle elevates the mandible. Contraction of all skeletal muscle is under voluntary control. Although operation of some skeletal muscles is "automatic," such as that of the muscles of respiration, which continue to work during sleep, we can still voluntarily override them, such as in holding one's breath. Skeletal muscle is also known as *striated muscle* because it appears striped in histological sections.

Nomenclature

The names of muscles are generally descriptive and give us either an indication of (1) shape (e.g., trapezius muscle), (2) number of origins (e.g., triceps, biceps), (3) location (e.g., temporalis), (4) number of bellies (e.g., digastric), (5) function (e.g., levator veli palatini), or (6) origin and insertion (e.g., thyrohyoid).

Parts

Skeletal muscle consists of a fleshy portion and a fibrous or tendinous portion.

Fleshy Portion. Muscle fibers are the basic functional and anatomical units of muscle. Fibers are actually elongated muscle cells, ranging in length from several millimeters to several centimeters; and contain several nuclei, specialized protoplasm or *sarcoplasm,* and myofibrils within the sarcoplasm. The cell membrane, or *sarcolemma,* encases the cell.

The cells derive their individual blood and nerve supply via sheets of fibrous connective tissue membranes through which the vessels and nerves run. Surrounding the individual muscle cells is a fibrous sheet of *endomysium.* Surrounding a bundle of several fibers (fasciculus) is a fibrous sheet of *perimysium.* Finally, surrounding several bundles, there is an overall fibrous coating of *epimysium* covering the entire muscle. Each of the three levels of surrounding membranes is interconnected, allowing vessels and nerves entering the outer layer eventually to reach individual fibers (Fig. 1.11).

Groups of muscles in the limbs can be bound into compartments by intermuscular septa, which separate various groups of muscles. An example is the anterior compartment of the arm containing flexor muscles and the posterior compartment of the arm containing extensor muscles (see Chapter 9).

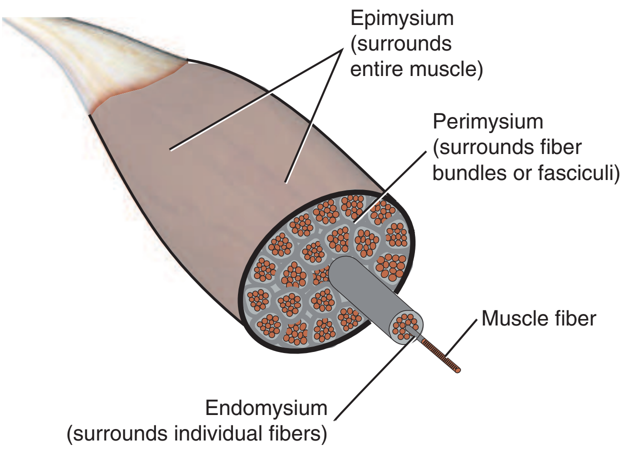
Fibrous or Tendinous Portion. Most sites of muscular attachment are to bone. The muscle fibers do not attach directly but rather through specialized extensions of the fibrous tissue coverings in the form of tendons. The tendons may take various forms.

Cylindrical Tendons. The fibers composing the tendon may be closely packed together in a cylindrical form, and their attachments to bone usually produce an elevation, or tubercle.

Linear Tendons. Some muscles exhibit broad, fleshy attachments, such as the origin of the temporalis muscle. The attachment to bone generally produces a linear ridge.

Aponeurosis. This is a flattened, broad tendon that takes the form of a fibrous membranous sheet.

Common Tendons. Occasionally a tendon may serve as a common attachment for two muscles. This type of tendon may take three forms. First, an *intermediate tendon* is a cylindrical type of tendon that is common to two fleshy bellies (e.g., the anterior and posterior bellies of the digastric muscles are united by an intermediate tendon). Second, a raphé occurs when two flat muscles share a common attachment. The fleshy fibers interdigitate and are separated by only a thin fibrous band or *raphé.* A raphé exists between the buccinator muscle and the superior constrictor muscle. The third form is an *aponeurosis.* Often an aponeurosis can serve as a common attachment for two muscles, such as the aponeurosis between the occipitalis and frontalis muscles.



• **Fig. 1.11** Cross section of skeletal muscle.

Origins and Insertions

Traditionally the proximal end of a muscle is called the *origin*, and the distal end is the *insertion.* In movements to or from the anatomical position, the insertion moves toward the stationary origin as the muscle contracts. Not all movements are made from the anatomical position, and technically origins and insertions can be interchanged because muscle movements can occur at either attachment, depending on which end is fixed and which end is movable. An example is flexing the forearm toward the fixed body in the anatomical position and flexing the body toward the forearm at the elbow while doing a chin-up on an overhead bar. Some texts get around this quandary by describing proximal and distal attachments of limb muscles, but this type of designation does not work well in describing attachments of head and neck muscles. The best advice is to think in terms of the most common movement of the muscle in question and consider the fixed end as the origin and the movable end as the insertion. For example, the muscles of mastication of the skull originate from the fixed skull, and their insertions are into the movable lower jaw or mandible.

Architecture

Muscles can be classified according to the *arrangement* of the muscle fiber bundles, or fasciculi.

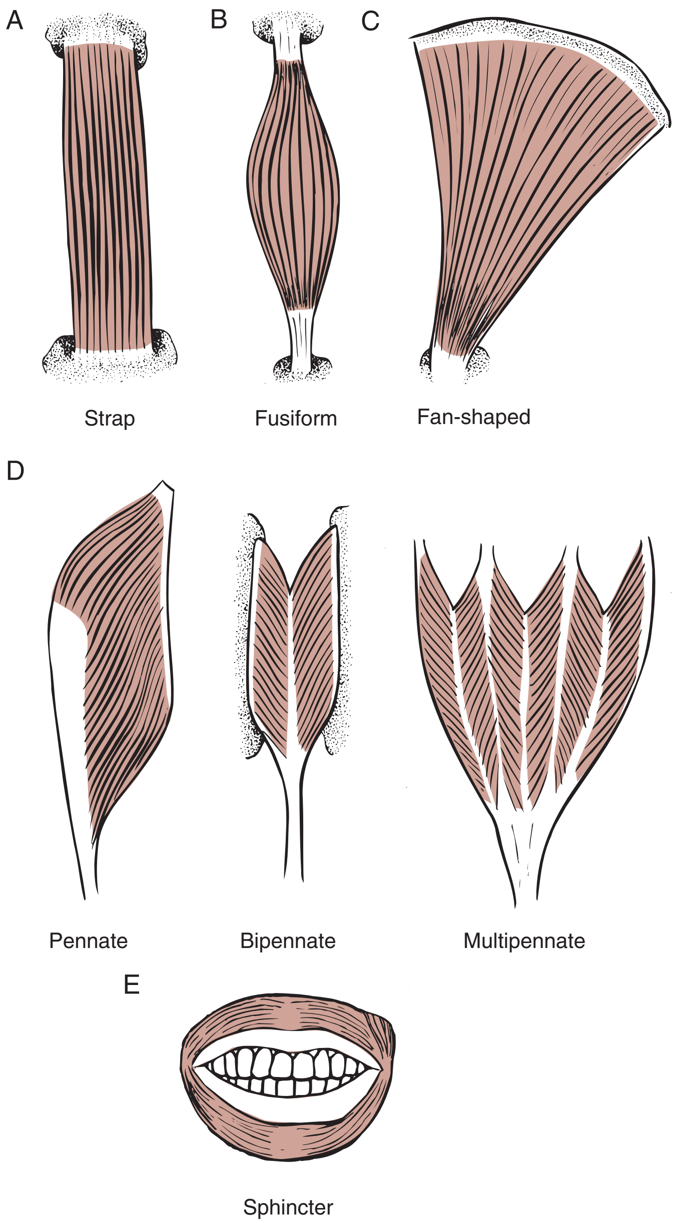
Parallel and Converging Fibers. Some muscles contain fiber bundles arranged in a parallel fashion along the long axis of the muscle. This arrangement gives the muscle a *great range of movement,* and such a muscle is capable of contracting from about one-third to one-half of its original length. Examples of this type are *rectangular* or *strap muscles* (Fig. 1.12A). Some fibers that have a linear origin and converge to a narrow insertion are triangular or fan-shaped muscles (Fig. 1.12C). In other muscles, fibers converge at both origin and insertion, with a wider intervening fleshy belly. These are fusiform muscles (Fig. 1.12B). In each case, however, the muscle bundles, or fasciculi, run uninterrupted from origin to insertion.

Pennate Muscles. This type of muscle is built for power rather than range of movement. The name means "featherlike," and in this arrangement a central tendon extends well into the fleshy belly. Attaching to the tendon are obliquely arranged muscle bundles in a unipennate, bipennate, or multipennate form (Fig. 1.12D).

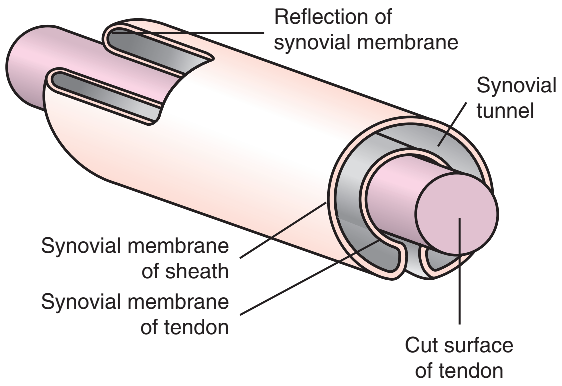
Sphincter Muscles. These circular muscles encircle openings, such as the eye and mouth (Fig. 1.12E). The muscle fibers are arranged in concentric fashion around the opening they encircle and can contract to close the opening.

Actions

Types of Contraction. Skeletal muscle can undergo two types of contraction: isotonic and isometric. **Isotonic contractions** of skeletal muscles produce actual movements around a joint. **Isometric contractions** of skeletal muscles contract or tense the muscles but produce no movements. Examples are tensing the abdominal muscles or tensing the muscles of mastication by clenching the teeth. Even



• **Fig. 1.12** Classification of skeletal muscle by fiber arrangement.



• **Fig. 1.13** Synovial sheath.

at rest, muscles are in a midrange state of contraction, exhibiting tension and a resistance to passive stretching.

Actions of Muscle Groups. For each of the possible movements contracting muscles can produce, groups of muscles have specific roles.

Prime movers are muscles that are called on by the brain via the pyramidal tract to initiate a particular movement. **Antagonists** are muscles that can produce movement in the opposite direction of the prime movers. The roles of antagonists and prime movers are interchanged. For example, the brachialis is a prime mover in flexing (bending) the elbow and contracts as the triceps brachii muscle of the arm relaxes. To extend (straighten) the elbow, the triceps (now the prime mover) contracts as the brachialis (now the antagonist) relaxes. **Synergists** are groups of muscles that are controlled by the extrapyramidal system of the CNS. This system controls and refines any undesirable movements after the prime movers have initiated a particular movement so that the desired movement takes place in a smooth, coordinated fashion. **Fixators** are muscles that play no direct part in the actual movement. Rather, they "fix" the body (through isometric contractions) in the most advantageous position for that particular movement. Other muscles, responding to gravity's pull, maintain posture. Once a prime mover is called into play by the motor area of the cerebral cortex, a secondary complex coordination and fine adjustment of this movement is performed by synergists and fixators.

Synovial Bursae and Sheaths

A **bursa** is a sac of synovial membrane that separates a moving tendon from underlying bone or muscle or overlying skin to reduce friction. **Synovial sheaths** (Fig. 1.13) are like elongated bursae or tunnels of synovial membrane, which surround and lubricate the long tendons of the hand and foot.

Blood and Nerve Supply

Vessels and nerves enter muscles as a neurovascular bundle and are conducted through the three fibrous tissue layers (see Fig. 1.11) to eventually reach each muscle cell. The arterial supply forms an internal anastomosing (interconnected) network. The draining veins have valves, and venous return depends on the massaging effect of the muscle as it contracts and relaxes.

Although muscles are said to be supplied by motor nerves, the nerves actually contain mixed fibers. Approximately three-fifths of a so-called motor nerve is composed of *motor (efferent)* fibers, and two-fifths is composed of *sensory (afferent)* fibers.

Efferent fibers eventually reach individual muscle cells, and the nerve fibers terminate as branches beneath the sarcolemma or cell membrane as motor end plates. Acetylcholine, released by the nerve endings, plays a role in the contraction of the muscle fibers, and therefore the efferent nerve supply to voluntary muscle is cholinergic.

Afferent fibers originate as specialized receptors on the muscle cell itself, on the fibrous connective tissue sheath, from muscle spindles within the muscles, and from tendon spindles located at the junction of muscle and tendon. These endings carry *proprioceptive* information back to the CNS. This information, along with proprioceptive information from joints, gives us an awareness of the position of various parts of our body in space. For example, we know when the mandible is in the wide-open position without having to look in a mirror.

Smooth Muscle

Whereas skeletal muscle generally spans joints to produce movements around a joint, smooth muscle helps form the *walls* of *hollow viscera* and *tubes.* On contraction, smooth muscles expel contents of hollow structures or narrow the lumen of tubes, such as blood vessels. Smooth muscle contraction is under the control of the involuntary visceral *(autonomic) nervous system.*

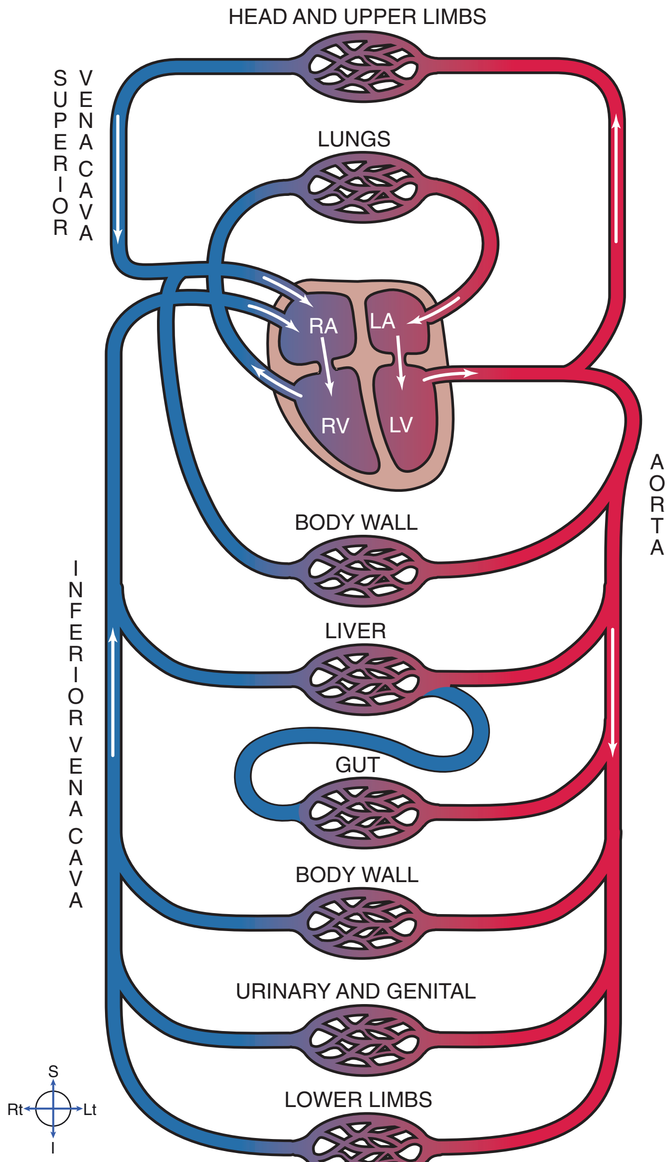
Smooth muscle is so named because it lacks the striations of skeletal muscle in histological preparations. Smooth muscle cells are long, tapered cells that overlap neighboring cells. Cells are bound to each other by delicate connective tissue that transmits the neurovascular supply to individual cells. The cells are arranged in sheets around tubes (e.g., the blood vessels, ureters, gut) or hollow organs (e.g., the gallbladder, urinary bladder, uterus). A **circular** arrangement of fibers *decreases lumen size* on contraction. **Longitudinally** arranged fibers cause a *shortening* in *tubal length.*

Cardiac Muscle

Cardiac muscle is similar in function to smooth muscle. Its rate of contraction is involuntarily controlled by the visceral (autonomic) nervous system, and it is found only in the heart, where it functions to expel blood from the various heart chambers. Histological sections of cardiac muscle, unlike those of smooth muscle, appear striated because of the presence of intercalated discs.

Voluntary Versus Involuntary Muscle (Exceptions)

There is, unfortunately, no sharp distinction between voluntary and involuntary muscle control. Some skeletal muscle, such as the upper end of the esophagus, is involuntarily controlled; and some smooth muscle, such as that in the urinary bladder, is under voluntary control. There is a definite distinction, however, in the type of contraction produced by both types of muscle. Skeletal muscle is capable of *rapid, powerful contractions* but becomes fatigued relatively quickly. Smooth muscle and cardiac muscle, on the other hand, are capable of *slow, sustained contractions* with no fatigue.



• **Fig. 1.14** Scheme of cardiovascular system.

