EXTREMELY IMPORTANT TIPS

on How to Get the Most out of This Book

Keep this page in sight as you do the first few pages

1. For maximum benefit, a supply of at least 20 colors (including 1 or 2 shades of gray) is desirable, although the plates can be worked with 12 colors including 1 gray. Colored pencils and felt-tip pens are preferable to wax crayons which tend to be messy and coarse.

2. Before beginning to color, look over the entire page, reading coloring instructions, captions, etc. It is not essential to thoroughly understand what you are looking at, but rather to get a feeling for the page and to know what to expect. If you find that certain material, including titles or structures to be colored, are too detailed or technical for your interest, it is recommended that you color them as part of the overall exposure to the subject—even though you are not concerned with memorizing or intimately understanding the material.

3. Color in the order given by the coloring instructions. These will be preceded by the letters CN, which stand for the colors needed for that page (excluding gray). CN will be followed by the actual number of colors needed or by a question mark in situations where because of the excessive number of colors to be used, you will need to repeat a color.

4. You may use any color you wish; however, certain specific colors are directed or suggested for structures which have a consistent color under natural circumstances or are portrayed in color atlases of the body in a consistent color, such as arteries (red), veins (blue), nerves (yellow), lymphatic vessels (green), fat (yellow), muscles (brown), etc. Where several different arteries, veins, nerves, etc. are to be colored, other colors, of course, must be used. As a general rule, use more neutral or light colors for the larger areas, and brighter or darker colors for smaller or more important areas. On occasion, you will be asked to use colors on a plate that were used for the same structures on a previous related plate. In these cases, color their titles first regardless of where they appear on the plate. Then go back to the top of the title list and begin coloring in the usual sequence (down the list in order). This procedure will prevent you from using a color already specified for another structure.

5. Do not color over the heavier outlines, for they are usually the border lines separating areas to be colored. The lighter lines are usually included to suggest texture or define form in an area to be colored; these lighter lines should be colored over. With a transparent marker, they will show through as desired. If you are using colored pencils, they will usually show through; for added dimension, you may wish to draw darker or heavier over these

lined areas to add to a 3-dimensional effect

6. When you see a small letter following a word or group of words printed in outlined letters, you should *always color in that word or words*, as well as the structure (bone, muscle, etc.) to which it refers. This practice will create a stronger visual link between the structure and its name. It will also aid in learning the spelling of unfamiliar words. It is recommended that you color in these words in the order that they are listed. Where the word or words is followed by an asterisk (*), it should be colored a middle gray. This will usually apply to subject headings which require careful note and emphasis. If the word or words is followed by a small black dot (•), color it dark gray or black. So as not to confuse titles or names, *use one color for each letter on that particular page.*

Different titles/structures with the same identifying letter but with a small number added on (a^1, a^2, etc.) all receive the same color. Such structures—though different—are sufficiently related to warrant the same color.

There will be times when all the structures to be colored do not have a letter identifying them. This may occur in the case of symmetrical structures, where the unlabeled side is to be colored as well. Or also in the case where one or two labels imply that all should be colored. Occasionally, background structure functionally unrelated to the subject of the plate may not be labeled. Do not color such background structure (in most cases, structure/spaces not to be colored will be indicated by a -ǀ- symbol).

7. Abbreviations and symbols used throughout are:

M=muscle	Ms=muscles	✳=color gray
N=nerve	Ns=nerves	•=color black
A=artery	As=arteries	n.s.=not shown
V=vein	Vs=veins	-ǀ- =not to be colored in

The appearance of a ..... or ooooooooo tailing an artery, vein, nerve, or duct means that structure is deep to (behind) the structure through which the dots pass.

8. Complete the pages of any section in the order given. A broader understanding will then be made possible when you view related pages together. You will find cross-reference page numbers in the upper right-hand corner.

9. A blank backup sheet is provided for you to slip under the page you are coloring.

10. Use the pronunciation guide in the back of the book as a ready reference when coloring and encountering difficult words.

Study of the human body requires an organized visualization of its internal parts. Dissection (*dis*, apart; *sect*, cut) is the term given to preparation of the body for general or specific internal inspection. Internal body structure is studied in sections cut along imaginary flat surfaces called *planes*. These planes are applied to the erect, standing body with limbs extended along the sides of the body, palms and toes forward, thumbs outward. See this "anatomical position" in the following page. Views of the internal body in life and after death can be obtained by a number of techniques that produce computer-generated representational images of human structure in series (sections) along one or more planes. These anatomic images may be produced by computerized tomography (CT) and magnetic resonance imaging (MRI).

The **median plane** is the midline longitudinal plane dividing the head and torso into right and left halves. The presence of the sectioned midline of the vertebral column and spinal cord is characteristic of this plane. Planes parallel to the median plane are sagittal. Watch out! "Medial" is not a plane.

The **sagittal plane** is a longitudinal plane dividing the body (head, torso, limbs) or its parts into left and right parts (*not* halves). It is parallel to the median plane.

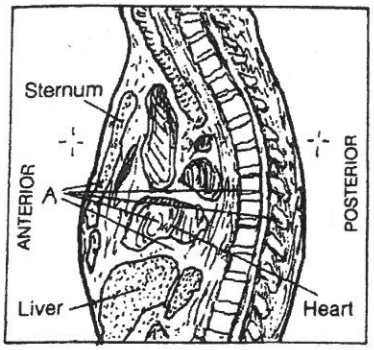
The **coronal** or **frontal plane** is a longitudinal plane dividing the body or its parts into front and back *halves or parts.* These planes are perpendicular to the median and sagittal planes.

The **transverse** or **cross plane** divides the body into upper and lower halves or parts (cross sections). This plane is perpendicular to the longitudinal planes. Transverse planes are horizontal planes of the body in the anatomical position.

ORIENTATION TO THE BODY
ANATOMIC PLANES & SECTIONS

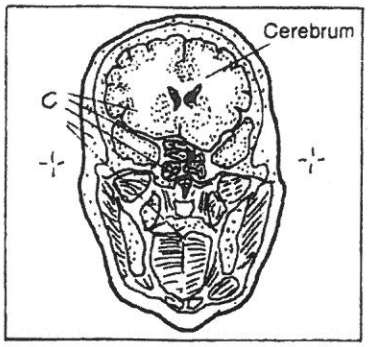
CN: Use your lightest colors on A–D. (1) Color a body plane in the center diagram; then color its name, related sectional view, and the sectioned body example. (2) Color everything within the dark outlines of the sectional views.

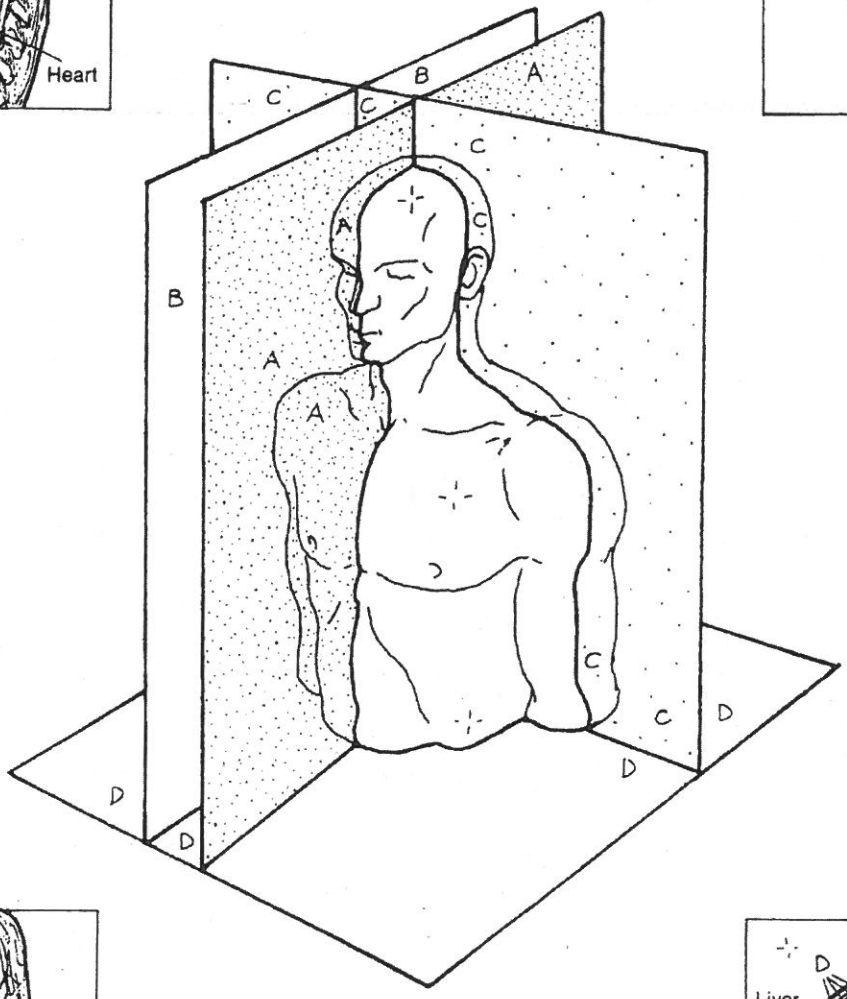
MEDIAN, A
SAGITTAL, B
CORONAL, FRONTAL, C
TRANSVERSE, CROSS, D

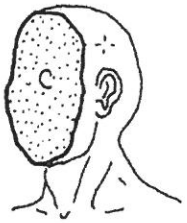


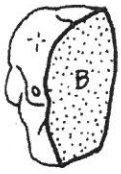
Median section through the thorax

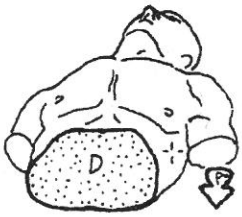
Coronal section through the head

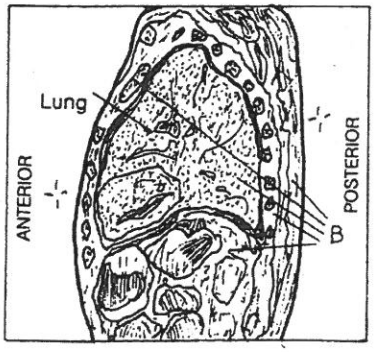




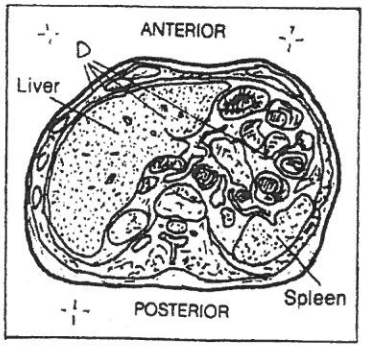








Sagittal section through the thorax



Cross section through the abdomen

Terms of position and direction describe the relationship of one structure on/in the body to another with reference to the *anatomical position*: body standing erect, limbs extended, palms of the hands forward, thumbs directed outwardly.