CARDIOVASCULAR SYSTEM (CARDIOLOGY AND ANGIOLOGY)

The cardiovascular system consists of a quantity of fluid, a pump, and a series of tubes that contains the fluid (Fig. 1.14). *Blood* carries respiratory gases and metabolites to and from the tissues. The heart pumps the blood through an enclosed system. *Blood vessels* transport the blood to capillaries where gases, metabolites, and fluid are exchanged at the tissue level. The *lymphatic system* conveys excess tissue fluid back to the circulation.

Blood

Approximately 5.5 L in volume, blood is composed of liquid (plasma) and cells. **Plasma** is primarily water (91%); the remainder consists of salts, metabolites, respiratory gases, proteins, and enzymes. The **cells** are *erythrocytes* (red blood cells), which transport respiratory gases; and *leukocytes* (white blood cells), which leave the blood vascular system to act as phagocytes or scavengers of debris. Some leukocytes (lymphocytes) take part in the body's immune mechanism. Bits of cytoplasm *(blood platelets)* are found along with the cells and take part in the blood-clotting mechanism.

The Heart

The heart is described only generally at this time. It is described in detail in Chapter 3. The heart is a four-chambered, muscular pump and can be divided into two sides based on function. The right side pumps blood through the lungs for oxygenation, constituting the *pulmonary,* or *lesser, circuit.* The left side pumps the oxygenated blood to the body tissues and constitutes the *systemic,* or *greater, circuit* (see Fig. 1.14). Clinicians generally refer to the *right heart (pulmonary)* and the *left heart (systemic).*

The heart consists of two receiving chambers **(atria)** and two pumping chambers **(ventricles).** Each chamber holds roughly 60 to 70 mL of blood. Connecting each atrium to its respective ventricle is an **atrioventricular orifice,** which is guarded by **atrioventricular valves** to prevent the backflow of blood from ventricle to atrium.

The thickness of the chamber walls is a reflection of their functions. The atria are thin walled because they need only empty their contents into the ventricle below. The ventricles are thick walled, with the left ventricle considerably thicker than the right, because high pressures are required to pump blood through the pulmonary circuit, and still higher pressures are required to pump blood through the systemic circuit.

Blood Vessels

Blood vessels are hollow tubes that conduct blood either *away from the heart* (arteries) or *to the heart* (veins). These definitions of *artery* and *vein* hold true for both systemic and pulmonary circuits.

Most blood vessels consist of three coats, or tunics, similar to those of the heart (Fig. 1.15). The **tunica intima** is the *innermost coat,* which lines the lumen of the vessels and consists of a layer of flattened endothelial cells over a layer of collagen fibers. The **tunica media** is a *middle coat,* consisting of elastic fibers and smooth muscle cells, both disposed in a circular fashion. Depending on the size and type of vessel, there may be a predominance of elastic fibers or smooth muscle. The **tunica adventitia** is an *outer layer* of connective tissue arranged more or less in longitudinal fashion. Through this layer run small vessels and nerves that supply the walls of larger vessels. In some vessels, longitudinal smooth muscle also may be found in this layer.

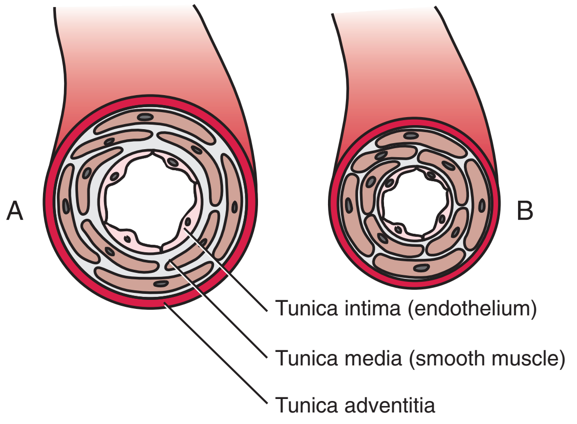
In general, arteries have thicker walls than their companion veins. The lumens of the veins, however, are larger than those of companion arteries.

Arteries

After leaving the heart, arteries become progressively smaller as they branch and rebranch on their way to supplying the tissues of the body. The structure of the arterial walls changes correspondingly to accommodate different functions and sizes.

Elastic arteries are large vessels (30 mm in diameter) that arise from the right and left ventricles as the pulmonary artery and aorta, respectively (Fig. 1.16). The media consists primarily of circumferentially arranged elastic fibers, which are designed to stretch and recoil to accommodate successive spurts of blood expelled from the ventricles. **Distributing** or **muscular arteries** arise from the aorta and branch and rebranch, becoming progressively smaller (ranging from several millimeters in width to less than half a millimeter). The tunica media consists mainly of circular smooth muscle cells under the control of the visceral (autonomic) nervous system, which can increase or diminish the blood flow to specific areas.

Arterioles are still smaller branches (about 100 μm in diameter) in which the intima consists of only a single cell layer of endothelium. The media consists of only a few layers of smooth muscle cells disposed in a circular or spiral fashion around the endothelium. As the arterioles become progressively smaller, only a single muscle layer is left, and the vessel becomes a *terminal arteriole.* Occasionally, terminal arterioles display thicker, sphincterlike arrangements of muscle cells, termed *precapillary sphincters.* Arterioles and precapillary sphincters have the ability to turn on and off the blood flow to specific areas and directly affect arterial blood pressure levels.



• **Fig. 1.15** Walls of a blood vessel. **A,** Dilated. **B,** Constricted.

Capillaries

The walls of the true capillary are reduced to a single layer of endothelial cells, which encircle a lumen of about 7 to 10 μm, large enough to accommodate erythrocytes one at a time or in single file. Capillaries form vast anastomosing networks, and it is here, through the endothelial barrier, that an exchange of gases and metabolites takes place. Capillary networks can accommodate large volumes of blood. The capillaries of certain tissues, such as spleen, liver, bone marrow, and certain glands, are somewhat wider and irregular and are termed *sinusoids.*

Veins

As the blood leaves the capillary beds, the vessels regroup as veins, which return blood to the heart.

Venules are small-caliber veins that drain the venous side of the capillary beds. These venules gradually coalesce with one another to form larger channels or veins of increasing diameter.

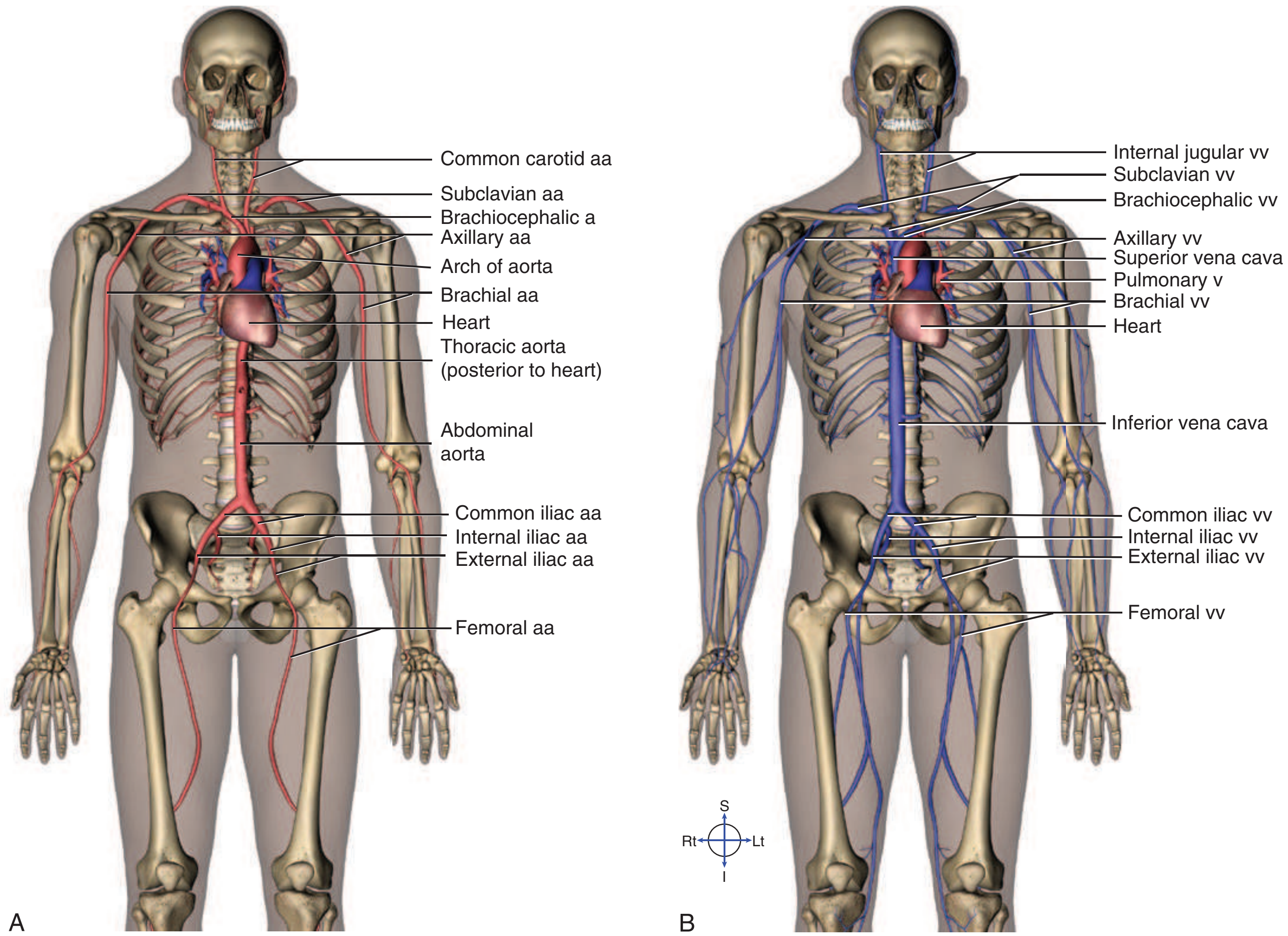
Veins generally accompany arteries but in a few instances are found without companion arteries. Superficial veins of the limbs course independently of accompanying arteries. In addition, certain areas possess a venous drainage totally unlike the arterial supply. These include the portal vein, which drains the gut; azygous veins, which drain the thoracic and abdominal walls; and the vertebral plexus of veins, which drains the vertebral column and spinal cord. No corresponding arteries accompany these veins.

Arteriovenous Anastomoses

Occasionally, in various tissues of the body, direct communications exist between arteries and veins. These communications are able to shunt large volumes of blood quickly through a tissue while bypassing the capillary bed. Arteriovenous anastomoses are found in the skin (e.g., hands, feet, nose, ear, lips), mucosa (e.g., nasal, gut), organs, and glands (genitalia, erectile tissue, thyroid gland).

Arterial Anastomoses and Collateral Circulation

Many tissues are richly supplied with several arteries whose branches join and communicate directly. These communications are termed ***anastomoses*** and allow constant uninterrupted flows to the areas they eventually supply. They also provide alternative channels when one usual channel is blocked. Alternative flow to a blocked area is termed ***collateral circulation.***



• **Fig. 1.16** Major blood vessels. **A,** Arteries. **B,** Veins.

End Arteries

Some arteries do not anastomose with neighboring arteries, and, if they are blocked, no collateral circulation develops to help supply the affected area. The result is that the area not supplied dies. The classic example is the central artery of the retina. It is the sole source of arterial supply to the retina, and if it is occluded, the retina degenerates and blindness results.

Fetal Circulation

During fetal development, the lungs of course are not functioning. There is therefore no reason for the fetal heart to send all its blood to the lungs for gas exchanges because CO_2/O_2 exchange takes place at the placenta. A number of shunts help deflect blood away from the pulmonary circulation to enable oxygenated blood to reach the tissues quickly (Fig. 1.17).

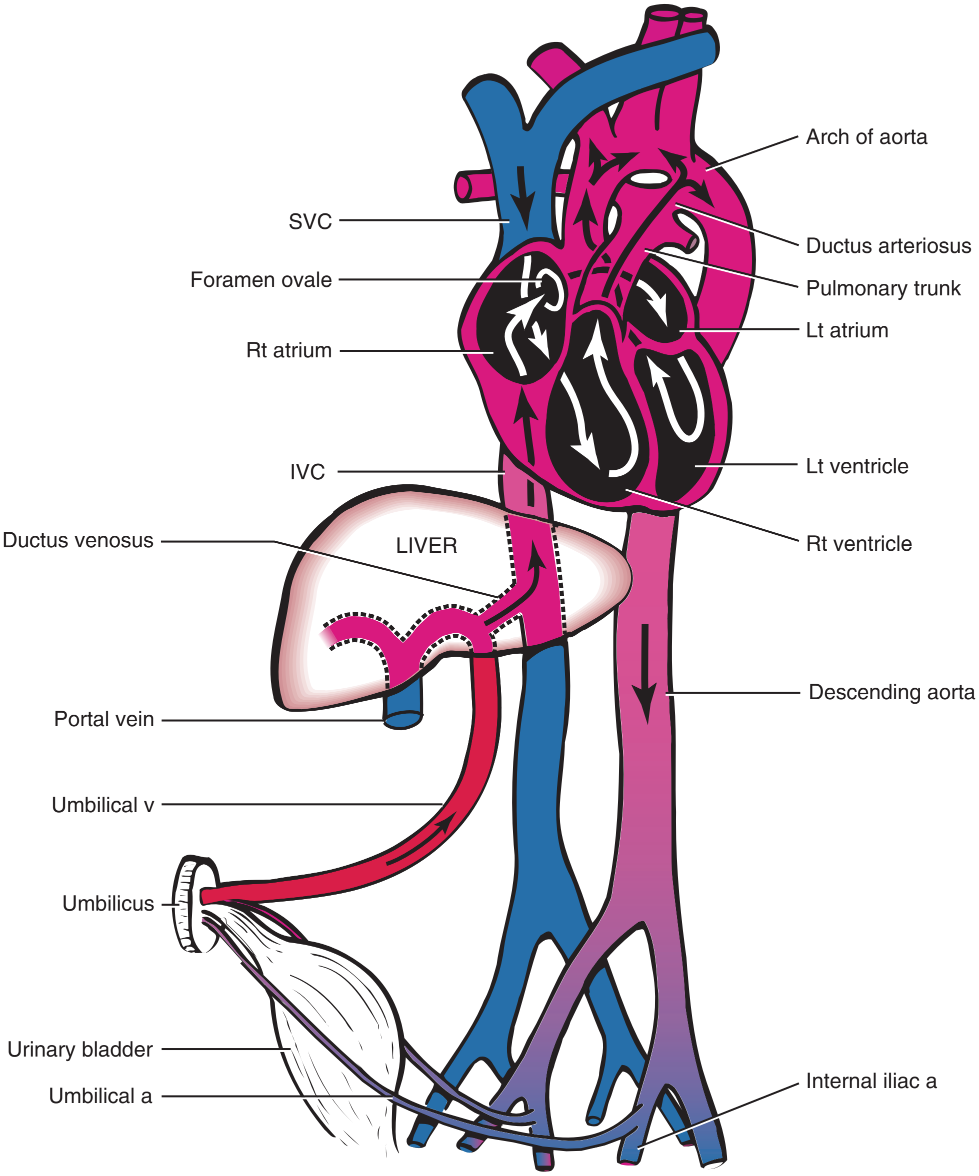
Blood is oxygenated at the placenta and enters the fetus via the **umbilical vein.** The umbilical vein ascends within the anterior abdominal wall to the liver but bypasses the liver via the **ductus venosus,** which shunts the blood to the inferior vena cava. From here the oxygenated blood ascends to the **right atrium** of the heart, where some of the blood passes through the foramen ovale (a hole in the interatrial septum) directly to the left atrium and then the **left ventricle.** The blood that remains in the right atrium passes to the right ventricle, and on contraction of the ventricle, blood is forced out of the pulmonary trunk. Blood in the pulmonary trunk is deflected by another fetal shunt joining the pulmonary trunk and the aorta, termed the ***ductus arteriosus.*** The left ventricle then pumps the blood out to the system via the aorta.

Return of deoxygenated blood to the placenta is through the **umbilical arteries,** which arise from the internal iliac arteries and ascend along the inside of the anterior abdominal wall to the umbilicus and then via the umbilical cord to the placenta.

Changes in Circulation at Birth

With the first breath of life, the lungs expand and begin to function. Pressure in the left atrium increases and closes the flaplike foramen ovale, which becomes fused after time. Spontaneously the ductus arteriosus closes and eventually undergoes fibrosis. Similarly the ductus venosus is obliterated, thus closing off the three major fetal shunts between arterial and venous circuits.

With the cutting and clamping of the umbilical cord, the umbilical vein becomes thrombosed, then fibrosed. The umbilical arteries are obliterated in the same way.



• **Fig. 1.17** Scheme of fetal circulation. *IVC,* Inferior vena cava; *SVC,* superior vena cava.

Each of the obliterated structures remains throughout postnatal life as a vestige of the fetal shunt but acquires a new name.

1. The foramen ovale becomes the fossa ovalis.
2. The ductus arteriosus becomes the ligamentum arteriosum.
3. The ductus venosus becomes the ligamentum venosum.
4. The umbilical vein becomes the ligamentum teres, or round ligament of the liver.
5. The umbilical arteries are simply referred to as the *obliterated umbilical arteries.*

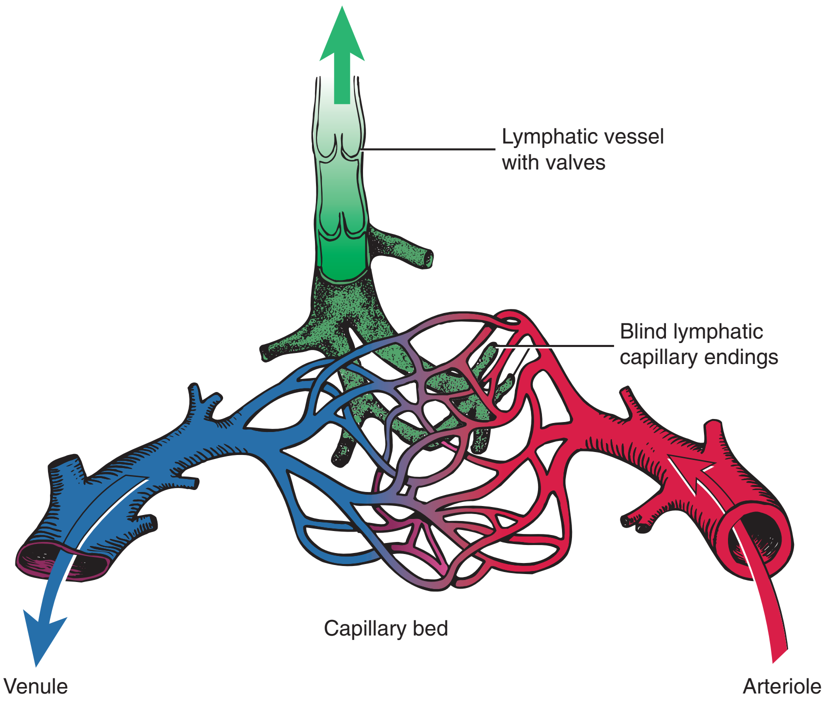
Lymphatic System

The lymphatic system consists of a series of *tubes* and *filters* that conveys excess tissue fluid from the extravascular tissue spaces back to the blood circulatory system. Unlike the blood vascular system, there is no heart pump to move the fluid through the lymph channels.

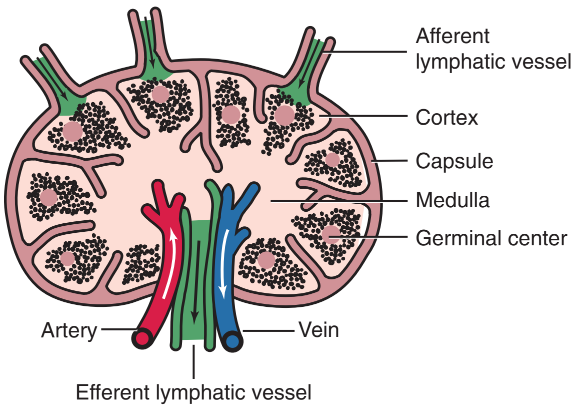
Lymph

As blood passes through the capillaries, fluid similar in composition to the blood plasma leaks across the semipermeable capillary walls to enter the tissue spaces (Fig. 1.18). At this level the individual cells receive nourishment from, and discard waste materials to, the tissue fluid. Most of the fluid and suspended colloidal protein moves back across the capillary wall to reenter the blood vascular system. The remainder of this fluid drains to the lymphatic system as lymph.

Lymph also contains two types of lymphocytes that are produced by the bone marrow but mature in different sites. **B cells** mature in the bone marrow and are then carried by the blood circulation to lymph nodes and other lymphoid tissues described later. **T cells,** on the other hand, mature in the thymus gland and on maturation leave through the circulation to populate lymphoid tissues. Lymphocytes leave the lymphoid tissue periodically to circulate through the lymphatic system and blood circulatory systems.



• **Fig. 1.18** Collection of lymph from capillary bed.



• **Fig. 1.19** Lymph node.

Lymph Capillaries

Lymphatic channels begin as blind-ended capillaries alongside blood capillaries. Excess tissue fluid moves across the semipermeable membrane of the lymph capillary to form a clear, almost colorless fluid called *lymph*. Lymphatics returning from the gut contain absorbed fat, which gives the lymph a milky appearance *(chyle)*.

Lymph Vessels

Lymph capillaries form vast networks, which eventually drain to larger channels or vessels. These lymphatic vessels are thin walled, contain many one-way valves, and generally accompany veins.

Lymph Nodes (Glands)

Lymph vessels pass through a series of enlarged filters or lymph nodes as they convey lymph back toward the blood vascular system (Fig. 1.19). The glands are somewhat flattened and vary in size from less than a millimeter to several centimeters in diameter. Within, they consist of a number of compartments separated by fibrous tissue septa. Each compartment contains spherical lymphoid follicles consisting of a germinal center and a surrounding cluster of lymphocytes.

Lymph nodes are found in groups throughout the body and in two particularly large groupings in the axilla **(axillary nodes)** and in the groin **(inguinal nodes).** Lymph nodes are palpable under certain pathological conditions. Within the nodes, foreign particulate matter is filtered out by phagocytic cells as the lymph passes through a fine network of capillaries.

Large Lymphatic Vessels

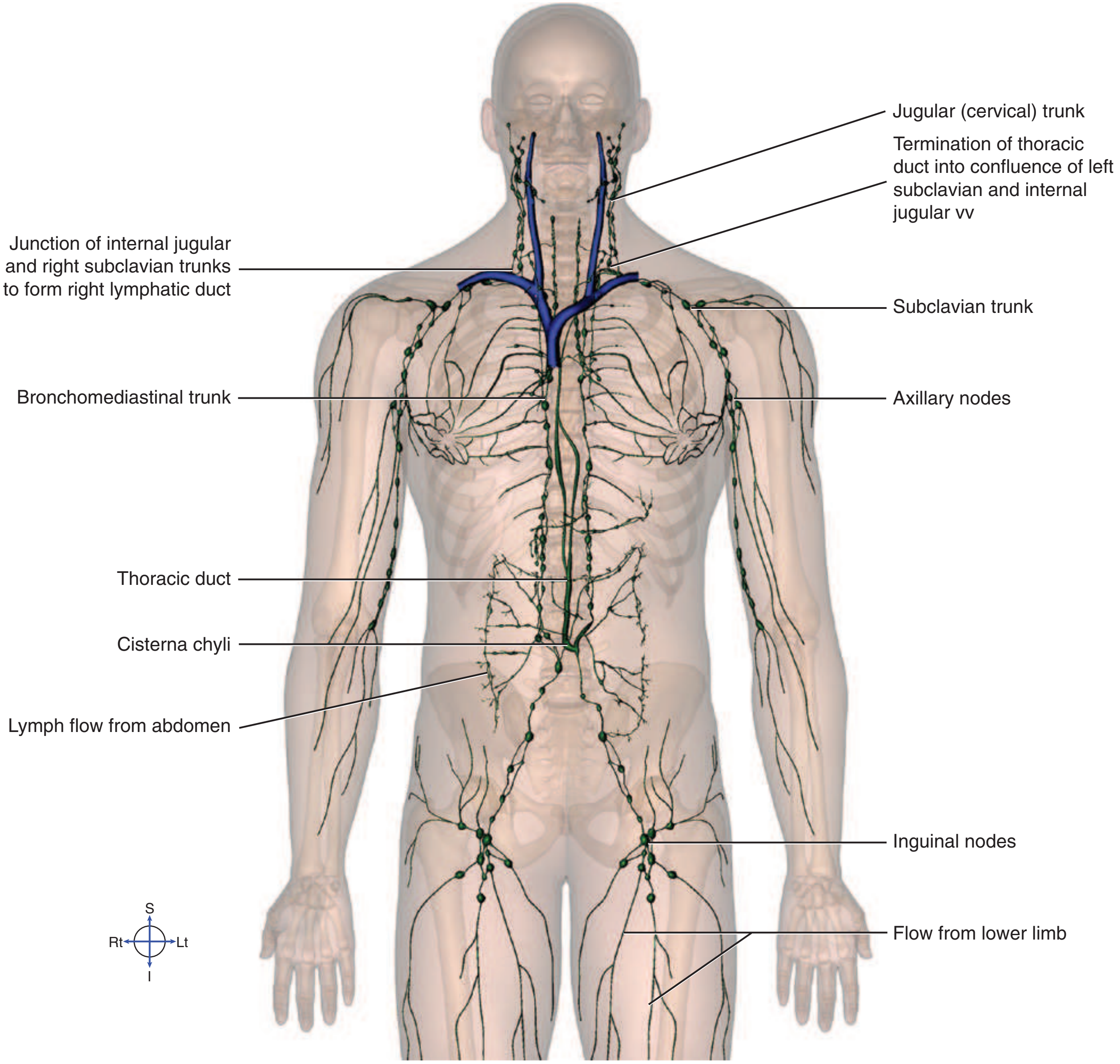
Lymphatics drain to larger lymph trunks that drain various regions of the body (Fig. 1.20).

1. The thoracic duct drains the lower limbs, abdomen, and chest wall.
2. The bronchomediastinal trunk drains the viscera of the thorax.
3. The subclavian trunks drain the upper limbs.
4. The jugular trunks drain the head and neck.

The thoracic duct empties its contents into the confluence of the subclavian and internal jugular veins on the left side only. The others drain into the same area on both the right and left sides.

Lymph Flow

Because lymph is not pumped through the system by the heart, lymph flow tends to be comparatively sluggish. Its flow is aided by (1) passage from the positive pressure abdominal cavity to the negative pressure thoracic cavity; (2) rhythmical contraction of the lymph vessels; (3) valves, which permit one-way flow only; and (4) massaging or milking of lymph vessels by neighboring active muscles of the upper and lower limbs.



• **Fig. 1.20** Scheme of lymphatic circulation.

Functions

The lymphatic system permits (1) drainage of tissue fluid and protein back to the blood venous system from the tissues, (2) conduction of fat from the intestines to the blood venous system, and (3) manufacture of antibodies and proliferation and circulation of lymphocytes that are active in an immune mechanism against foreign tissues within the body.

Lymphoid Tissues

The lymph nodes mentioned previously are examples of lymphoid tissues. There are other structures that contain lymphoid tissues.

Tonsils. The tonsils (see Chapter 7) include the **palatine tonsils, pharyngeal tonsils** (adenoids), and **lingual tonsils.** Tonsils are clusters of lymphoid follicles that are buried below oral mucosa.

Spleen. The spleen (see Chapter 4) is a large abdominal organ containing lymphoid follicles and is characterized by small arterioles that pass through the follicles.

Thymus Gland. The thymus gland differs from the other lymphoid tissues in two ways. The thymus gland possesses no organized follicles. Instead, the lymphoid tissue is continuous throughout the cortex of the gland. In addition, T cells mature only in the thymus gland.

Lymphoid Tissue of the Gut. Lymphoid follicles are found throughout the mucosa of the gut. In the jejunum (distal portion of the small intestine), there are larger aggregations of follicles called ***Peyer patches.***

NERVOUS SYSTEM

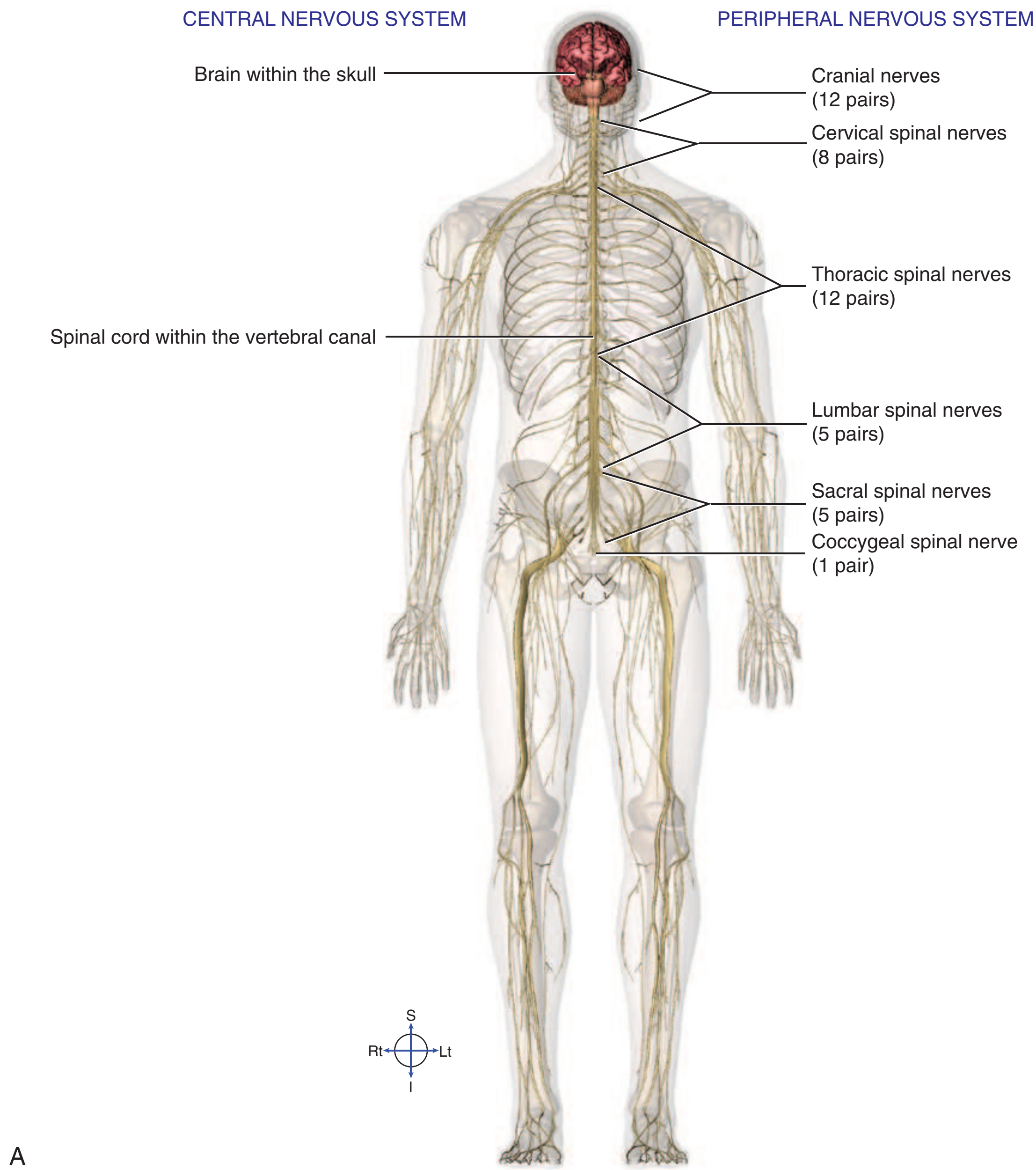
The human nervous system (Fig. 1.21A) is a highly complex and specialized system that reacts to the external and internal environment by integrating and interpreting incoming stimuli and then directing the body to respond in the appropriate manner. Appreciation of and response to environmental stimuli are either at a *conscious* or at an *unconscious* level. The nervous system is populated by two types of cells: (1) **neuroglia** that perform *supportive functions,* and (2) **neurons,** which are *reactive* cells that respond to stimuli.