Cranial and **superior** refer to a structure being closer to the top of the head than another structure in the head, neck, or torso (excluding limbs).

Anterior refers to a structure being more in front than another structure in the body. **Ventral** refers to the abdominal side; in bipeds, it is synonymous with anterior. **Rostral** refers to a beak-like structure in the front of the head or brain that projects forward.

Posterior and **dorsal** refer to a structure being more in back than another structure in the body. *Dorsal* is synonymous with *posterior* (the preferred term) except in quadrupeds.

Medial refers to a structure that is closer to the median plane than another structure in the body.

Lateral refers to a structure that is farther away from the median plane than another structure in the body.

Employed only with reference to the limbs, **proximal** refers to a structure being closer to the median plane or root of the limb than another structure in the limb.

Employed only with reference to the limbs, **distal** refers to a structure being farther away from the median plane or the root of the limb than another structure in the limb.

Caudal and **inferior** refer to a structure being closer to the feet or the lower part of the body than another structure in the body. These terms are not used with respect to the limbs. In quadrupeds, *caudal* means closer to the tail.

The term **superficial** is synonymous with *external*, the term **deep** with *internal*. Related to the reference point on the chest wall, a structure closer to the surface of the body is superficial; a structure farther away from the surface is deep.

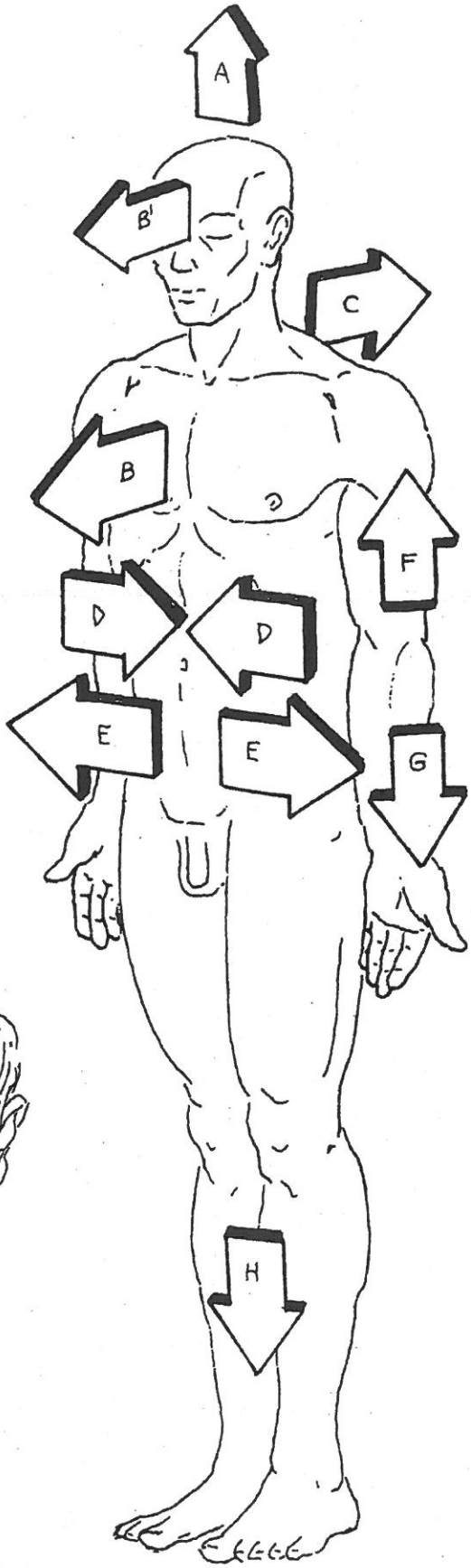
Ipsilateral means "on the same side" (in this case, as the reference point); **contralateral** means "on the opposite side" (of the reference point).

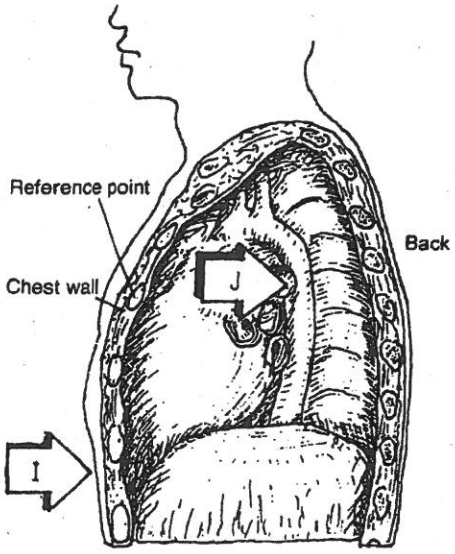
The **quadruped** presents four points of direction: head end (cranial), tail end (caudal), belly side (ventral), and back side (dorsal).

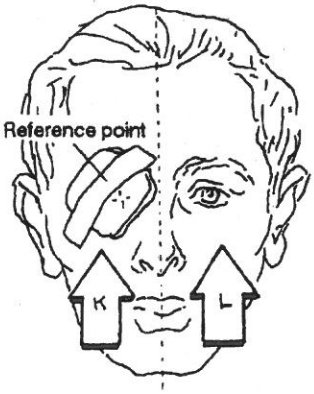
ORIENTATION TO THE BODY
TERMS OF POSITION & DIRECTION

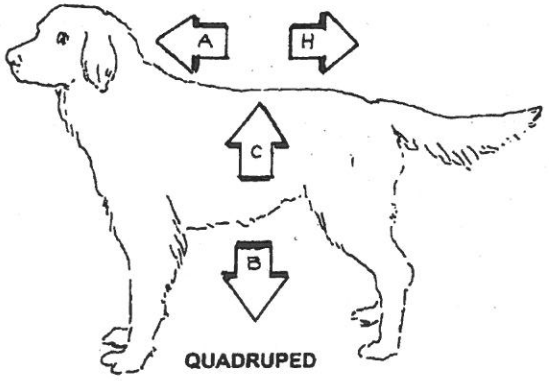
CN: Color the arrows and the names of the positions and directions, but not the illustrations.

CRANIAL, SUPERIOR, A
ANTERIOR, VENTRAL B
ROSTRAL B'
POSTERIOR, DORSAL C
MEDIAL D
LATERAL E
PROXIMAL F
DISTAL G
CAUDAL, INFERIOR H
SUPERFICIAL I
DEEP J
IPSILATERAL K
CONTRALATERAL L









CLOSED BODY CAVITIES

Closed body cavities are not open to the outside of the body. Though organs may pass through them or exist in them, their cavities do not open into these closed cavities. Closed body cavities are lined with a membrane.

The **cranial cavity** is occupied by the brain and its coverings, cranial nerves, and blood vessels (page 68). The **vertebral cavity** houses the spinal cord, its coverings, related vessels, and nerve roots (page 77). Both cavities are lined by the **dura mater**, a tough, fibrous membrane. The dura mater of the vertebral cavity is continuous with the cranial dura at the foramen magnum.

The **thoracic cavity** contains the lungs, heart, and neighboring structures in the chest. Its skeletal walls are the thoracic vertebrae and ribs posteriorly, the ribs anterolaterally, and the sternum and costal cartilages anteriorly (page 28). The roof of the cavity is membranous; the floor is the muscular thoracic diaphragm (page 48). The middle of the thoracic cavity, called the *mediastinum* (page 103), is a partition packed with structures (e.g., heart). It separates the thoracic cavity into discrete left and right parts that are lined with **pleura** and contain the lungs.

The **abdominopelvic cavity**, containing the gastrointestinal tract and related glands, the urinary tract, and great numbers of vessels and nerves, has muscular walls anterolaterally (page 49), the lower ribs and muscle laterally, and the lumbar and sacral vertebrae and muscles posteriorly (page 48). The roof of the abdominal cavity is the thoracic diaphragm. The abdominal and pelvic cavities are continuous with one another. The pelvic cavity, containing the urinary bladder, rectum, reproductive organs, and lower gastrointestinal tract, has muscular walls anteriorly, bony walls laterally, and the sacrum posteriorly. The internal surface of the abdominal wall is lined by a serous membrane, the **peritoneum**, that is continuous with the outer membrane of the abdominal viscera (page 138). The serous secretions enable the mobile abdominal viscera to slip and slide frictionlessly during movement.

OPEN VISCERAL CAVITIES

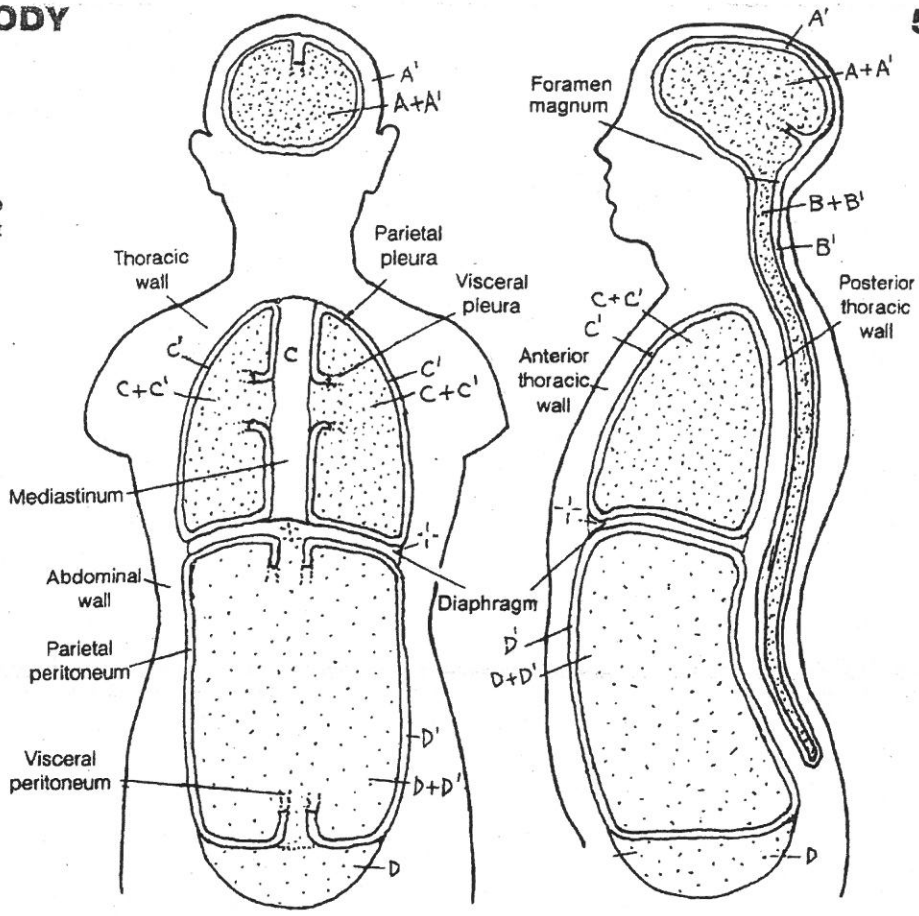
Open visceral cavities are largely tubular passageways (tracts) of visceral organs that open to the outside of the body (page 14), and include the **respiratory tract**, open at the nose and mouth, the **digestive tract** that opens at both the mouth and the anus, and the **urinary tract** that opens in the perineum at the urethral orifices. These cavities are lined with a mucus-secreting layer (**mucosa**) that is the working tissue of open cavities (providing secretion, absorption, and protection). The mucosa is lined with epithelial cells, and supported by a vascular connective tissue layer and a smooth muscle layer.

ORIENTATION TO THE BODY CAVITIES & LININGS

CN: Use light colors for the cavities A–D and slightly darker shades of the same color for the linings A^1–D^1. (1) Start with the names and color A in the upper two drawings, and complete both sides before going on to B, C, and D. (2) Color the names and open visceral cavities in the lower part of the page. Note that the inner lining, H, is the same color throughout; pick a bright color for it.

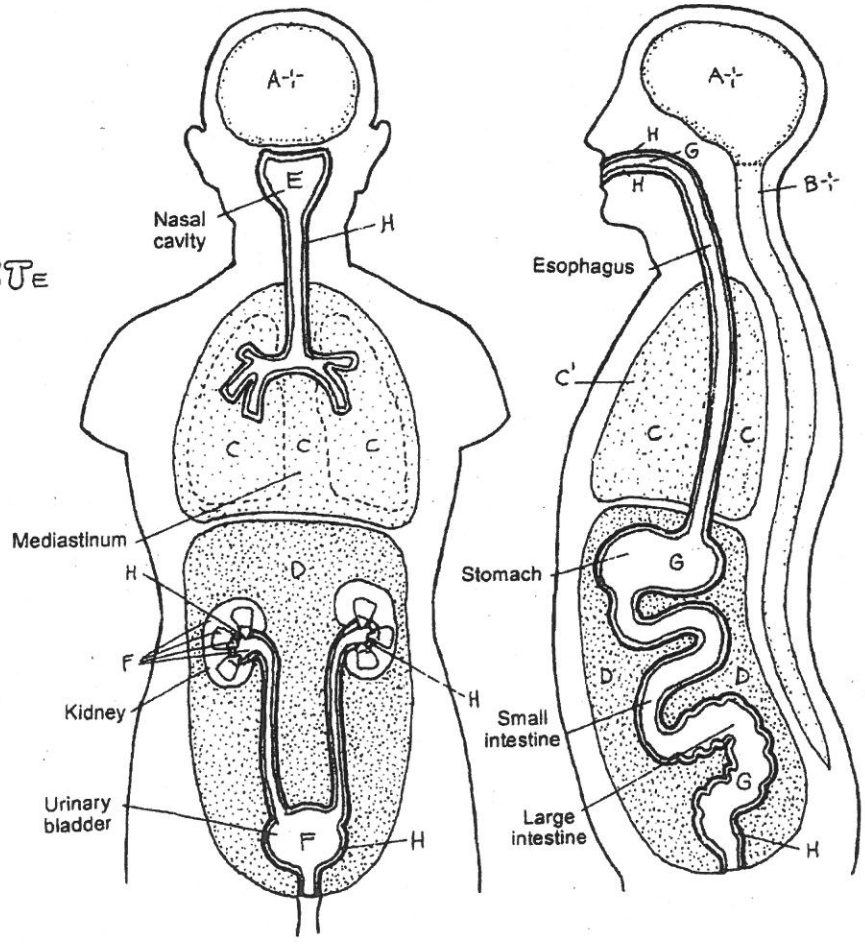
CLOSED BODY CAVITIES

CRANIAL A
DURA MATER A'
VERTEBRAL B
DURA MATER B'
THORACIC C
PLEURA C'
ABDOMINOPELVIC D
PERITONEUM D'



OPEN VISCERAL CAVITIES

RESPIRATORY TRACT E
URINARY TRACT F
DIGESTIVE TRACT G
MUCOSA H



The excitable **nervous system** consists of neurons (cell bodies and processes) arranged into a highly integrated central part (**central nervous system** or **CNS** and a more diffuse **peripheral nervous system** or **PNS**). The CNS consists of the *brain* in the head and the *spinal cord* in the vertebral column of the torso. The PNS is a vast collection of bundled neuronal processes (*nerves*) located throughout the body, as well as islands of neuronal cell bodies (ganglia). These neurons are supported by nonconducting *neuroglia* and a rich blood supply. Neurons of the CNS are interconnected to form centers (nuclei; gray matter) and long and short axon bundles (tracts; white matter). The brain and spinal cord are packaged in fibrous membranes called meninges (not shown).

The **brain** is the center of sensory awareness and movement (except for spinal reflexes), emotions, rational thought and behavior, foresight and planning, memory, speech, language, and the interpretation of language.

The **spinal cord**, an extension of the brain, begins at the foramen magnum of the skull, traffics in ascending/descending impulses, and is a center for spinal reflexes. It provides motor commands for muscles and is a receiver of sensory input below the head.

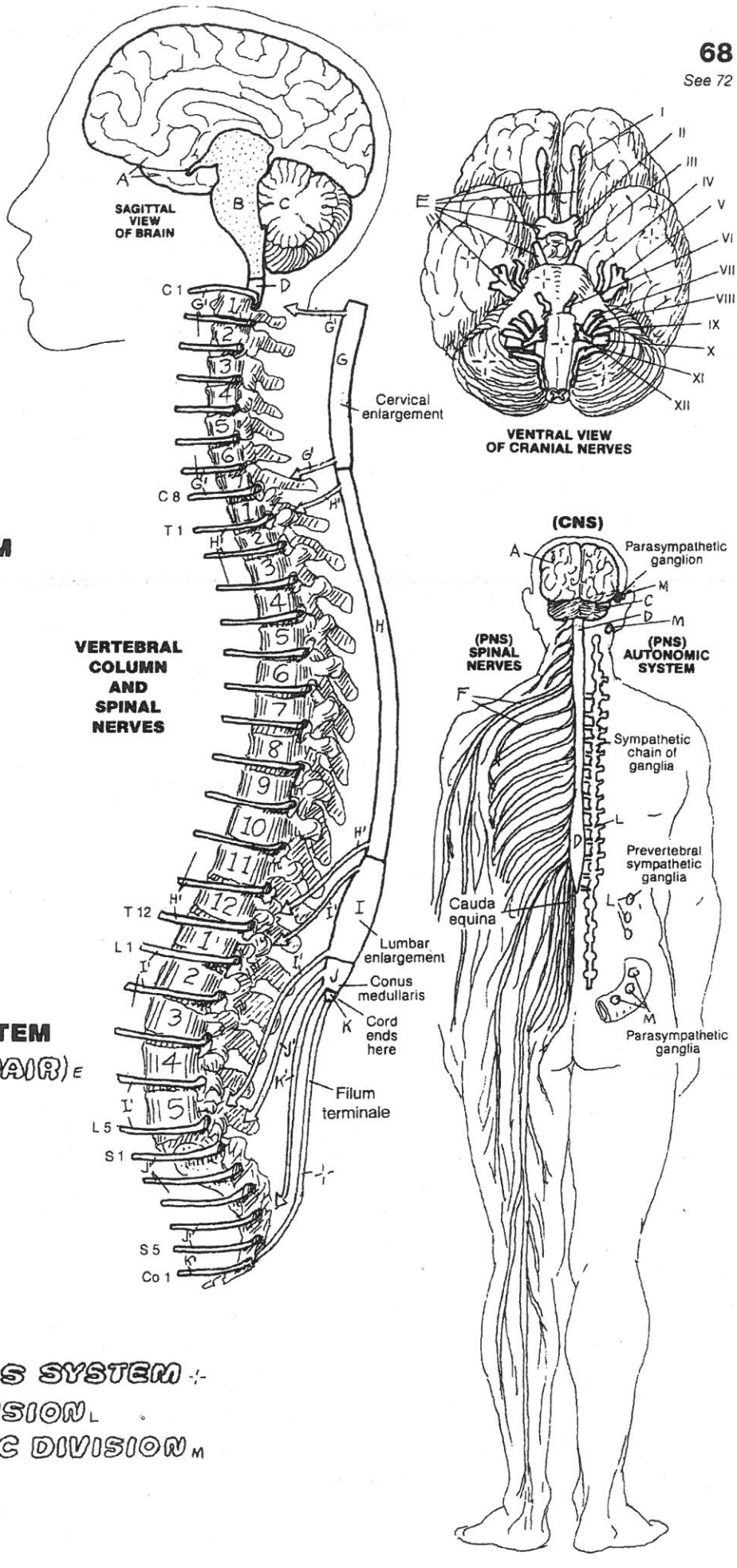
The PNS consists largely of bundles of sensory and motor axons (nerves) radiating from the brain (**cranial nerves**) and spinal cord (**spinal nerves**) segmentally and bilaterally and reaching to all parts of the body, somatic and visceral, through a highly organized pattern of distribution. **Branches** of spinal nerves are often called *peripheral nerves*. Nerves conduct all sensations/sensory input from the body to the brain and spinal cord. Nerves conduct motor commands to all the smooth and skeletal muscles of the body.