The Neuron

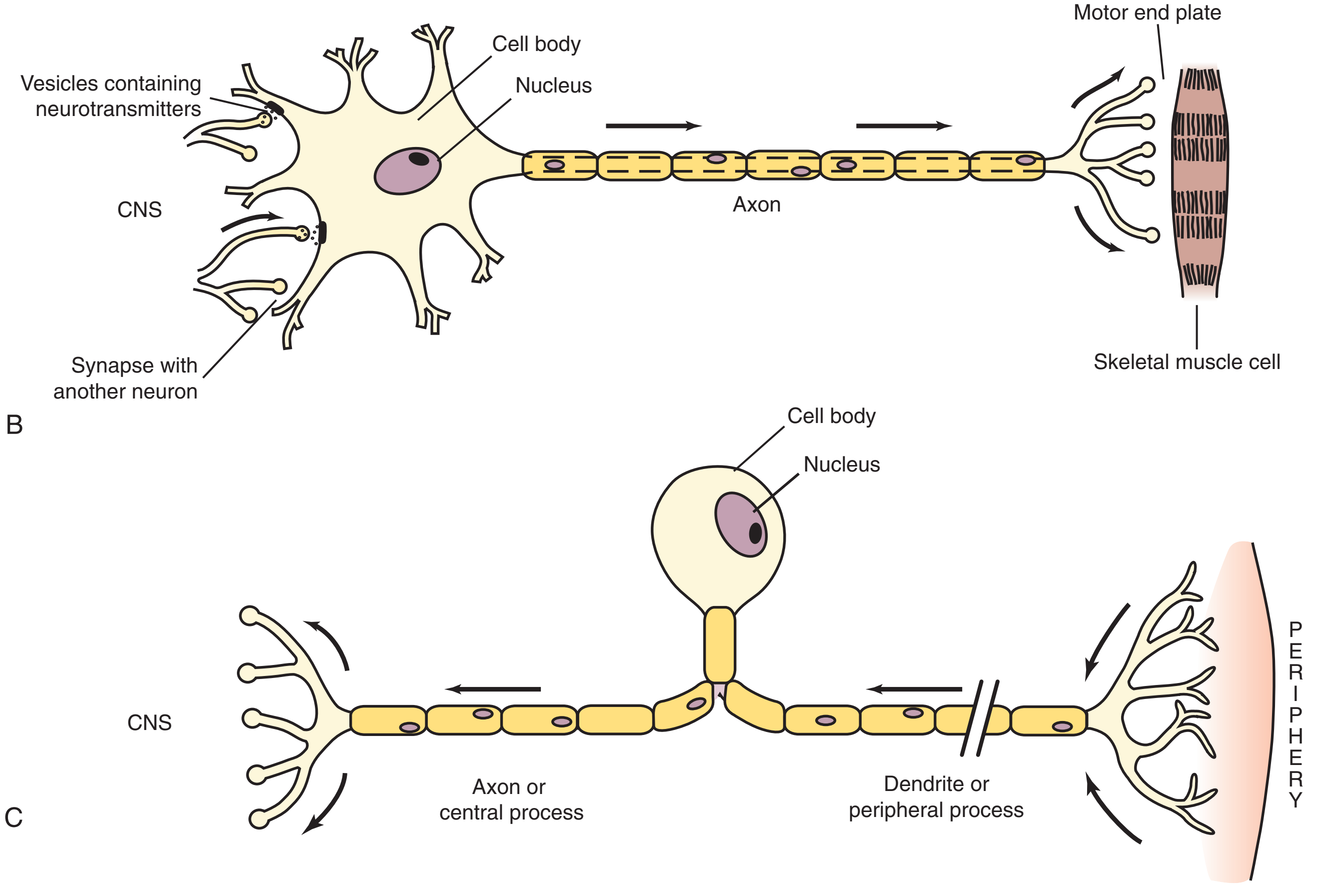
The neuron is the basic functional unit of the nervous system and responds to either excitation or inhibition. Like all cells, neurons consist of a plasma membrane encasing a mass of cytoplasm and a nucleus. Neurons differ in that they can conduct electrical impulses and communicate with each other through long cellular extensions and **synapses.** Neurons exist in a great variety of shapes and sizes, but only two types—motor and sensory—are described.

Motor Neuron

Motor neurons (Fig. 1.21B) consist of a **cell body (soma)** that contains a nucleus and cellular extensions, either *dendrites* or *axons.* **Dendrites** are short, branching cellular extensions that conduct impulses toward the cell body. **Axons** are long cellular extensions that conduct impulses away from the cell body. Near its termination the axon branches, with each branch ending as a bulbous **axon terminal** or **bouton.** Axon terminals synapse with muscle cells. Motor neurons are classified as being **multipolar** because several extensions arise from the cell body.



• Fig. 1.21 **A,** Central and peripheral components of the human nervous system. *Continued*



• **Fig. 1.21, cont'd** **B,** Multipolar motor neuron. **C,** Unipolar sensory neuron.

Sensory Neuron

The body of a sensory neuron (Fig. 1.21C) has only one cellular extension, or process, and is therefore classified as **unipolar.** The single process is short and divides into two **axons.** One axon continues to the periphery as the **peripheral process** and ends as several branches. Each branch is either a sensory receptor or synapses with sensory receptors. Some authors refer to the branching component as ***dendrites.*** The other axon extends into the CNS as the **central process.**

Synapses

Synapses (see Fig. 1.21B) occur at the intercellular junctions of nerve processes or between nerve processes and cells of effector organs. Between the approximating cell surfaces is a **synaptic cleft** separating the *presynaptic cell membrane* from the *postsynaptic cell membrane.* Electrical impulses travel along an axon and at its terminus cause the release of chemical **neurotransmitters,** which diffuse across the cleft to receptor sites on the postsynaptic side. The neurotransmitter may be either *excitatory,* initiating an impulse on the postsynaptic side, or *inhibitory,* stopping the impulse at that point. Excitatory transmitters depolarize the postsynaptic membrane; an inhibitory transmitter hyperpolarizes the postsynaptic membrane. Target neurons receive from only a few to more than 1000 synapses with other neurons, some of which are inhibitory and some of which are excitatory. The target neuron may or may not propagate the impulse, depending on the net depolarization of its membrane. Fig. 1.21B, shows a presynaptic neuron synapsing with a typical multipolar motor neuron, which synapses with a muscle cell.

Neuroglia

Neuroglia are nonreactive nerve cells that fulfill a *supportive* role. They function to (1) maintain homeostasis in the extracellular environment, (2) electrically insulate nerve processes from each other, and (3) provide nutrition for the neurons. There are six classes of neuroglia, and their names and specific functions are covered in standard textbooks of neuroanatomy.

Definitions and Terms

Aggregations of cell bodies and their axonal processes ensheathed in myelin have distinct appearances and give rise to the following terms and definitions:

Gray Matter. Neuronal bodies grouped together appear gray or pinkish gray and are referred to as *gray matter.* Gray matter is found in the central part of the spinal cord surrounding the central canal; on the surfaces of the cerebral and cerebellar hemispheres (cortex); and scattered throughout the CNS as discrete, internal patches or nuclei.

White Matter. Myelin has a shiny white appearance and imparts this color to grouped bundles of myelinated axons within the CNS.

Peripheral Nerve. A bundle of myelinated axons that travel outside the CNS is called a *(peripheral) nerve.* Nerves arise from the brain as cranial nerves and from the spinal cord as spinal nerves. Nerves (with some cranial nerve exceptions) contain both motor (efferent) and sensory (afferent) axons.

Tract. A group of myelinated axons that travel together within the CNS and share a common origin, destination, and function are called a *tract.* Tracts are similar to nerves, but they run entirely within the brain and spinal cord.

Nucleus. Within the CNS, a group of neuronal cell bodies located in the same area and sharing the same function is called a *nucleus.* The *dorsal horns* of the spinal cord are elongated sensory nuclei; the *ventral horns* of the spinal cord are elongated motor nuclei.

Ganglion. Ganglia are similar to nuclei in that they are also collections of neuronal cell bodies with the same functions. A ganglion, however, sits outside the CNS as a discrete swelling. Examples are dorsal root ganglia and autonomic ganglia. There is one glaring exception to this definition. The basal ganglia of the cerebral hemispheres encountered in neuroanatomy are by definition nuclei.

Afferent Fibers. Afferent fibers are axons that carry impulses *toward* the CNS or toward higher centers. They are also referred to as *sensory* or *ascending fibers.*

Efferent Fibers. Efferent fibers are axons that carry impulses *away* from the CNS to muscles and glands. They are also referred to as *motor* or *descending fibers.*

The nervous system is conveniently divided into components based on *location* (central and peripheral nervous systems) and *function* (somatic and autonomic nervous systems).

Division Based on Location

Central Nervous System

The CNS includes the **brain,** contained within the skull, and the **spinal cord,** contained within the vertebral canal (see Fig. 1.21A). Functionally the CNS consists of (1) a *sensory component,* in which incoming data are received at a conscious or unconscious level; (2) a *motor component,* from which outgoing commands originate; and (3) an *association component,* which connects and coordinates the various CNS centers. The brain is not discussed in detail in this textbook.

Peripheral Nervous System

There are **31 pairs of spinal nerves** that arise from the spinal cord, and **12 pairs of cranial nerves** that arise from the brain (see Fig. 1.21A). Peripheral nerves consist of bundles of axons that convey information to and from the CNS. Peripheral nerves are described in greater detail later.

Division Based on Function

Somatic Nervous System

The somatic nervous system controls the body's **voluntary** and **reflex activities** through *somatic sensory* and *somatic motor* components of both the central and peripheral nervous systems.

Visceral (Autonomic) Nervous System

The visceral nervous system is that portion of both the CNS and the peripheral nervous system that controls **involuntary** smooth muscle, cardiac muscle, or glandular tissue. It has a *motor component* that is capable of controlling smooth muscle contractions of viscera and blood vessels and the secretions of glands. An *autonomic sensory component* provides feedback for CNS control of viscera, vessels, and glands.

The autonomic nervous system is further divided into the *parasympathetic division* and the *sympathetic division.*

Parasympathetic Division. The parasympathetic division is *necessary to sustain life* and is concerned with minute-to-minute vegetative functional activities of the viscera and glands. For example, it slows the heart, increases peristalsis and glandular secretions, and opens gut sphincters.

Sympathetic Division. The sympathetic division in contrast is *expendable* and may be cut with no loss to life. It is antagonistic to the parasympathetic division, and its effects are obvious during periods of stress or emergency. For example, in emergency situations the hair stands on end, the pupils dilate to allow more light to reach the retina, the heart beats faster to supply more blood to skeletal muscles for "fight or flight," respiration is increased, and the bronchioles dilate to oxygenate the increased blood flow.

Functions controlled by the parasympathetic division that are not necessary at this time of emergency slow down. Salivary secretions decrease, peristalsis of the gut decreases, and the urinary bladder relaxes.

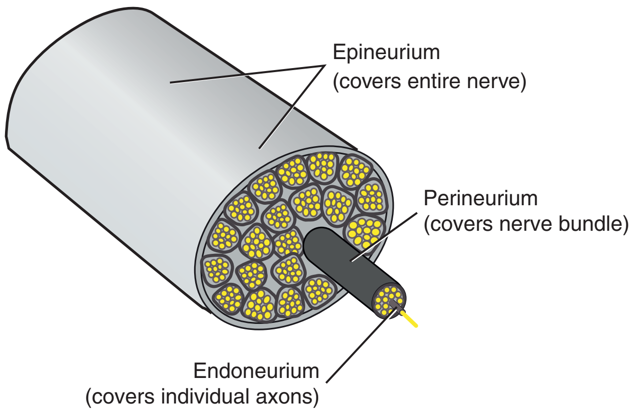
Peripheral Nerves

Structure

The basic unit of a peripheral nerve is the axon (Fig. 1.22). Each individual axonal process is wrapped by myelin-containing **neurilemma (Schwann) cells** that act as insulators separating the axons from each other. Surrounding each process and its coatings is an outer fibrous layer called the ***endoneurium.*** Surrounding bundles of processes is a fibrous layer of **perineurium**; surrounding several bundles, which make up the entire peripheral nerve, is a final coating of epineurium. The **epineurium** in turn is in contact with surrounding areolar tissue, through which passes the blood supply to the nerve, eventually reaching each individual nerve cell via the interconnecting septa of fibrous connective tissue sheaths.

Function

During embryonic development, mesoderm gives rise to both an external body **(soma)** covered with skin and an internal tube lined



• **Fig. 1.22** Cross section through a peripheral nerve.

with mucosa that forms the gut and its associated glands **(viscera).** In addition, viscera of the cardiovascular, genitourinary, and respiratory systems develop concurrently with the gastrointestinal viscera. Skeletal muscles develop within the body for movement and locomotion, and smooth muscle develops within the viscera for peristalsis and emptying of contents. These two basic body areas are controlled by **motor (efferent)** and **sensory (afferent) nerves.**

In this scheme there are four modalities: (1) **somatic efferent** to voluntary, skeletal muscles; (2) **somatic afferent** (touch, pain, temperature, pressure, and vibration) from skin and proprioception from endings in muscles, tendons, and joints; (3) **visceral efferent (autonomic)** to visceral smooth muscles and glands; and (4) **visceral afferent** providing sensory feedback from the organs and glands. These four modalities are found in all spinal nerves.

In the head region, two more modalities are added: (5) **special sensory** to accommodate the special senses of smell, vision, taste, hearing, and balance and (6) **branchial efferent** to supply those skeletal muscles of the head and neck that are derived from branchial arches.

To complicate matters considerably, developmental neuroanatomists have burdened us with extremely cumbersome and sometimes confusing classifications. The classic classification is presented as a footnote solely for reference and not for learning purposes.

CLASSIFICATION OF FUNCTIONAL COMPONENTS BASED ON TISSUE ORIGINS

Structures of the body supplied by afferent and efferent nerves fall into three main categories based on derivation. **Somatic structures** are derived from embryonic paraxial somites. **Visceral structures** include all structures derived from the gut or the genitourinary, cardiovascular, and respiratory systems, including associated glands. Branchial structures develop from the branchial arches. Modalities of spinal nerves are said to be ***general;*** those of cranial nerves are said to be ***special.***

In this scheme there are seven modalities: (1) **general somatic afferent** (exteroceptive and proprioceptive sensation from structures of somatic origin); (2) **general visceral afferent** (interoceptive sensation from involuntary muscles and glands); (3) **special somatic afferent** (vision, hearing, and equilibrium); (4) special visceral afferent (smell and taste); (5) **general somatic efferent** (to skeletal muscles of somatic origin); (6) **general visceral efferent** (autonomic to smooth and cardiac muscle, and glands); and (7) **special visceral efferent** (to skeletal muscles of branchial arch origin).

Central Nervous System Origins of Somatic Peripheral Nerves

Voluntary Motor (Somatic and Branchial Efferent) Components. Motor pathways comprise two groups of neurons—upper and lower motor neurons (Figs. 1.23 and 1.24). The **upper motor neurons** reside in the *motor cortex of the cerebrum.* Axons of these neurons descend in bundles called *tracts* that cross the midline (decussate) at some point during their descent. They descend to synapse with **lower motor neurons** that give rise to motor components of peripheral nerves.

Cranial Nerves. The lower motor neurons are located in cranial nerve motor nuclei that are found in the brainstem. Bundles of their axons pass out of the brainstem as motor components of cranial nerves. Cranial nerves III, IV, VI, and XII carry **somatic efferent fibers** that innervate skeletal muscles of the head derived from somites.

Cranial nerves V, VII, IX, and X carry **branchial efferent fibers** to supply cranial muscles of branchial arch origin, but they follow the same scheme as somatic efferent pathways.

Spinal Nerves. In the spinal cord the lower motor neurons are located in the ventral (anterior) horn, an elongated motor nucleus that extends the length of the spinal cord. Axons of these neurons leave the spinal cord as ventral (anterior) roots that form the motor component of each of the 31 pairs of spinal nerves. These motor nerves supply all the skeletal muscles of the trunk and limbs.

General Sensory (Somatic Sensory) Components. General sensory pathways feature three sets of neurons (primary, secondary, and tertiary), which ultimately synapse with neurons in the sensory cortex of the brain.

Cranial Nerves. The cell bodies of the **primary neurons** of cranial nerves are located near the brainstem within *sensory ganglia,* swellings on cranial nerves that have a sensory component (cranial nerves V, VII, IX, and X). Peripheral processes pick up stimuli from various regions of the head (e.g., the skin of the face, mucosa of the oral and nasal cavity, pulps of teeth) and carry the stimuli past the ganglia and through central processes to *sensory nuclei* containing **secondary neurons** within the brainstem. Their axons decussate and rise to synapse with **tertiary neurons** in the *thalamus,* and these in turn send axons up to the *sensory cortex.*

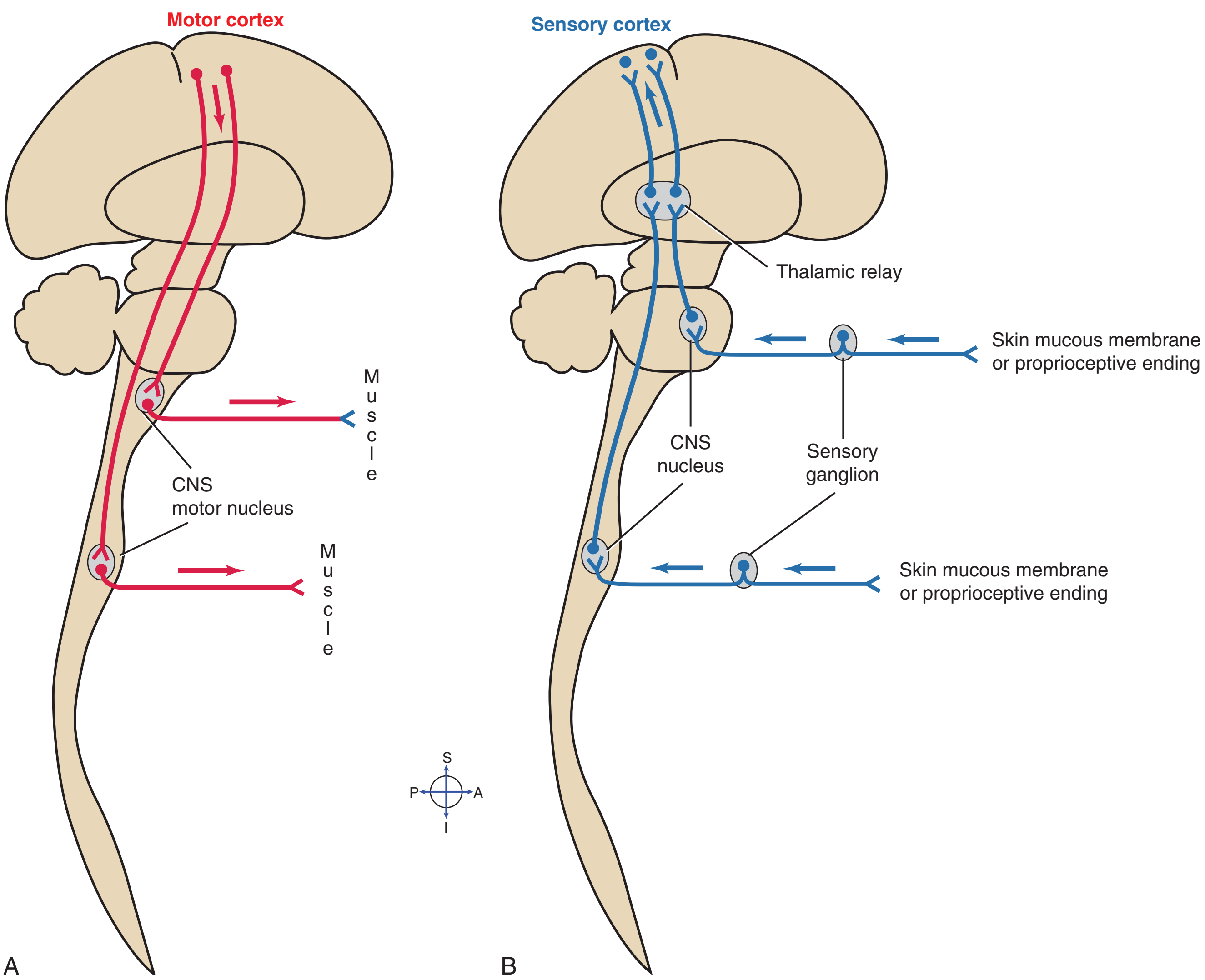
Spinal Nerves. The cell bodies of the **primary neurons** of spinal nerves are contained in the *dorsal root ganglia* adjacent to the spinal cord. Their peripheral processes transmit impulses from sensory receptors in the skin or proprioceptive receptors in muscles, tendons, and joints. Central processes pass into the CNS through dorsal roots to synapse with **secondary neurons** contained within the *dorsal (posterior) horn,* which is a long sensory nucleus that runs the length of the spinal cord. Axons of these neurons cross the midline (decussate) and ascend to synapse with **tertiary neurons** located in the thalamus of the brain. These neurons send axons up to synapse with the final set of neurons located in the **sensory cortex** of the brain, where sensations are ultimately perceived.