The **ANS** or **autonomic (visceral) nervous system** is a subset of ganglia and nerves in the PNS dedicated to muscular activity and glandular secretion in organs with cavities (viscera). That is, the ANS is a motor system only; visceral sensations are conducted to the spinal cord and brain by peripheral nerves in the same manner as somatic structures. There are two divisions of the ANS: (1) the **sympathetic (thoracolumbar) division,** responsible for driving fight or flight activities in which the extremes of function are called upon for the sake of safety and survival; and (2) the **parasympathetic (craniosacral) division**, responsible for maintaining vegetative functions of the respiratory tract, ingestion and digestion of food, and disposal of wastes.

NERVOUS SYSTEM ORGANIZATION

See 72

CN: Use light colors wherever there is a risk of obscuring detail with dark colors. (1) Color the names and structures of the CNS in the illustration at left. Do not color the vertebral column. Do color the diagram of the spinal cord regions and the spinal nerves. (2) Color the cranial nerves in the ventral view of the brain at upper right. (3) Color the names and structures of the spinal nerves and the autonomic nervous system structures at lower right.



CENTRAL NERVOUS SYSTEM

BRAIN -/-
- CEREBRUM A
- BRAINSTEM B
- CEREBELLUM C

SPINAL CORD D
- CERVICAL G
- THORACIC H
- LUMBAR I
- SACRAL J
- COCCYGEAL K

PERIPHERAL NERVOUS SYSTEM

CRANIAL NERVES (12 PAIR) E

SPINAL NERVES & BRANCHES F
- CERVICAL (8) G'
- THORACIC (12) H'
- LUMBAR (5) I'
- SACRAL (5) J'
- COCCYGEAL (1) K'

AUTONOMIC NERVOUS SYSTEM -/-
- SYMPATHETIC DIVISION L
- PARASYMPATHETIC DIVISION M

The 12 pairs of **cranial nerves** are referred to in Roman numerals (I through XII), I being the most rostral, XII being the most caudal. Cranial nerves I and II are derived from the forebrain. Cranial nerve XI was once held to be a cranial nerve but definitive research finds that it is actually a spinal nerve. Cranial nerve II is a derivative of the diencephalon; as such, the optic nerve is an externalized projection of the tract of the brain. Cranial nerves are functionally classified on an embryologic basis. For an explanation of definitions and classifications, see glossary (Cranial Nerve Functional Classification).

All motor nerves cited include proprioceptive fibers (sensory for muscle, tendon, and joint movement).

I **SVA:** special visceral afferent fibers; smell-sensitive (**olfactory**) receptors in roof/walls of nasal cavity.

II **SSA:** special somatic afferent fibers; light-sensitive (visual) receptors in the retina of the eye.

III **GSE:** general somatic efferent fibers; to extrinsic eye muscles (except lateral rectus and superior oblique); **GVE:** general visceral efferent fibers; parasympathetic to ciliary and pupillary sphincter muscles via ciliary ganglion in the orbit.

IV **GSE:** general somatic efferent; to superior oblique muscle of the eye.

V **GSA:** general somatic afferent; from face via three divisions (V_1, V_2, V_3) indicated; **SVE:** special visceral efferent; via V_3 to muscles of mastication, tensor tympani, tensor veli palatini, mylohyoid, and digastric muscles (developed from embryonic gill arches).

VI **GSE:** to lateral rectus muscle of the eye.

VII **SVA:** from taste receptors anterior tongue; **GSA:** from external ear; **SVE:** to muscles of facial expression, stapedius (middle ear), stylohyoid, posterior digastric muscles; **GVE:** to parasympathetic glands of nasal/oral cavity, lacrimal gland (via pterygopalatine ganglion in fossa of same name), submandibular/sublingual salivary glands (via submandibular ganglion in region of same name).

VIII **SSA:** cochlear part is sound sensitive: vestibular part is sensitive to head balance and movement (equilibrium).

IX **GSA:** from external ear and auditory canal; **SVA:** from taste receptors posterior one-third of tongue; from mucous membranes of posterior mouth, pharynx, auditory tube, and middle ear; **GVA:** from pressure and chemical receptors in carotid body and common carotid artery; **SVE:** to superior constrictors of the pharynx and stylopharyngeus; **GVE:** parasympathetic fibers to parotid gland (via otic ganglion in infratemporal fossa).

X **SVA:** from taste receptors at base of tongue and epiglottis; **GSA:** from external ear and auditory canal; **GVA:** from pharynx, larynx, and thoracic and abdominal viscera; **SVE:** to muscles of palate, pharynx, and larynx; **GVE:** parasympathetic to muscles of thoracic and abdominal viscera (via intramural ganglia).

XI **GSE:** spinal root (C1–C5) ascends through foramen magnum and departs through the jugular foramen; to trapezius and sternocleidomastoid muscles; classification pending.

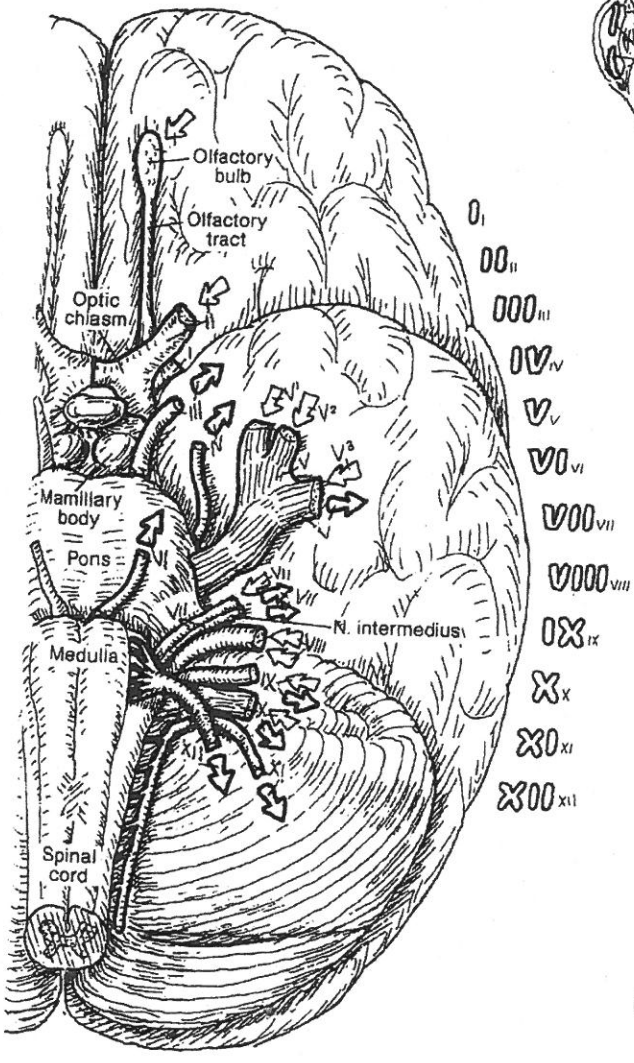
XII **GSE:** to extrinsic and intrinsic muscles of tongue.

CRANIAL NERVES

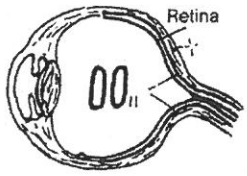
CN: Use light colors. (1) Beginning with the first cranial nerve, color the name at upper left; the large Roman numeral, the cranial nerve seen on the ventral brain stem, and the related function arrow at lower left; and the Roman numeral and accompanying illustration at upper right. Repeat with each nerve. (2) Note the direction of the function arrows at lower left; sensory is incoming; motor is outgoing.

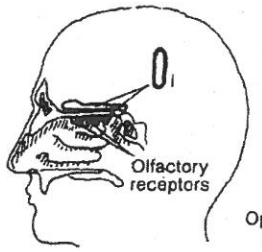
CRANIAL NERVES

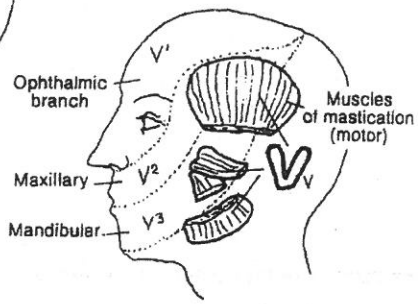
OLFACTORY (I) I
OPTIC (II) II
OCULOMOTOR (III) III
TROCHLEAR (IV) IV
TRIGEMINAL (V) V
ABDUCENS (VI) VI
FACIAL (VII) VII
VESTIBULOCOCHLEAR (VIII) VIII
GLOSSOPHARYNGEAL (IX) IX
VAGUS (X) X
ACCESSORY (XI) XI
HYPOGLOSSAL (XII) XII

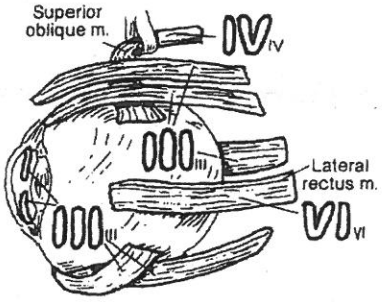


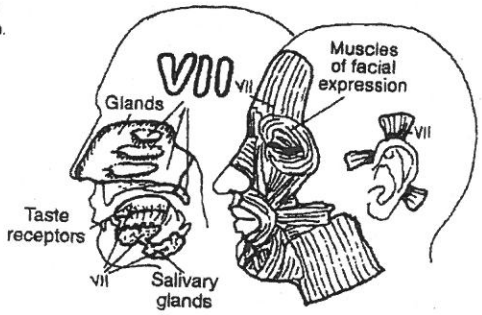
ANTERIOR-INFERIOR SURFACE
(Left brain, brain stem, and cerebellum)

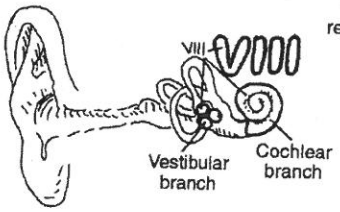


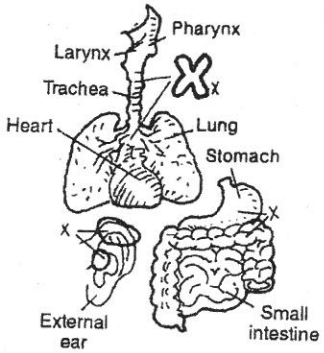


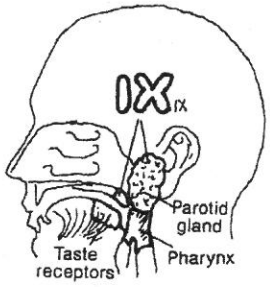


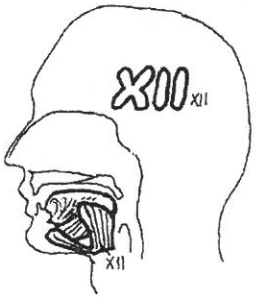


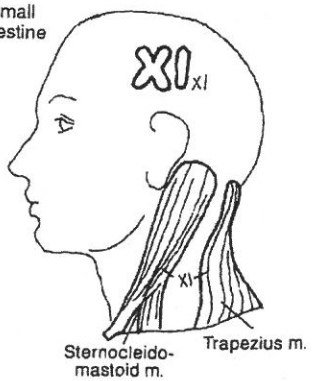












A *reflex* is an involuntary muscle response to a stimulus. A *stimulus* is an event that induces a sensory neuron to respond. Having the pointy end of a reflex hammer applied painlessly to the patellar ligament of the knee will do the trick. With no thought on your part, the muscle that extends the knee joint will mildly and reflexively contract, causing your knee joint to "jerk" (extend). It's a fundamental activity of the nervous system. Most body movements, including those of viscera, are reflexive (e.g., heart rate, respiratory rate, peristaltic contraction of gastrointestinal muscles, etc.). This useful feature allows you to run on "automatic" while concentrating on more sophisticated thoughts. **Spinal reflexes** involve sensory receptors, sensory neurons, usually interneurons of the spinal cord, motor neurons, and effectors (muscles).

A *stretch* (**monosynaptic** or *myotatic* **reflex**), the simplest spinal reflex, involves two neurons and one synapse. The knee jerk is such a reflex. It is activated by stretching the tendon (as in striking it gently with a reflex mallet) of a specific muscle, such as the tendon of the quadriceps femoris at the knee. The *receptors* responsive to such a stretch are (1) the *neurotendinous organs* in the patellar ligament and (2) the muscle spindles in the belly of the quadriceps muscle. Neurotendinous organs are tendons with receptors specifically sensitive to distortion or stretch. **Muscle spindles** are encapsulated, specialized muscle fibers within muscle bellies that have nerve endings sensitive to muscle stretch. Referring to the uppermost drawing, electrochemical ("nerve") impulses generated in these receptors by a stimulus are (1) conducted by **sensory neurons** (2) to the **spinal cord** (3), these neurons synapse in the gray matter of the cord with the anterior horn **motor neurons** (4). The motor neuron conducts the electrochemical impulses to the **end plates** of the **effector muscle** (the muscle that responds to the stimulus with an effect, specifically shortening) (5). The muscle contracts sufficiently, in the case of the knee reflex, to extend ("jerk") the knee joint momentarily (6).

Polysynaptic reflexes have more than two neurons in the circuit. They range from simple withdrawal reflexes (shown below) to complex reflexes involving several segments of the spinal cord and brain. The complexity of a polysynaptic reflex relates to the number of interneurons in the reflex and the number of synaptic contacts between stimulus and response. In this case, temperature receptors (not shown) and **pain receptors** respond to the sharp increase in heat; **sensory neurons** conduct the impulses to the spinal cord. An **interneuron** receives the impulse. Branches of the interneuron excite two interneurons, one **facilitatory** and one **inhibitory**. The excitatory interneuron facilitates (+) the firing of the motor neuron that induces the extensor muscle to contract, lifting the fingers from the flame. Simultaneously, the inhibitory neuron depresses (–) the firing of the second motor neuron (C3) and the antagonist flexor muscle is stretched without contracting, permitting the fingers to be withdrawn from the flame.

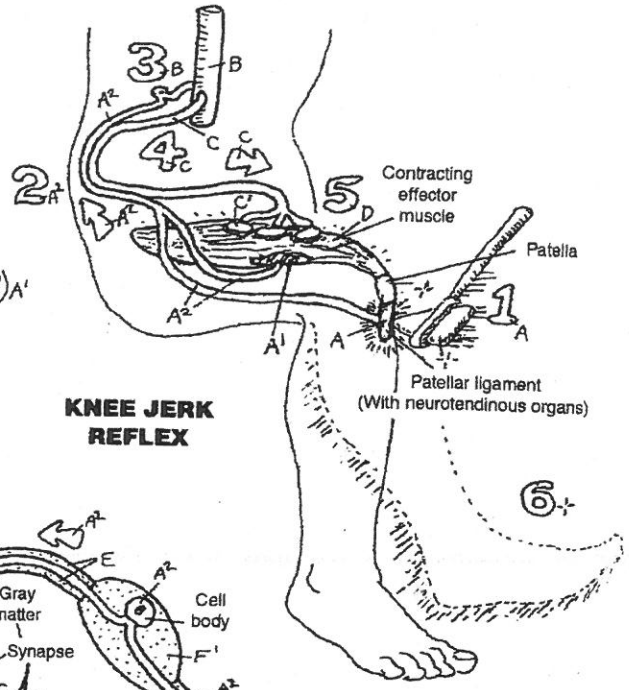
SPINAL REFLEXES

See 69, 70

CN: Use light colors for D, and use the same colors for the spinal nerve roots as you did on the preceding page. (1) Color the upper two illustrations simultaneously, in numerical sequence 1–5, including the arrows. The small arrows at the end of the muscle segments indicate contraction (pointing toward each other) or stretch (pointing away from one another). (2) Color the lower two illustrations similarly. Note that the motor neuron synapsing with the inhibitory interneuron, and the inhibited effector, are not colored.

MONOSYNAPTIC REFLEX

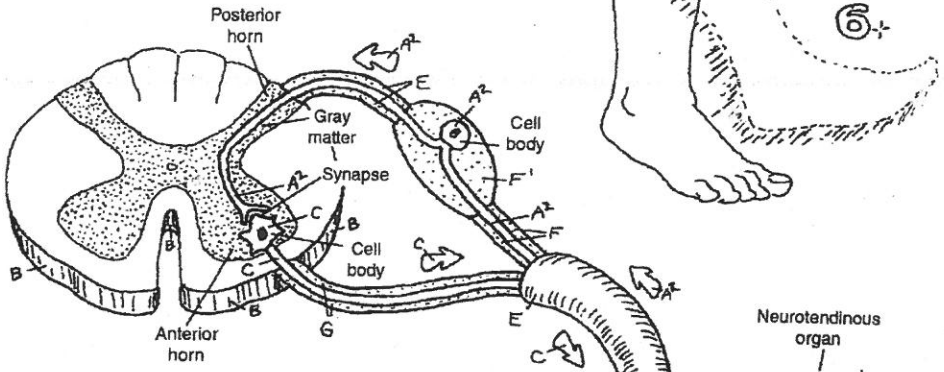
STRETCH RECEPTOR (N-T ORGAN) A
STRETCH RECEPTOR (MUSCLE SPINDLE) A'
SENSORY NEURON A^2
SPINAL CORD B
MOTOR NEURON C
END PLATE C'
EFFECTOR MUSCLE D