Central Nervous System Origins of Autonomic (Visceral) Nerves

Autonomic Motor (Visceral Efferent) Components. The visceral efferent or autonomic pathways consist of a two-neuron chain. The first neurons reside in *autonomic motor nuclei* within the CNS. They send axons outside the CNS that ultimately synapse with a second set of neurons within an *autonomic ganglion* outside the CNS. The second neurons send out axons (postsynaptic fibers) to the smooth muscle and glands of the viscera. As mentioned previously, there are two divisions: parasympathetic and sympathetic.

Parasympathetic Division. This division (Fig. 1.25) originates from the brain and from the sacral region of the spinal cord **(craniosacral outflow).** The first neuron lies within parasympathetic motor nuclei in either the brain or sacral portion of the spinal cord.

Cranial preganglionic fibers arise from parasympathetic motor nuclei within the brainstem and leave as components of cranial nerves III, VII, IX, and X. The parasympathetic components of cranial nerves III, VII, and IX supply cranial visceral elements (mainly glands). The parasympathetic supply of cranial nerve X is far more extensive. It supplies the respiratory system, cardiac system, and most of the gut and associated glands up to the left colic flexure (foregut and midgut derivatives).



• **Fig. 1.23** **A,** General scheme of voluntary efferent (motor) cranial and spinal nerve components. **B,** General scheme of afferent (sensory) cranial and spinal nerve components. Not obvious from this lateral view is that sensory and motor tracts cross over (decussate) within the CNS so each side of the brain controls the opposite side of the body. *CNS,* central nervous system.

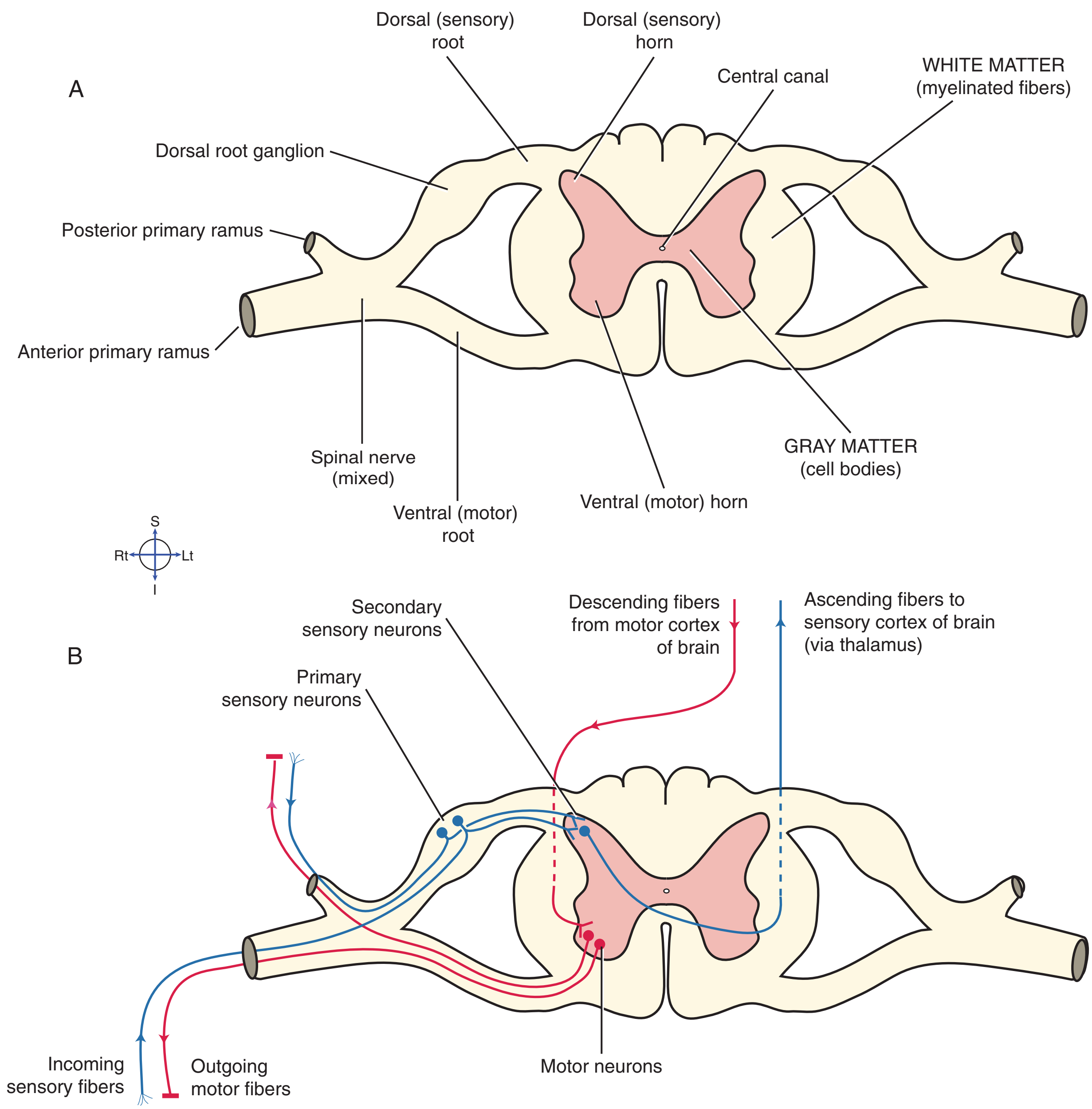
Sacral preganglionic fibers arise from parasympathetic motor nuclei in the ventral horns of the spinal cord at levels S2, S3, and S4 and leave through the ventral roots of pelvic spinal nerves. They then form discrete pelvic splanchnic nerves that supply the distal portion of the gut (hindgut derivatives) and pelvic viscera. They synapse in parasympathetic ganglia that are close to or within the pelvic viscera they ultimately supply.

Sympathetic Division. Sympathetic outflow originates from the spinal cord at levels T1 to L2 (Figs. 1.26 and 1.27). The first neurons lie within the **intermediolateral horns,** found only in this region of the spinal cord. Preganglionic fibers leave the spinal cord along with the anterior spinal nerve roots (see Fig. 1.27). On leaving the vertebral canal and the intervertebral foramen, the fibers leave the spinal nerve as myelinated **white communicating rami.**

On either side of the vertebral column are a right and a left chain of sympathetic *(paravertebral)* ganglia. These are the **sympathetic trunks,** and they run the entire length of the vertebral column. There is a sympathetic ganglion at each vertebral level. In the cervical region the ganglia at levels C1 to C4 fuse to form the *superior cervical ganglion.* The ganglia at levels C5 and C6 fuse to form the *middle cervical ganglion,* and the ganglia at levels C7 and C8 fuse to form the *inferior cervical ganglion.*

Running to the sympathetic trunk from spinal cord levels T1 to L2 are the **white communicating rami,** which enter the adjacent sympathetic ganglia. Within the sympathetic trunk, preganglionic fibers may (1) synapse with the neurons of the ganglion at that level; (2) travel up or down the sympathetic trunk to synapse in a ganglion at a higher or lower level; or (3) leave the sympathetic trunk as **splanchnic nerves,** which stream down into the abdomen to synapse in remote *prevertebral ganglia.* The postganglionic fibers in the first and second categories rejoin the spinal nerves as unmyelinated **gray communicating rami** and are distributed along with the spinal nerves.

There are only 14 pairs of white communicating rami arising from spinal levels T1 to L2. Leaving the sympathetic trunk to join the spinal nerves, however, are 31 pairs of gray rami.



• **Fig. 1.24** Cross section through spinal cord to show origins of spinal nerves. **A,** Features seen in a typical cross section. **B,** Pathways of sensory and motor components. *Note:* These pathways are bilateral. Both ascending and descending pathways cross midline so that sensations and muscle movements on one side are perceived and controlled on opposite side of brain.

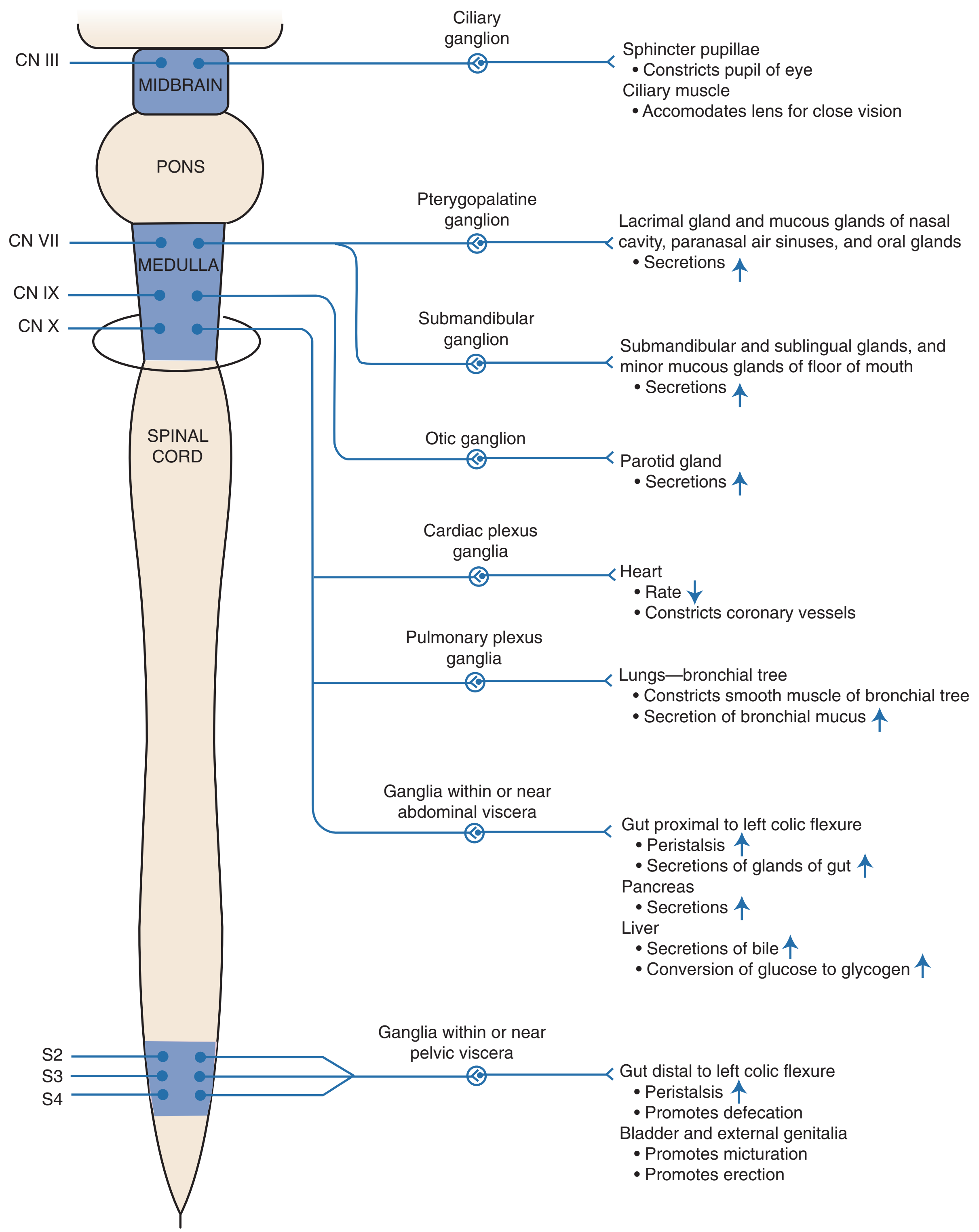
Distribution of Postganglionic Sympathetic Fibers

Trunk and Limbs. Gray rami leave the sympathetic trunk at each spinal cord level to join each pair of spinal nerves. They are then distributed by the spinal nerves to the trunk and limbs where they supply smooth muscle of blood vessels. In addition, sympathetic fibers pass to the skin to supply sweat glands and *arrector pili muscles* that produce goose bumps and cause hair to stand on end.

Head and Neck. Preganglionic fibers of the sympathetic trunk rise to the *superior cervical ganglion.* Within the superior cervical ganglion, the preganglionic fibers synapse with the second set of neurons. Postganglionic fibers leave the ganglion to join the nearby carotid arteries as the **carotid periarterial plexus,** an external nerve plexus surrounding the vessel. The sympathetic postganglionic fibers are then distributed to the visceral effector organs of the head by the various branches of the external and internal carotid arteries (see Chapter 8).

Thorax. Postganglionic fibers of the three cervical sympathetic ganglia stream down to the thorax to form the *cardiac* and *pulmonary plexuses,* which supply the heart and smooth muscle of the bronchial tree.

Abdominal and Pelvic Viscera. Preganglionic fibers leave the sympathetic trunk in the thorax as **splanchnic nerves,** which then enter the abdomen to synapse in remote *prevertebral ganglia* (celiac and preaortic ganglia). Postganglionic fibers from these ganglia travel via branches of the abdominal aorta to the viscera of the abdomen. Thoracic splanchnic nerves supply the derivatives of the foregut and midgut. Hindgut derivatives and urogenital pelvic

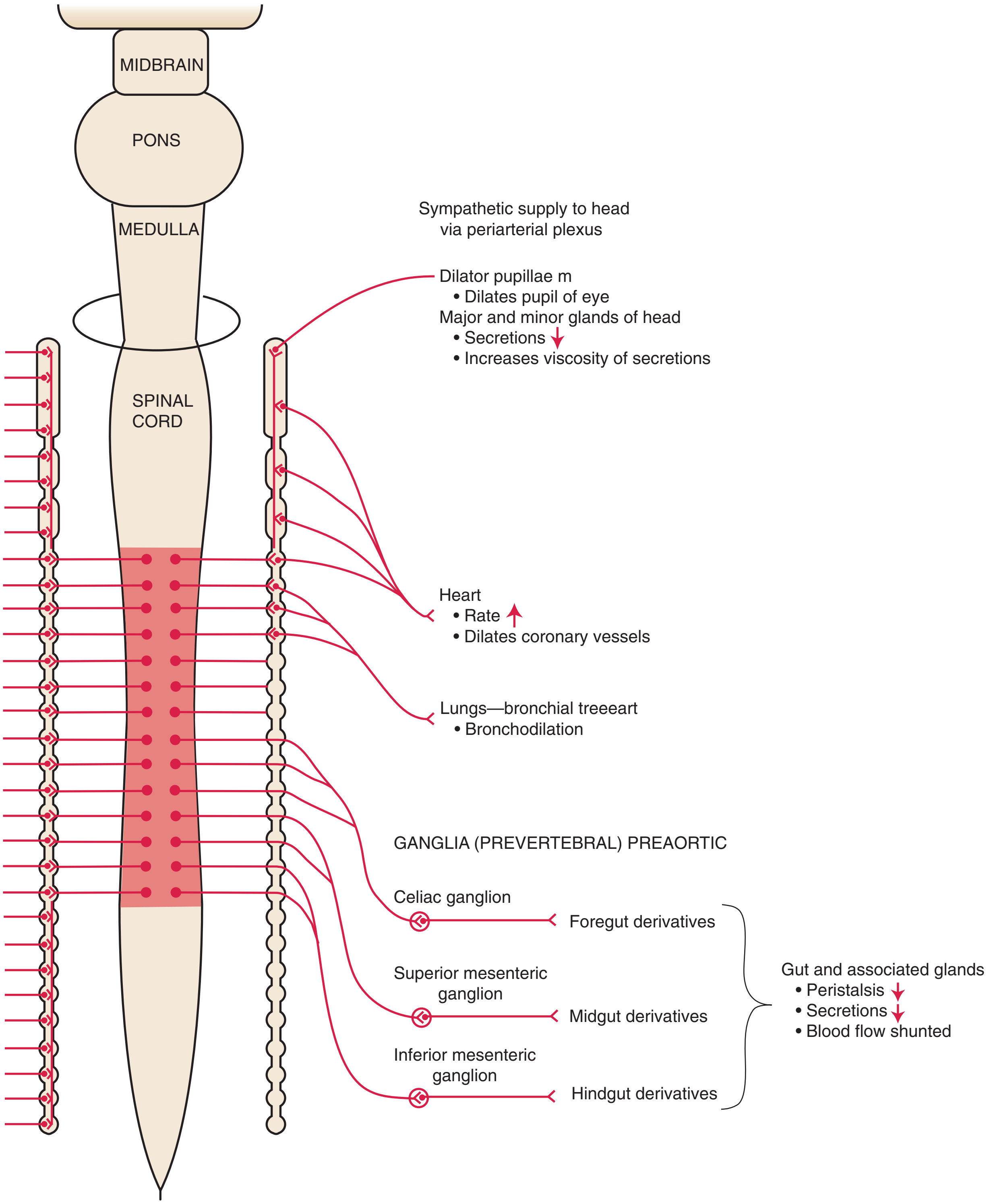


• **Fig. 1.25** Scheme of parasympathetic division origins and distributions. *CN,* cranial nerve.

viscera are supplied from **lumbar splanchnic nerves** arising from the sympathetic trunk of the lumbar region.