KNEE JERK REFLEX

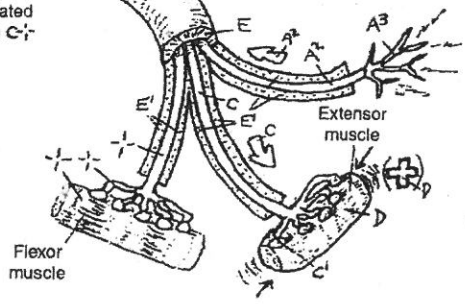
SPINAL NERVE / ROOTS

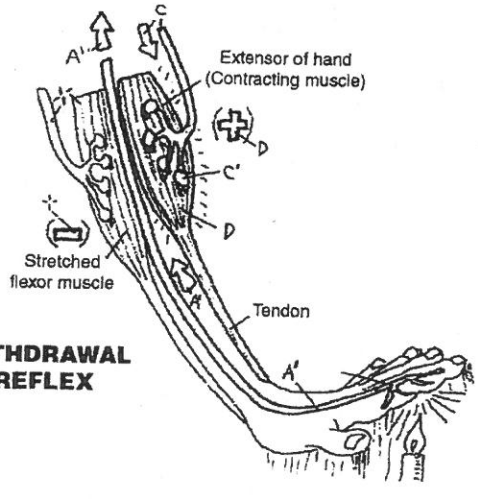
SPINAL NERVE E
BRANCH E'
POSTERIOR ROOT F
GANGLION F'
ANTERIOR ROOT G



POLYSYNAPTIC REFLEX

PAIN RECEPTOR A^3
SENSORY NEURON A^2
INTERNEURON H –
FACILITATORY (+) H'
INHIBITORY (–) H^2
(+) D MOTOR NEURON C / EFFECTOR D
(–) MOTOR NEURON C / EFFECTOR D





WITHDRAWAL REFLEX

Blood consists of **plasma**, the liquid phase; and the **formed elements** (cells and platelets). Allowed to remain in a test tube following centrifugation, blood will separate into plasma (55% of the volume) and the formed elements (45% of the volume). Decant off the plasma, and the erythrocytes will occupy 99% of the volume, and the 1% leukocyte and platelet fraction ("buffy coat") rises to the top. The erythrocyte fraction is called the *hematocrit* in the clinical laboratory; generally, males have a slightly higher hematocrit (45–49% than females (37–47%). A significantly low hematocrit can be an indication of several disorders, including anemia and hemorrhage.

Erythrocytes (*erythro-*, red; *-cyte*, cell; red blood cells, RBCs) number approximately 4.5–6.2 million in each cubic millimeter (mm^3) of blood in men and 4–5.5 million in each cubic mm^3 in women. They are formed in the bone marrow as true cells (i.e., they are nucleated). As they approach maturity, each erythrocyte *loses its nucleus and most of its organelles* prior to entering the peripheral blood. Recently released immature erythrocytes may retain some ribosomes, giving a slightly reticulated appearance when stained (*reticulocytes*). The circulating erythrocyte is a nonrigid, biconcave-shaped, membrane-lined sac of hemoglobin. Hemoglobin is a protein that contains iron to which oxygen binds and which gives a red color to the erythrocytes. Hemoglobin is the principal carrier of oxygen in the body, plasma being the second. Erythrocytes pick up oxygen in the lungs and release it in the capillaries to be taken up by nearby tissues/cells. After 120 days, aged erythrocytes are removed from the circulation in the spleen.

Thrombocytes (platelets) (150,000–400,000/mL of blood; 2–5 µm in diameter) are small bits of cytoplasm from giant cells (*megakaryocytes*) of the bone marrow. They play a significant role in limiting hemorrhage: aggregation of platelets releases thromboplastin, which enhances formation of clots (*coagulation*). When blood is allowed to clot, the cells disintegrate (*hemolysis*), forming a thick yellow fluid called *serum* (not shown). Serum is plasma minus the clotting elements.

Leukocytes are white blood cells that primarily have a protective function. They may be **granular** (granulocytes include neutrophils, eosinophils, and basophils) or **nongranular** (lymphocytes, monocytes).

Segmented **neutrophils** arise in the bone marrow and live short lives in the blood and connective tissues (hours–4 days). Immature forms ("bands") may be seen in the blood during acute infections. Neutrophils destroy microorganisms and take up cellular debris.

Eosinophils exhibit colorful granules when properly stained. Eosinophils are phagocytic in immune reactions with allergens, and particularly against parasites.

Basophils contain dark-staining granules. Basophils are mediators of allergic reactions and parasitic infections.

Lymphocytes (20–45% of WBCs), which arise from bone marrow, roam lymphoid tissues as well as blood. Lymphocytes are associated with immunity. See page 120.

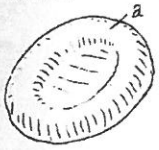
Monocytes (2–8% of WBCs) arise in the bone marrow, mature in the blood, and then leave the circulation to enter the extracellular spaces as **macrophages**.

CARDIOVASCULAR SYSTEM
BLOOD & BLOOD CELLS*

CN 12

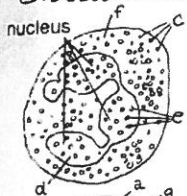
1. Each of the blood cells shown consists of cytoplasm, nucleus, and granules. Properly stained, they demonstrate several colors. To gain the full effect, each part of the cell (lettered but not named) should be colored as follows: a–pale orange; b–pale blue, c–red; d–reddish purple; e–dark purple; f–light purple; g–golden brown; h–straw (light tan). These colors are consistent with the stains usually employed to observe these microscopic cells.
2. Notice that the granules become larger as you go from neutrophil to basophil. Do not be concerned with covering each granule with the appropriate color.
3. The names of the various leukocytes should be left uncolored.
4. In the right half of the test tube diagram, notice that the areas representing the water portion of the plasma and the leukocytes & platelets portion of blood cell fraction should be left uncolored.

ERYTHROCYTES (RED BLOOD CELLS)a



Erythrocytes are formed in the bone marrow, lose their nucleus, and enter the blood circulation for about 120 days after which they are usually trapped in the spleen and broken down. The circulating RBC is a membrane-lined sac of hemoglobin, which has a powerful affinity for oxygen. Erythrocytes pick up the oxygen in the lungs and release it in the capillaries to the tissues/cells. Erythrocytes are the principal carriers of oxygen in the body, however, they do not normally leave the circulatory system except when they are broken down by the spleen. There are about 5 million RBC's per milliliter of blood (fewer in women).

LEUKOCYTES (WHITE BLOOD CELLS)
GRANULAR LEUKOCYTES*



NEUTROPHILS

Neutrophils make up about 65% of the total leukocyte population. Arising in the bone marrow, they contain strong enzymes in their granules. They take up bacteria at sites of infection and kill them. Masses of bacteria-stuffed neutrophils are known as pus.

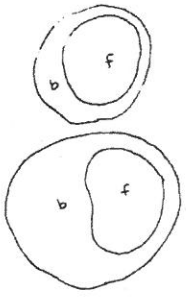
EOSINOPHILS

Eosinophils make up about 3% of the total leukocyte population, and their granules are quite colorful when properly stained. Their precise function is unknown, but their concentration rises during allergic reactions.

BASOPHILS

Basophils make up less than 1% of the white blood cell population, and their dark staining granules are quite characteristic. Their function is not known.

NONGRANULAR LEUKOCYTES*



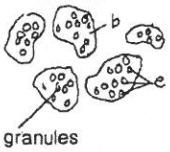
LYMPHOCYTES

Lymphocytes, making up about 30% of the leukocyte numbers, arise from lymph tissues (lymph nodes, thymus, spleen) and bone marrow. Lymphocytes secrete antibodies and assist in rejection of foreign tissue transplants. They are an essential part of the body defense system.

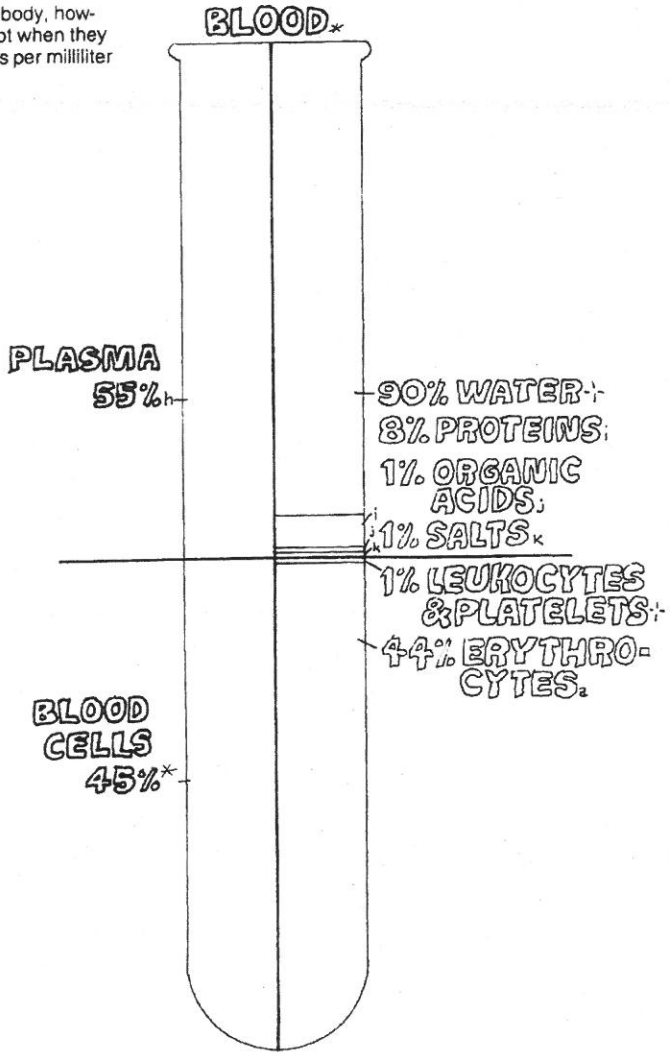
MONOCYTES

Monocytes are the largest of the leukocytes. They can readily enter and leave the circulatory system, and are capable of ingesting bacteria voraciously. These, with the neutrophils and lymphocytes, play an important part in the body defense (immune) system.

PLATELETS*



Platelets, small bits of cytoplasm from giant cells of the bone marrow, are found in the circulatory system at about 250,000 per milliliter of blood. The granules of the platelets are responsible for the clotting mechanism seen at injured blood vessels.



If whole blood is centrifuged in a test tube as shown, the *red cell volume* will settle to the bottom, the *leukocyte fraction* will form a buffy coat on top of that, and the *plasma* will form on top making up 55% of the total volume. The protein content of the plasma (plasma proteins) plays a critical role in the clotting mechanism. Fluid of the blood remaining after clotting is called serum.

Blood circulation begins with the heart, which pumps blood into arteries and receives blood from veins. Regardless of the amount of oxygen (oxygenation) in that blood, arteries conduct blood away from the heart and veins conduct blood toward the heart. *Capillaries* are networks of extremely thin-walled vessels throughout the body tissues that permit the exchange of gases and nutrients between the vessel interior (vascular space) and the area external to the vessel (extracellular space). Capillaries receive blood from small arteries and conduct blood to small veins.

There are two circuits of blood flow: (1) the **pulmonary circulation** that conveys oxygen-depleted blood from the right side of the heart to the lungs for oxygenation/release of carbon dioxide and takes fresh blood back to the left side of the heart; and (2) the **systemic circulation**, which carries **oxygen-rich blood** from the left side of the heart to the body tissues and returns **oxygen-poor blood** to the right side of the heart. The color red is generally used for depicting oxygenated blood, and blue for oxygen-poor blood.

Capillary blood is mixed; it is largely oxygenated on the arterial side of the capillary bed, and is more deoxygenated on the venous side. This is a consequence of delivering oxygen to and picking up carbon dioxide from the tissues it supplies.

One *capillary network* generally exists between an artery and a vein. There are exceptions: the portal circulation of the liver involves two sets of capillaries between artery and vein (on this page, see the portal vein and the additional capillary network between the capillaries of the gastrointestinal tract and the heart); for more detail, see page 118. Other portal systems exist between the hypothalamus and the pituitary gland (the hypophyseal portal system; page 150); and within the kidney, between the glomerulus and the peritubular capillary plexus (page 148).

SCHEME OF BLOOD CIRCULATION

CN: (1) Color the upper central terms A-C first; use blue for A, purple for B, and red for C. Use colors for D and E that do not distract from A, B, and C. (1) Color the terms "Systemic Circulation," D, and "Pulmonary Circulation," E, the two figures, and the two capillaries, B, purple. (2) Color the brackets (D, E) of the circulatory scheme. Begin in the right atrium of the heart (BEGIN HERE) and color the flow of oxygen-poor blood, A, into the lungs. The blood is oxygenated in the lungs, B to C. (3) The oxygenated blood, C, returns to the left side of the heart, and is pumped out into the systemic circulation to capillary networks throughout the body. Deoxygenated blood, A, is returned to the heart, to repeat the cycle.

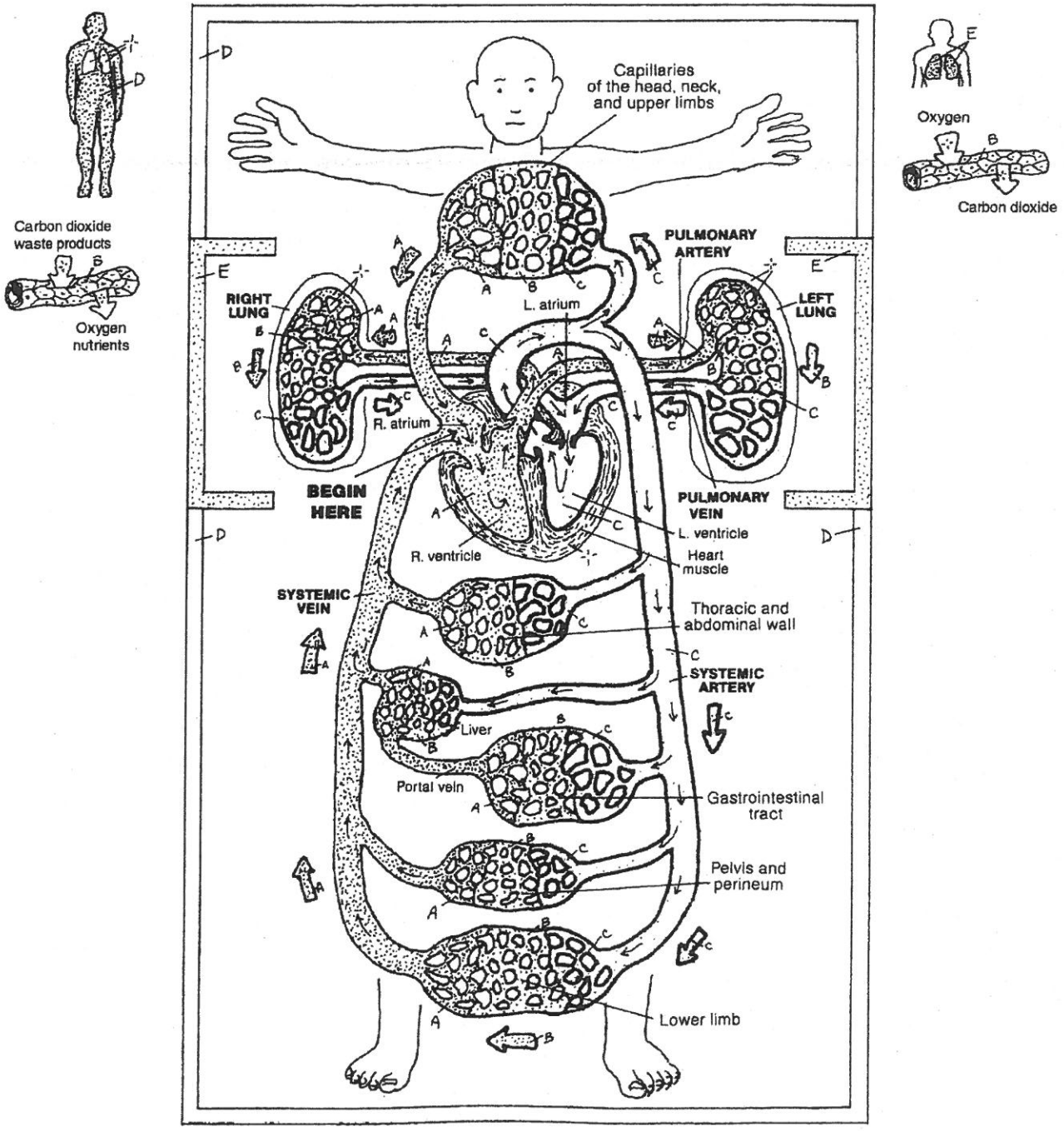
OXYGEN-POOR BLOOD$_A$

CAPILLARY BLOOD$_B$

OXYGEN-RICH BLOOD$_C$

SYSTEMIC CIRCULATION$_D$

PULMONARY CIRCULATION$_E$



The *vascular system* is the name for the collection of **blood vessels** and lymph vessels of the body. Arteries take blood away from the heart (pump) and deliver it to capillary networks for distribution to cells and tissues. Veins bring the blood back to the heart from the capillary networks. See page 120 for the lymph vascular section.

Arteries are characterized by smooth muscle and one or two elastic laminae in their walls. The layers of an arterial wall are generally distinctive except in the largest (endothelial-lined elastic tubes) and smallest (precapillaries). Small arteries (**arterioles**; resistance vessels) can cut off blood to a maze of capillaries when required. **Medium arteries** tend to be vessels of distribution, diverting flow as needed. **Large arteries** are the equivalent of elastic aqueducts, moving large volumes of blood out of the heart or aorta to distant parts (head, lower limbs, etc.). All arteries have a fibrous outer layer (**tunica externa** or adventitia). Within this tunic, much smaller nutrient blood vessels (*vasa vasorum*) and motor/sensor nerves (*nervi vasorum*) are found.

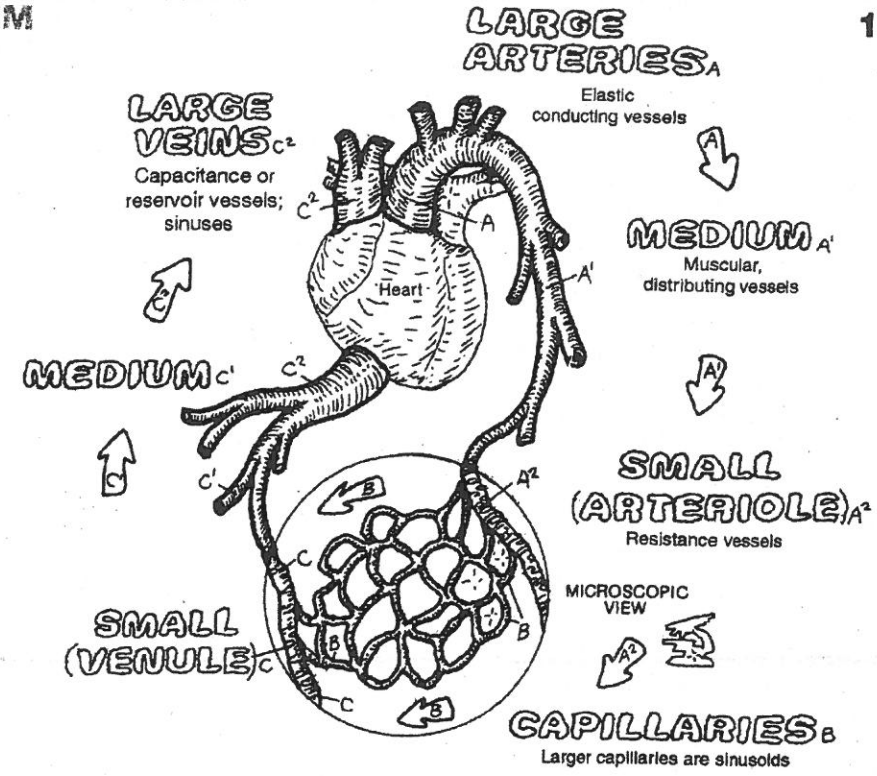
Arteries have the ability to respond to changing circumstances by vasodilating to increase flow and decrease blood pressure, by vasoconstricting to decrease flow and increase blood pressure, by diverting/redirecting blood flow, and literally shutting circulation down in a particular locale (e.g., capillary blanching when in shock, or suspension of bleeding in a traumatically amputated limb).