Autonomic Sensory (Visceral Afferent) Components. Visceral receptors monitor smooth muscle tone in viscera and vessels, blood chemistry (chemoreceptors), blood pressure (baroreceptors), and the content volume in hollow organs. This information is conveyed back to the CNS via sensory components of autonomic nerves. Unlike general sensations (e.g., pain, temperature, touch) conveyed by somatic afferent nerves, we are generally unaware of visceral sensations. There are, however, exceptions.

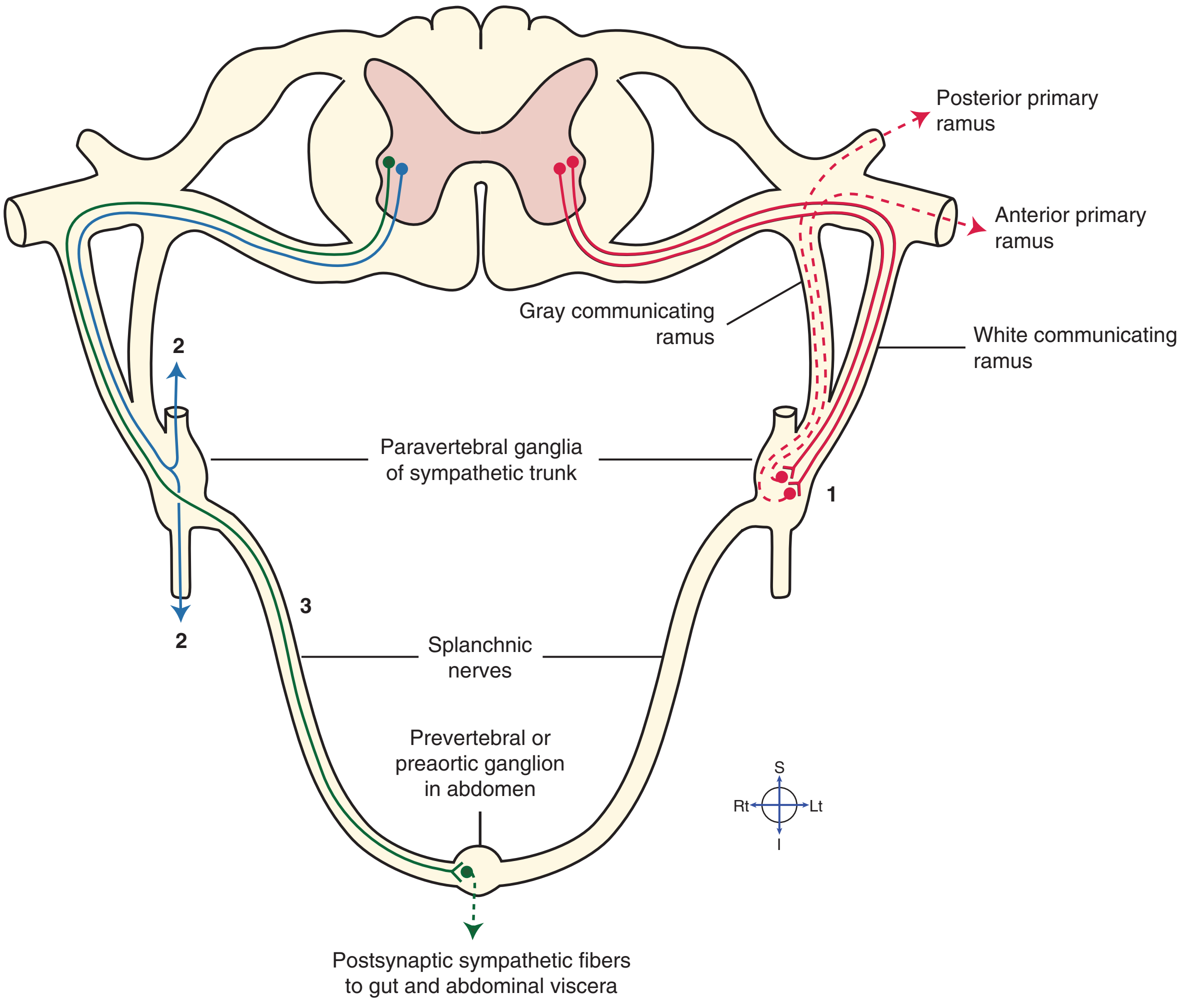
We are aware of a sense of fullness of the stomach, rectum, and bladder. We are also aware of hunger and, when things go wrong, nausea. Afferent impulses that convey these conditions travel back to the CNS along *parasympathetic nerves*. The primary



• **Fig. 1.26** Scheme of sympathetic division origins and distributions. *Note:* To simplify scheme, sympathetic contributions are shown on right side and sympathetic innervation to head and viscera is shown on left side. Both sets of fibers are bilateral.

cell bodies of spinal nerves reside in the same ganglia (dorsal root ganglia) occupied by somatic afferent nerves, and the primary cell bodies of cranial nerves reside in sensory cranial ganglia for cranial nerves. The pathways for visceral or autonomic sensation within the CNS are the same as those for the somatic afferent nerve fibers.

Feelings of pain or cramps, however, travel back to the CNS along *sympathetic nerves.* The brain does not localize the sites of origin of visceral pain and instead refers the pain to somatic sites that share the same spinal nerve innervation. Thus cardiac pain (angina) is localized to the chest wall and left arm, and pain from appendicitis is felt in the umbilical (midabdominal) region. The



• **Fig. 1.27** Cross section through thoracic spinal cord to demonstrate origin and distribution of sympathetic nerves. All sympathetic nerves originate in lateral horn of thoracic cord (T1-L2, and their outgoing fibers can synapse at three different sites). *1,* Some fibers synapse at their own level and join spinal nerves. *2,* Other fibers pass up or down sympathetic trunk to synapse at a higher or a lower level and join spinal nerves at that level. *3,* Some fibers leave as discrete splanchnic nerves that travel to abdomen to synapse in remote prevertebral ganglia.

primary cell bodies are found in dorsal root ganglia of spinal nerves. Within the CNS, axons follow the same pathway as the somatic afferent fibers.

Nomenclature and Summary

Cranial Nerves. There are 12 pairs of cranial nerves, which originate from the brain. They are individually named and by convention assigned Roman numerals (Table 1.1). Note the functional components listed for each cranial nerve. Some nerves, such as the trochlear nerve (cranial nerve IV), contain only one component (motor); other nerves, such as the glossopharyngeal nerve (cranial nerve IX), contain five functional components. The distributions and structures supplied by the cranial nerves are described in detail in Chapter 7 and reviewed as a group in Chapter 8.

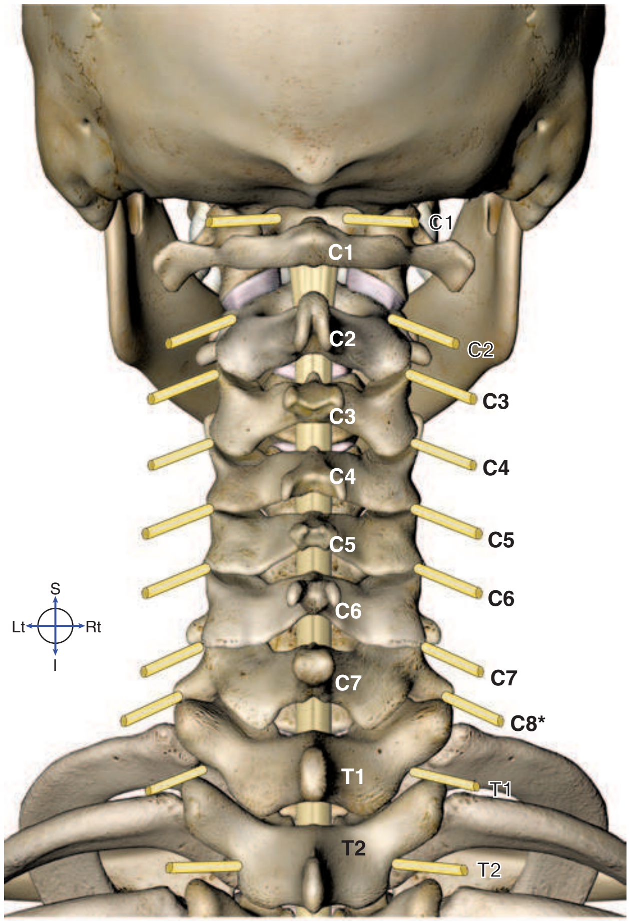
Spinal Nerves. The formation of a typical spinal nerve is illustrated in Fig. 1.24. The dorsal (sensory) root and the ventral (motor) root combine to form a mixed sensory and motor spinal nerve. Spinal nerves exit through intervertebral foramina and immediately break up into two main branches (*rami*; singular, *ramus*). The **posterior rami** supply mixed sensory and motor nerves to the structures of the back, the back of the neck, and the back of the head. The **anterior rami** supply mixed sensory and motor fibers to the lateral and anterior aspects of the trunk and all of the upper and lower limbs.

Spinal nerves derive their names from the vertebrae between which they arise (Fig. 1.28). By convention, spinal nerves C1 to C7 take their names **from the vertebrae below.** For example, spinal nerve C1 arises between the skull and vertebra C1. Similarly, C2 exits between vertebrae C1 and C2 and so on. There are only seven cervical vertebrae, but there are eight cervical nerves. Spinal nerve C8 arises between the seventh cervical and first thoracic vertebrae. From vertebral level T1 downward, each spinal nerve derives its name **from the vertebra above,** so that spinal nerve T1 emerges between vertebrae T1 and T2, and so on.

Nerve Plexuses. In certain regions of the spinal cord, anterior rami tend to join and divide in complex patterns called *nerve plexuses* (Fig. 1.29). The **cervical plexus** is formed by the anterior rami of spinal nerves C1 to C4. It supplies structures in the anterior and

TABLE 1.1 The Cranial Nerves and Their Functional Components

Number	Name	Functional Components
I	Olfactory nerve	Special afferent (smell)
II	Optic nerve	Special afferent (sight)
III	Oculomotor nerve	Somatic motor, visceral efferent
IV	Trochlear nerve	Somatic motor
V	Trigeminal nerve	Somatic afferent, branchial motor
VI	Abducens nerve	Somatic efferent
VII	Facial nerve	Somatic afferent, branchial efferent, visceral efferent, special afferent (taste)
VIII	Vestibulocochlear nerve	Special afferent (hearing and balance)
IX	Glossopharyngeal nerve	Somatic afferent, branchial efferent, visceral efferent, visceral afferent, special afferent (taste)
X	Vagus nerve	Somatic afferent, branchial efferent, visceral efferent, visceral afferent, special afferent (taste)
XI	Spinal accessory nerve	Branchial efferent
XII	Hypoglossal nerve	Somatic efferent



• **Fig. 1.28** Schematic posterior view of skull and cervical vertebrae to explain the nomenclature of spinal nerves. From vertebral levels C1-C7, spinal nerves arise above their respective vertebrae. From vertebral levels T1 downward, spinal nerves arise below their respective vertebrae. Spinal nerve C8 arises between C7 and T1. (*There is a spinal nerve C8, but there is no vertebra C8.)

lateral regions of the neck. The **brachial plexus** is formed from the anterior rami of spinal nerves C5 to T1. It supplies all of the structures of the upper limb. The **lumbar plexus** is formed by the anterior rami of spinal nerves L1 to L4 and supplies the pelvis and the entire lower limb. The **sacral plexus** is formed by the anterior rami of spinal nerves L4 to S4 and supplies the perineum and lower limb. The **coccygeal plexus** is formed by the anterior rami of spinal nerves S4 to Co1 and supplies skin of the coccygeal area.

Cutaneous Distribution

The sensory distribution from the skin of the body is shown in Fig. 1.30. Most of the body is innervated by spinal nerves. However, the face and anterior scalp are innervated largely by cranial nerve V (trigeminal nerve).

BODY COVERINGS, BODY CAVITIES, AND FASCIA

The body is lined within and without by epithelial coverings, which are supported by underlying connective tissue layers (Fig. 1.31). Externally the lining is **skin**; internally the linings of the gut and respiratory and genitourinary tracts are **mucous membrane,** which is red and kept moist by mucous glands. Areas of transition from skin to mucous membrane are found at both ends of the alimentary canal, at the nose, and on the external genitalia.

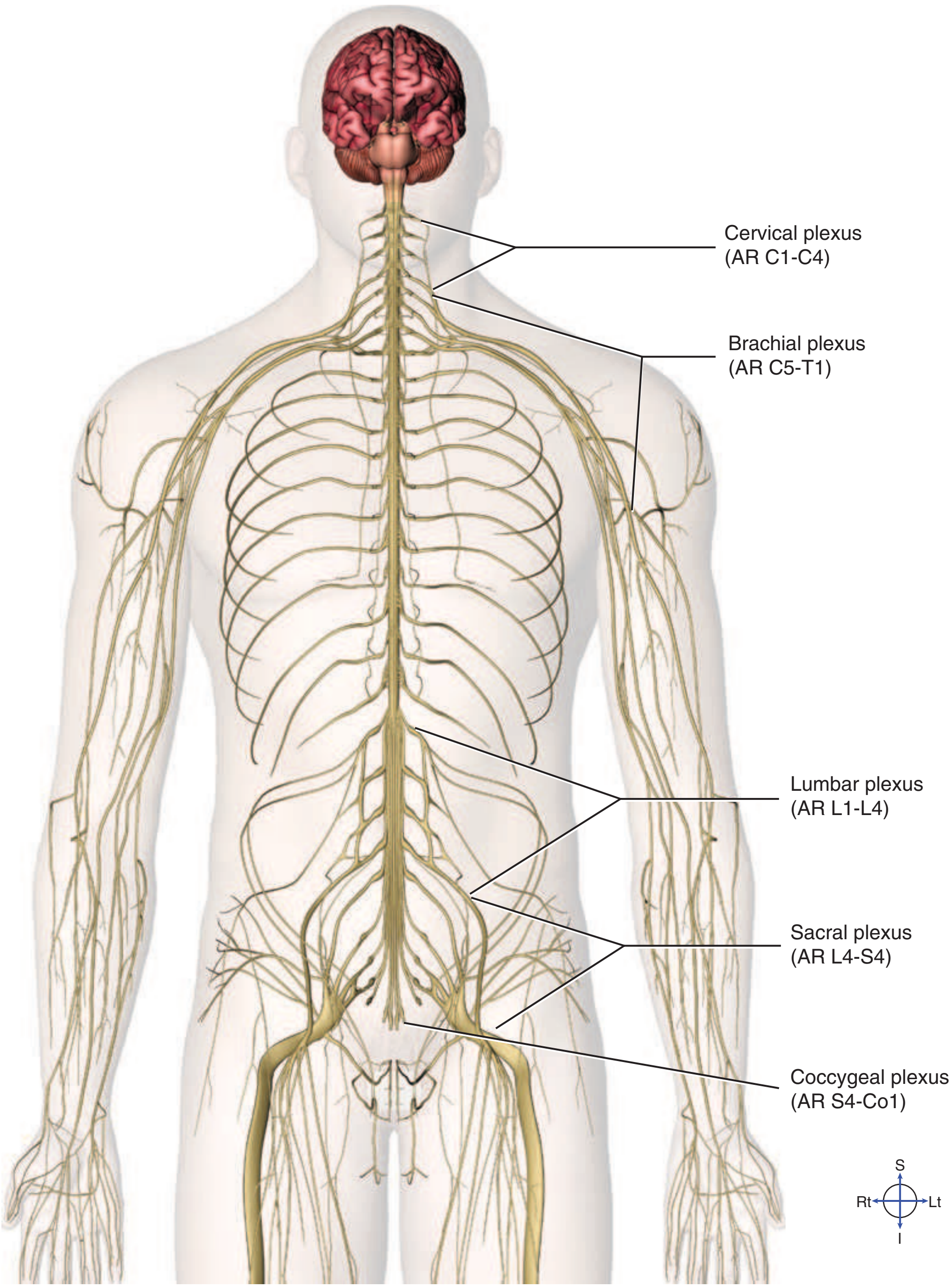
Invaginations of epithelium invade the underlying connective tissue to form (1) glands, teeth, and digestive organs, such as the liver and pancreas *from mucous membrane;* and (2) hair follicles, nail beds, sebaceous glands, and sweat glands *from skin.*

Mucous Membrane

The morphology of mucous membrane depends on its primary function. It can be (1) *mechanically protective,* as in the esophagus; (2) *secretory,* as in the stomach; (3) *absorptive,* as in the intestines, and (4) *protective* against foreign material, as in respiratory mucosa containing cilia. Mucous membrane is considered in greater detail in Chapters 3 and 4, dealing with the study of the gastrointestinal, genitourinary, and respiratory systems.

Skin

There are two types of skin. **Thick skin** covers the *palmar* and *plantar* surfaces of the hands and feet. Thick skin is completely devoid of hair, and its surface is heavily ridged for protection against wear and for grip (hands) and traction (feet). **Thin skin** covers the remainder of the body and is covered with hair or at least some fuzz. The skin covering the posterior aspect of the body is somewhat thicker than the skin of the anterior region.



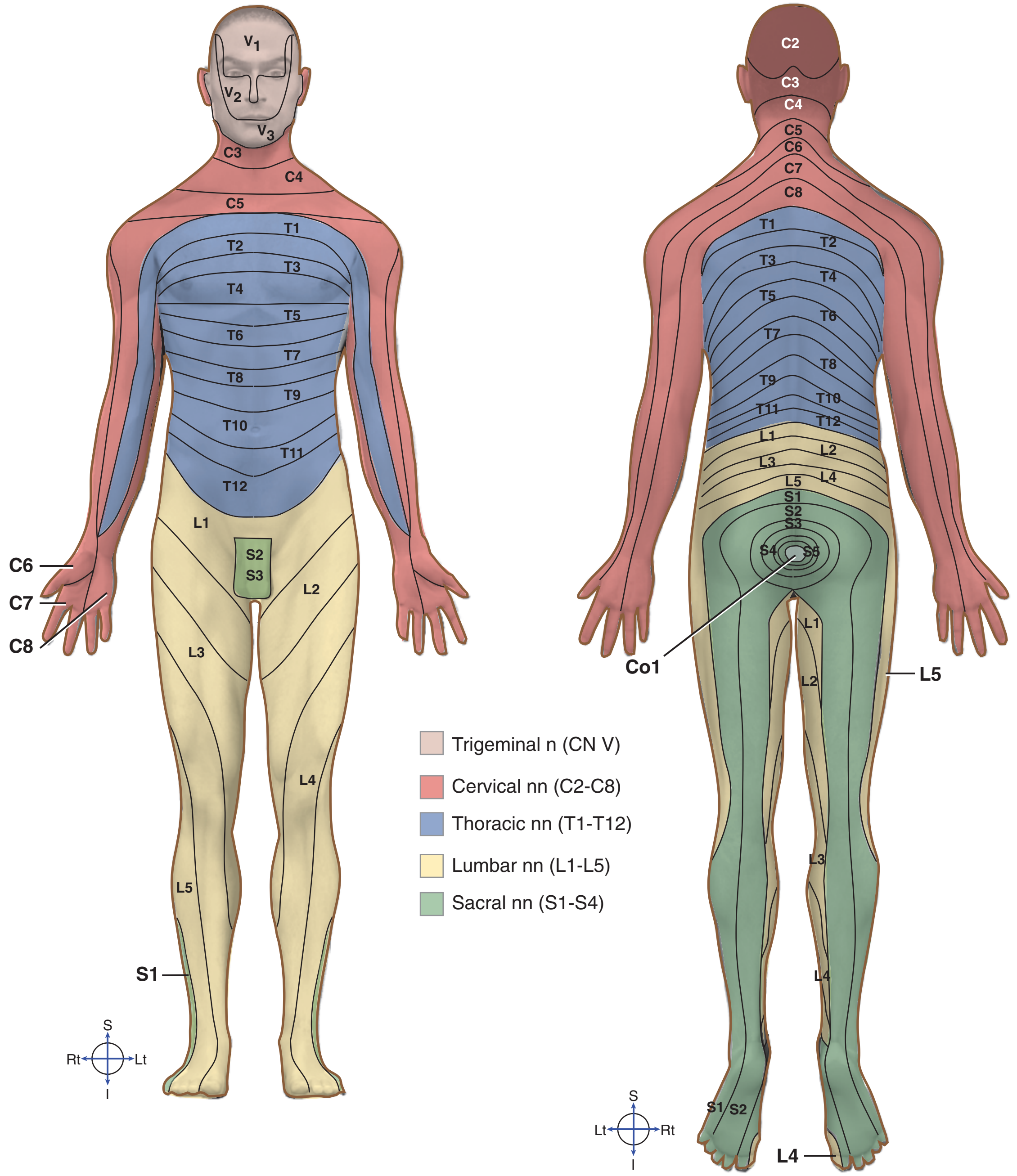
• **Fig. 1.29** Examples of nerve plexuses. Anterior rami *(AR)* of spinal nerves in cervical, upper thoracic, and lumbar and sacral regions form nerve plexuses. Cervical plexus supplies some anterior and lateral structures of neck; brachial plexus supplies upper limb; lumbosacral plexus supplies lower limb.

Skin color can vary among individuals and ranges from pale to dark, depending on the amount of melanin, a brown pigment found in the skin. In addition, exposure to sunlight increases the production of melanin and deepens the color. In fair-skinned people, underlying vessels contribute to skin coloring. Diminished blood flow beneath the skin causes pallor; increased flow causes flushing.

Two components make up the total layer of skin. **Epidermis** is an outer epithelial layer, and **dermis** is an underlying connective tissue layer.

Epidermis

The epidermis consists of four layers and is classified as *stratified squamous epithelium* (Fig. 1.32). The deepest layer proliferates to produce cells, which then migrate upward through four different levels, changing from columnar cells at the base to flattened, scalelike squamous cells near the surface. As the cells rise to the surface, they produce keratin within the cytoplasm and undergo cell degeneration with loss of the nuclei. The flat, keratinized cells at the surface are dead and are constantly being sloughed off as new cells rise from below as replacements.



• **Fig. 1.30** Cutaneous distribution (dermatomes) of spinal nerves for the trunk and limbs and the trigeminal nerve (cranial nerve [CN] V) for the head.

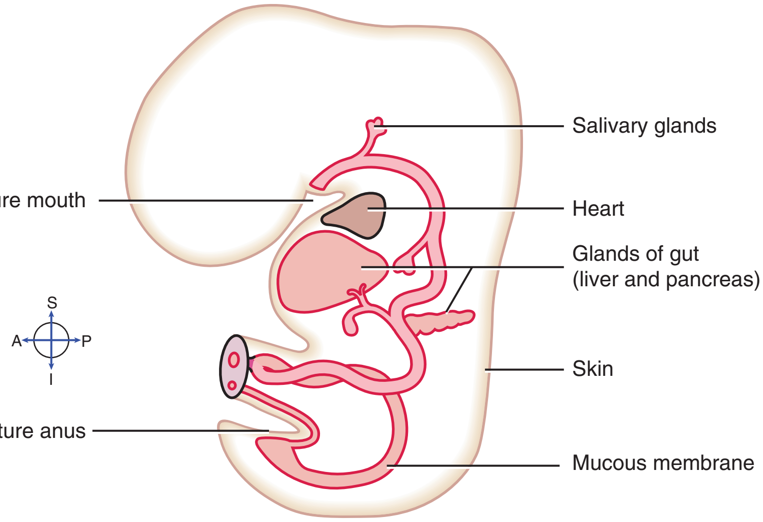
Dermis

The junction between the epidermis and dermis is ridged (see Fig. 1.32). The dermis is a layer of connective tissue consisting of cells in a matrix of relatively dense collagenous and elastic fibers. Scattered throughout this layer are deposits of *fat cells,* or *adipose tissue.* Running through the dermis from deeper layers are cutaneous branches of veins, arteries, and nerves, which supply but do not invade the overlying epithelial epidermis.

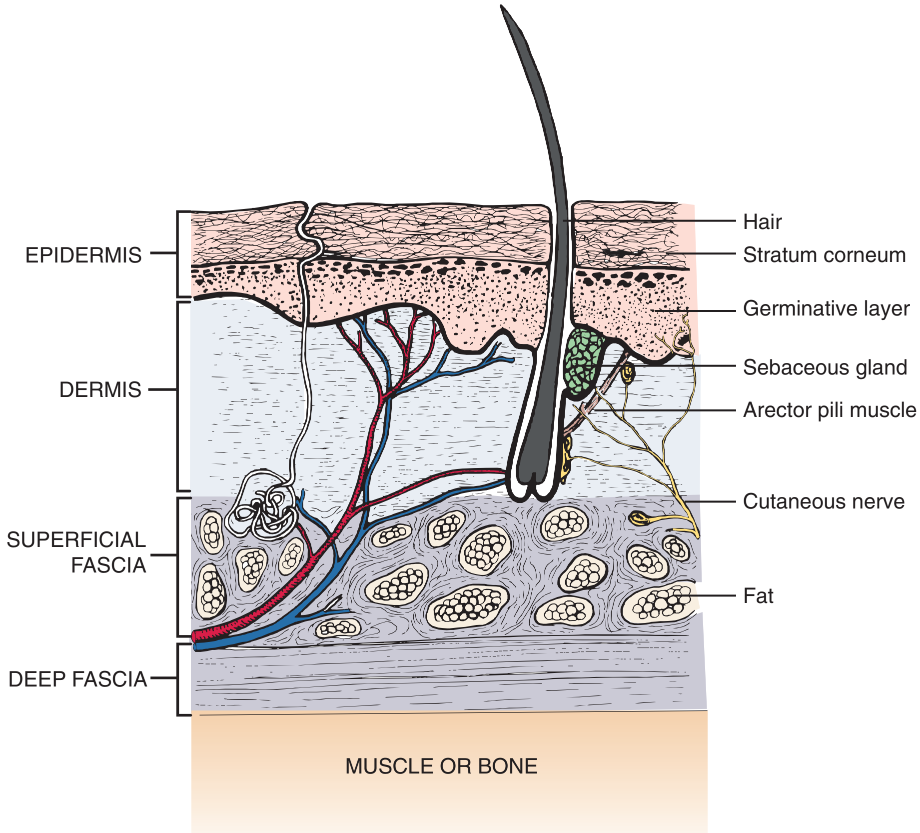
Functions

Mechanical Envelope. The skin acts as a physical barrier, preventing physical damage to, and evaporation of, underlying tissues.

Organ. *Vitamin D production* takes place in the skin when it is exposed to sunlight. *Heat regulation* of the body is a result of the constriction or dilation of underlying blood vessels of the skin. Secretions of the sweat glands cool the body on evaporation. Water, salts, and some urea are *excreted* through the skin glands. Sensations



• **Fig. 1.31** Longitudinal section through embryo at 35 days' gestation shows development of external body (covering skin) and internal gut lining (mucosa). Note that two coverings approach each other at sites of future mouth and future anus.



• **Fig. 1.32** Skin and fascia.

of touch, temperature, and pain are transmitted via cutaneous nerve receptors within the skin.

Fascia

Deep to the dermal portion of the skin lies another layer of connective tissue, called *fascia.* It contains collagenous and elastic fibers, which are continuous with those of the dermis above (see Fig. 1.32). There is no clear demarcation, however, between fascia and dermis. The two basic layers of fascia are superficial and deep fascia.

Superficial Fascia (Tela Subcutanea)

Because this layer is found immediately deep to the dermis, it is also called *subcutaneous tissue.* It contains collagenous and elastic fibers and considerably more fat. The superficial fascia of the ear, eyelid, and penis contains no fat.

Functions. Superficial fascia acts as a **storage depot.** Superficial fascia can contain considerable deposits of both water and fat. **Conduction** is another function. Superficial fascia contains nerves and blood vessels, which are transported to and from the skin above. Superficial fascia provides a **protective cushion.** Stored fat and water provide protection against mechanical shock. The layer of fat and water provides **thermal insulation** against rapid loss of body heat.

Superficial Muscles. Thin sheets of skeletal muscles are found within the superficial fascia of certain areas of the head and neck. In the face they are known collectively as *muscles of facial expression.* Because their insertions are into the skin of the face, the muscles are therefore able to move the skin into various positions or expressions.

Deep Fascia

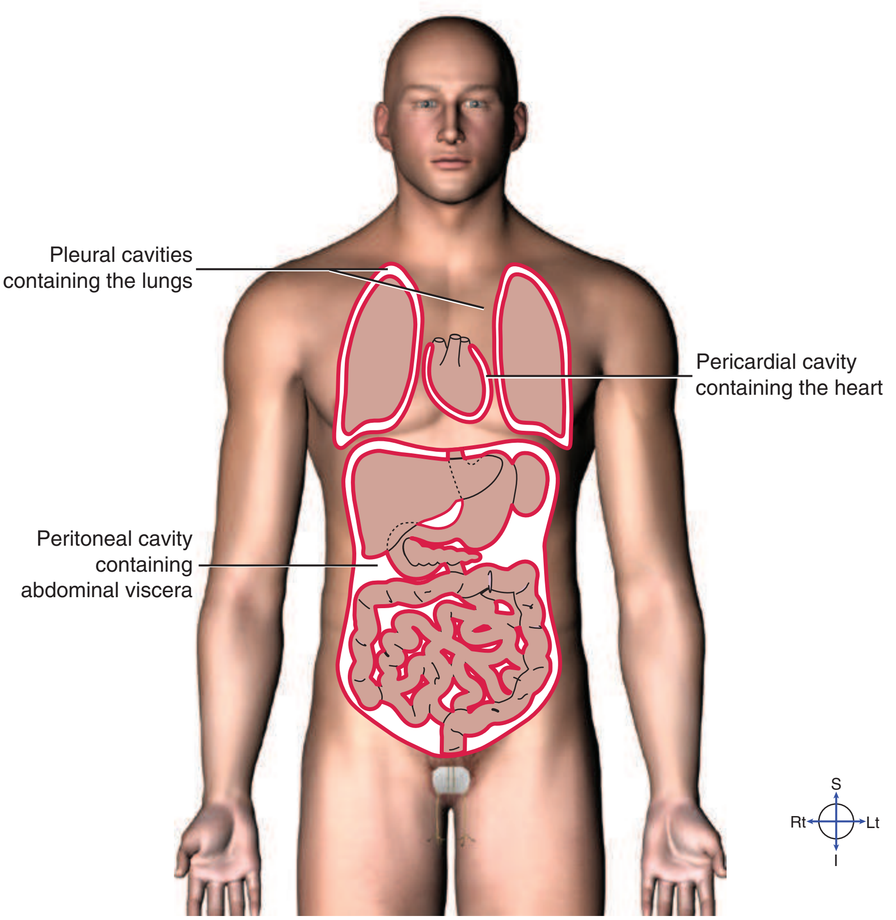
Deep fascia forms a connective tissue covering or sheath for structures (muscles, vessels, and nerves) deep to the superficial fascia (see Fig. 1.32). The collagenous fibers are more organized and run in parallel fashion, unlike the unorganized arrangement in the superficial fascia. Deep fascia generally contains little or no fat.

Functions. Deep fascia has three functions. The first function is **conduction.** Blood vessels and nerves are transported by means of the deep fascia to deep underlying structures, such as muscles and organs. Its second function is to facilitate the **movement of muscle.** Muscles wrapped in deep fascia are able to slide over one another. Last, the deep fascia serves as an **attachment for some muscles.** Some muscles, such as the temporalis muscle, gain partial attachment from deep fascia.

Fascial Planes. Areas between layers of deep fascia are termed *fascial clefts,* or *planes.* These sites are possible routes of infection; consequently an understanding of fascial architecture is necessary for the diagnosis and treatment of spread of infection.

Serous Body Cavities

During embryonic development, a split occurs in the embryonic mesodermal layer, producing an intraembryonic coelom, or hollow cavity. This cavity develops into four serous membrane–lined body spaces: right and left pleural cavities housing the right and left lungs, the pericardial sac housing the heart, and the peritoneal cavity housing the gut and its associated glands (Fig. 1.33). Each of these organs initially invades the spaces it ultimately occupies and in doing so assumes the serous membrane coverings of the cavities it invades. In general, the serous membrane lining the body cavity is referred to as the ***parietal layer,*** and the serous membrane that covers the visceral organs is termed the ***visceral layer.*** Each of these body cavities is described in greater detail in the appropriate chapters (the pleural and pericardial cavities in Chapter 3 and the peritoneal cavity in Chapter 4).



• **Fig. 1.33** Scheme of body cavities that are lined with parietal serous membranes. Each contains organs that are covered with visceral serous membranes.

Review Questions

1. The coronal plane ________________.
   a. divides the body into equal right and left halves
   b. divides the body into anterior and posterior components
   c. divides the body into superior and inferior components
   d. is parallel to the sagittal plane
   e. is parallel to the transverse plane
2. All of the following structures contain hyaline cartilage EXCEPT ________________.
   a. the external ear or auricle
   b. apposing surfaces of synovial joints
   c. the nasal septum
   d. the bronchial tree
   e. the larynx
3. An opening or a hole through a bone is termed a ________________.
   a. *sulcus*
   b. *fissure*
   c. *foramen*
   d. *fossa*
   e. *tubercle*
4. Which of the following statements concerning joints is FALSE?
   a. The elbow is an example of a hinge or ginglymus synovial joint.
   b. Sutures are synarthrodial joints allowing no movement between the bones they unite.
   c. The joints between vertebral bodies are symphyses.
   d. Synchondroses permit growth between apposing bones.
   e. Proprioceptive nerve endings or Ruffini corpuscles in the capsular ligament of a synovial joint convey a sense of pain.
5. Muscle fibers arranged for power rather than ranges of movement are found in ________________.
   a. parallel muscles
   b. converging muscles
   c. sphincter muscles
   d. digastric muscles
   e. pennate muscles
6. Which of the following statements regarding characteristics of smooth muscle is FALSE?
   a. Smooth muscle is capable of rapid, powerful contractions and fatigues quickly.
   b. Smooth muscle has no bony origin or insertion.
   c. Most smooth muscle is controlled by autonomic efferent nerves.
   d. Smooth muscle is nonstriated.
   e. Smooth muscle, in hollow organs or tubes, contracts to expel contents.
7. Which of the following statements concerning blood vessels is FALSE?
   a. A capillary wall consists of a single cell layer of endothelial cells.
   b. The tunica media of a terminal arteriole consists of a single muscle cell layer.
   c. The tunica media of the aorta contains elastic tissue but no smooth muscle.
   d. The retina of the eye receives good collateral circulation.
   e. An arteriovenous anastomosis shunts blood across the capillary bed.
8. Which of the following statements concerning the lymphatic system is FALSE?
   a. Lymph is propelled through the lymphatic vessels by the heart.
   b. Lymphocytes are produced in the bone marrow.
   c. Lymph nodes filter out bacteria, viruses, and cancer cells.
   d. Lymphatic vessels returning from the gut contain relatively high amounts of fat.
   e. The thoracic duct drains the lower limbs, abdomen, and chest wall.
9. The connective tissue sheath that intimately surrounds a peripheral nerve is termed the ________________.
   a. *sarcolemma*
   b. *endoneurium*
   c. *perineurium*
   d. *deep investing fascia*
   e. *epineurium*
10. The parasympathetic nervous system ________________.
    a. speeds up the heart
    b. decreases peristalsis
    c. closes gut sphincters
    d. is necessary to life
    e. decreases glandular secretions
11. Internal epithelial (mucous membrane) linings give rise to the ________________.
    a. teeth
    b. liver
    c. pancreas
    d. mucous glands
    e. all of the above

2

The Back

CHAPTER OUTLINE

The skeleton of the back is presented in Fig. 2.2. It consists of the skull, the vertebral column, and the ribs, which are appendages of the thoracic component of the vertebral column.

SURFACE FEATURES OF THE BACK

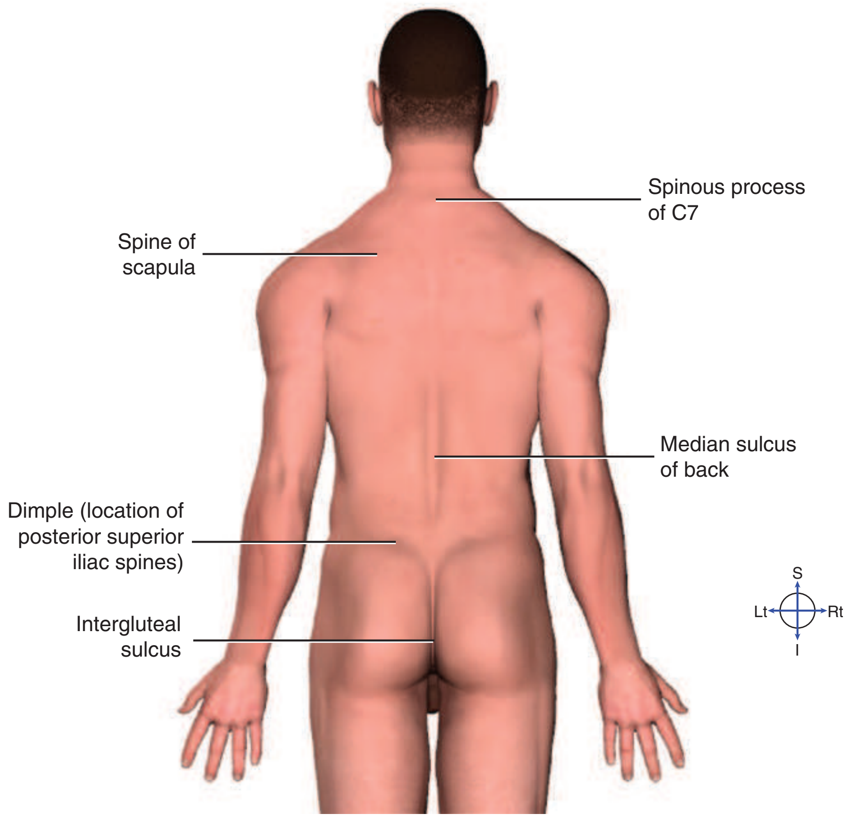
The surface features of the back aid in identifying levels of the vertebral column and spinal cord and posterior positions of the thoracic and abdominal viscera for clinical examination. In the erect position the **spine of C7** (vertebra prominens) is normally the only spine visible (Fig. 2.1). The **median sulcus of the back** lies immediately above the **intergluteal sulcus.** A median sulcus that deviates laterally would indicate scoliosis, described previously. To either side of the interior end of the median sulcus are dimples that indicate the positions of the **posterior superior iliac spines** of the os coxae.

SKELETAL PARTS

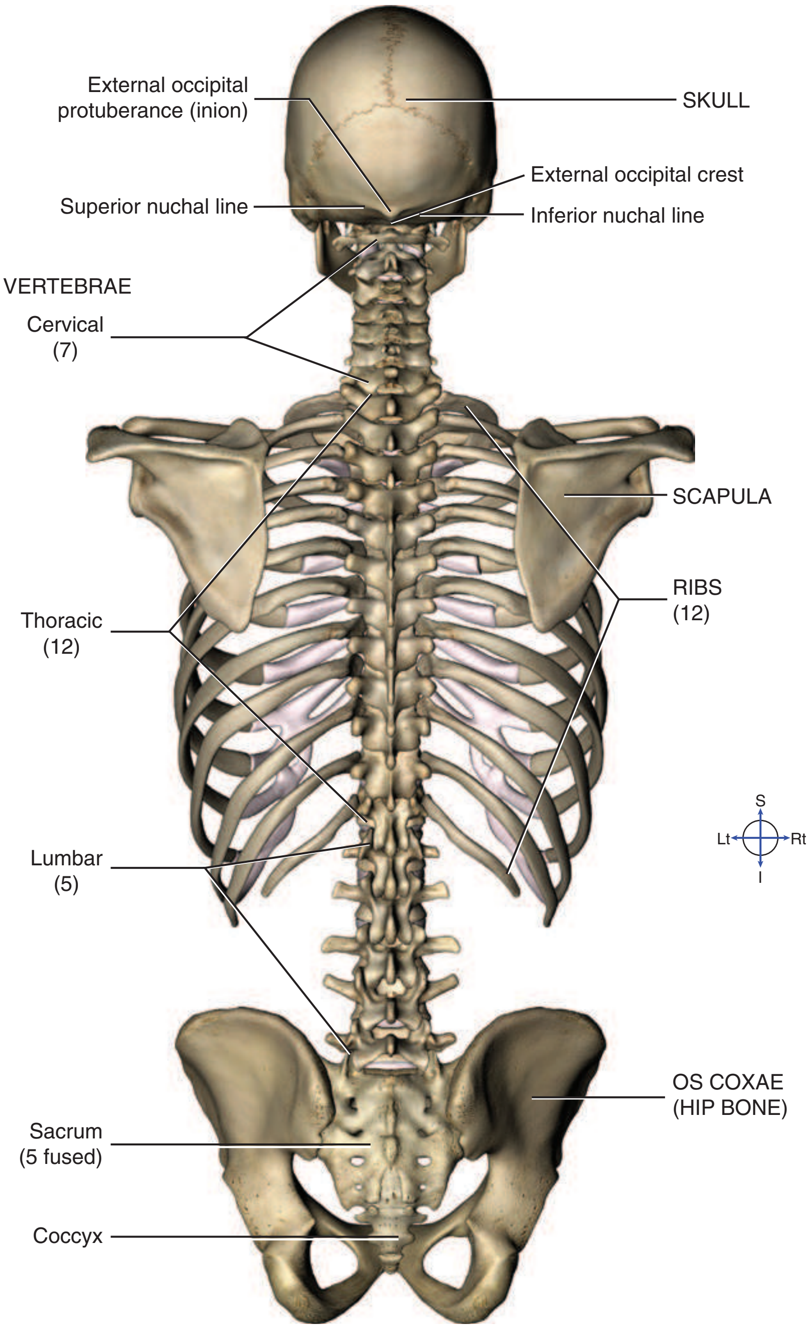
The bones associated with the back include the skull, vertebrae, scapula, ribs, and os coxae (Fig. 2.2).

Posterior Aspect of the Skull

The various views and bones of the skull are considered in Chapter 6. Only the posterior aspect of the skull is described here. The posterior surface of the skull is convex and is commonly called



• **Fig. 2.1** Surface features of the back.



• **Fig. 2.2** Skeleton of back.

the ***occiput.*** The **external occipital crest** is a midline ridge running superiorly from the foramen magnum. Arising from this crest are two transverse lines, the **inferior nuchal line** and above it the **superior nuchal line.** The external occipital crest ends at the midpoint of the superior nuchal line as a lump called the ***inion,*** or ***external occipital protuberance.*** Some muscles of the back extend up to this area of the skull and insert into these features.

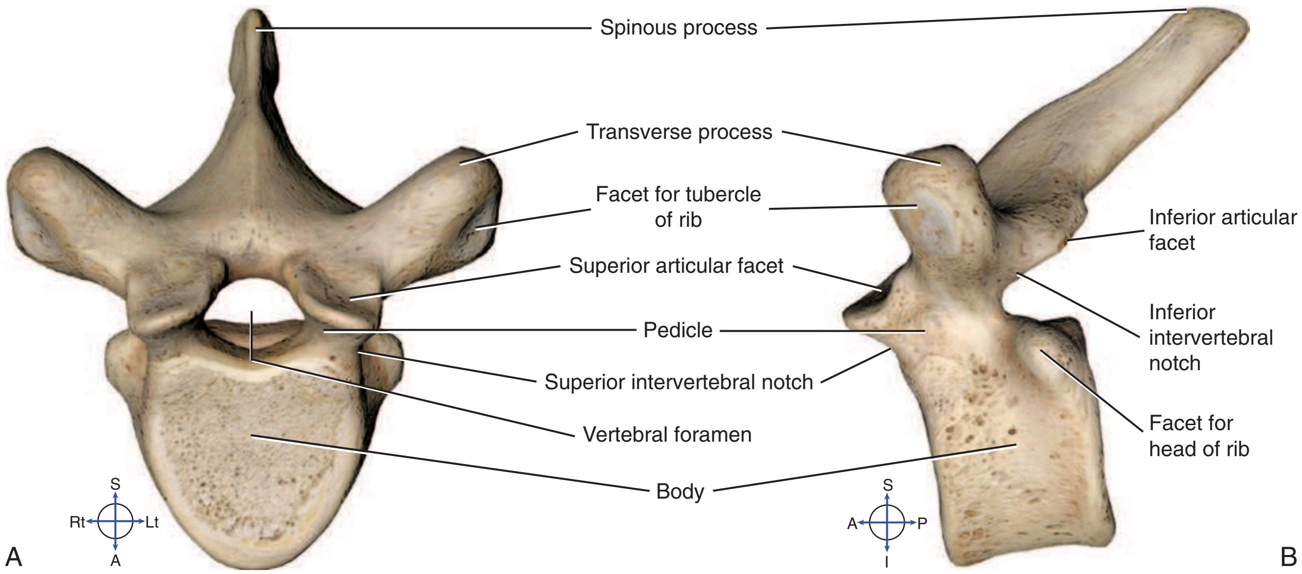
Vertebral Column

The vertebral column, or spine, consists of 33 vertebrae: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral (fused), and 4 coccygeal (fused); and the joints between the stacked components.

Vertebrae: Typical Features

All vertebrae have certain features in common. Learning these features and then noting regional differences makes the study of vertebrae far less difficult. A midthoracic vertebra is generally chosen as exhibiting features common to most other vertebrae (Fig. 2.3A).

The **body** is a spool-shaped mass of bone that provides support. All vertebrae (except C1) have a body. A vertebral arch is fastened to the posterior aspect of the body. The arch has two components: a *pedicle,* or short bony root, which fastens the arch to the body; and a *flattened lamina,* which forms the roof of the arch and body. The vertebral arch and body form the *vertebral foramen,* which



• **Fig. 2.3** **A,** Superior view of a typical vertebra. **B,** Left lateral view of two articulated vertebrae.

encloses and protects the delicate spinal cord within. The arches in an articulated *vertebral column* form the vertebral canal, which houses the entire spinal cord.

Bilateral **superior** and **inferior articulating processes** are situated between the pedicle and lamina. They are bilateral articulating facets that are covered with hyaline cartilage and allow the vertebra above to articulate with the vertebra below (Fig. 2.3B).

Bilateral **superior** and **inferior vertebral notches** are found on the superior and inferior aspects of the pedicles. In the articulated spinal column the superior and inferior notches form the **intervertebral foramina,** which *transmit the spinal nerves.*

Attached to the vertebral arch are three processes that provide attachment for muscles of the back and therefore *act as levers in response to muscle contractions.* A single **spinous process** extends posteriorly and inferiorly from the top of the vertebral arch. Arising laterally from the arch are two **transverse processes.**

Cervical Vertebrae

Of the seven cervical vertebrae, C3 to C6 are considered typical of the cervical region in that they exhibit all of the features of vertebrae in general. They also display certain features that distinguish them as cervical vertebrae.

Typical Features. In addition to the general features, cervical vertebrae exhibit (1) a **transverse foramen,** a hole through the transverse processes to transmit the vertebral artery and vein; (2) a **bifid spinous process;** and (3) a transverse process, which ends laterally as an **anterior** and a **posterior tubercle** for attachment of cervical muscles (Fig. 2.4C).

Atypical Features

Atlas (C1). The first cervical vertebra (Fig. 2.4A) differs from the remaining cervical vertebrae in the following ways: (1) the concave superior articulating facet is *bean-shaped* to accommodate the reciprocally shaped occipital condyles of the skull; (2) the body of the atlas is lost early in development and becomes fused to the body of the axis below, leaving only an anterior arch in its place; (3) there is no anterior tubercle on the transverse process; and (4) it exhibits two grooves for the vertebral arteries just posterior to the superior articulating facets.

The atlas consists of four segments: an **anterior** and **posterior arch** and two lateral masses from which the transverse processes project laterally. The atlas has no spine but has a small elevation on the posterior arch termed the ***posterior tubercle*** (not to be confused with the posterior tubercle of the transverse processes).

Axis (C2). This vertebra (Fig. 2.4B) differs from the typical vertebrae of the cervical region in two respects: (1) the original body of C1 is fused to the body of the axis as the **dens,** or **odontoid process**; and (2) the axis has no anterior tubercle on its transverse process.

C7. This vertebra (Fig. 2.4D) displays two atypical features: (1) it is the last component of the cervical segment and closely resembles the thoracic vertebrae below, with a long, slender spinous process in contrast to the bifid spines of the vertebrae above; and (2) it has no anterior tubercle on its transverse process. Although it resembles a thoracic vertebra, it is distinctly cervical because it does have a transverse foramen.

Thoracic Vertebrae

The 12 thoracic vertebrae (see Fig. 2.3) exhibit a number of features that distinguish them from other vertebrae: (1) the spinous process is long and slender; (2) the body has an articulating facet for the head of a rib; (3) the transverse process has an