Veins generally lack significant layers of smooth muscle and elastic tissue in their walls. They function largely as conduits with considerable increased capacity when subjected to pressure loads. Large veins are especially capacious (see dural sinuses, page 115). **Venules** (small veins) are formed by the merging of capillaries and are of basically the same construction. Veins get progressively larger as they approach the heart. Veins, like rivers, have tributaries, not branches (except in portal circulations). Most medium veins of the neck and extremities have a series of small pockets, called *valves*, formed from the endothelial layer. These valves are paired and point in the direction of blood flow. They are particularly numerous in the lower limbs. Though offering no resistance to blood flow, a reversed blood flow closes the valves (and the lumen) of the vein. Venous flow in the lower limbs is enhanced by the contraction of skeletal muscles, whose contractile bulges give an antigravity boost to the movement of blood.

Capillaries, the smallest of the lot, are thin-walled, potentially porous endothelial tubes with some fibrous support. Lacking muscle and elastic tissues, capillaries are concerned with the release of nutrients, gases, and fluids to surrounding tissue, and the taking-up of carbon dioxide and other "unnecessary" gases and microparticulate matter. Capillaries can generally accommodate the passage of cells between endothelial cells. Specialized capillaries of this nature are called *sinusoids* (see page 124).

CARDIOVASCULAR SYSTEM
BLOOD VESSELS

CN: Use red for A, purple for B, and blue for C (colors you used in the previous page) for the names and related types of blood vessels above. (1) Begin with the name "Large Arteries" in the upper illustration, and color all the vessels and names. (2) Color the names of the blood vessel types in the section titled "Vessel Structure," and their characteristic components. Use very light colors for D, F, and H. (3) Note that the vas and nervus vasorum in the fibrous tissue layer, H, of the lower arterial cross section are not to be colored. (4) In the two diagrams of the vein, C^1, at far right, note the closed venous valves in the lower vein, and the functioning valves in the upper vein. The blood between the two valves in the upper drawing is to be colored gray so as not to be confused with the vein structure.



VESSEL STRUCTURE

TUNICA INTERNA

ENDOTHELIUM D

INTERNAL ELASTIC LAMINA E

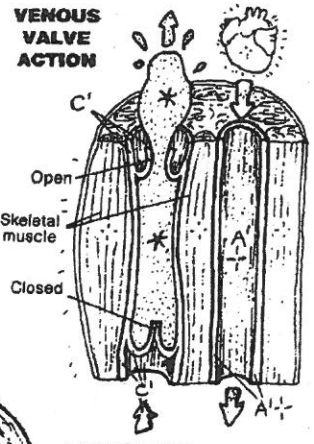
TUNICA MEDIA

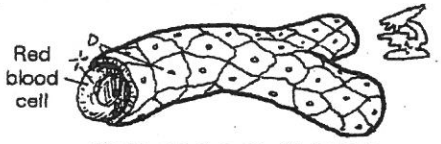
SMOOTH MUSCLE F

EXTERNAL ELASTIC LAMINA G

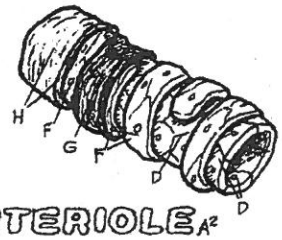
TUNICA EXTERNA

FIBROUS TISSUE H

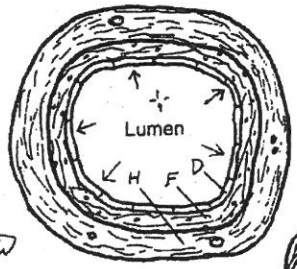




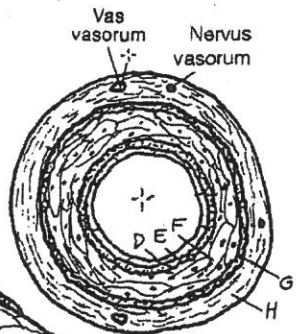
CAPILLARY B



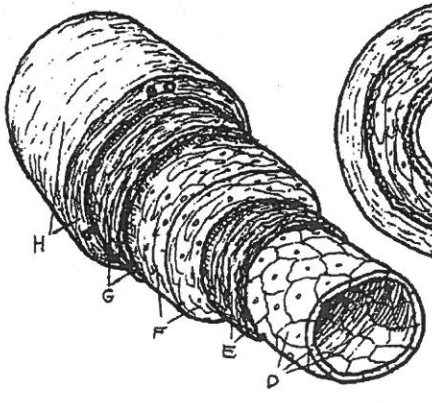
ARTERIOLE A²



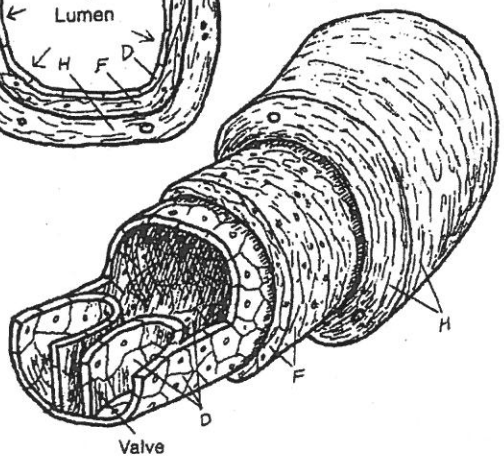
VEIN C'



CROSS-SECTIONAL VIEW



ARTERY A'



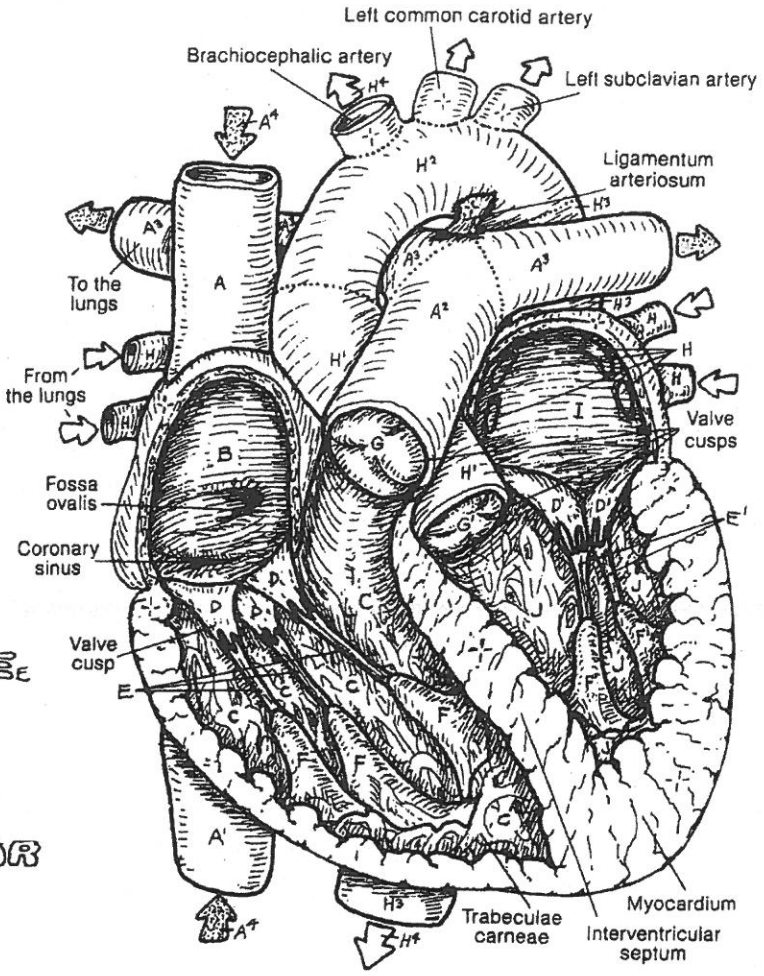
The heart is the muscular pump of the blood vascular system. It contains four cavities (chambers): two on the right side (pulmonary heart) and two on the left (systemic heart).

The pulmonary heart includes the **right atrium** and **right ventricle**. The thin-walled right atrium receives poorly oxygenated blood from the **superior** and **inferior vena cavae** and from the coronary sinus (draining the cardiac vessels). The thin-walled **left atrium** receives richly oxygenated blood from **pulmonary veins**. Atrial blood is pumped at a pressure of about 5 mm Hg into the **right** and **left ventricles** simultaneously through the atrioventricular orifices, guarded by the three-cusp **tricuspid valve** on the right and the two-cusp **bicuspid valve** on the left. The cusps are like panels of a parachute, secured to the **papillary muscles** in the ventricles by **chordae tendineae** (tendons). These muscles contract with the ventricular muscles, tensing the cords and resisting cusp over-flap as ventricular blood bulges into them during ventricular contraction (*systole*). The right ventricle pumps oxygen-deficient blood to the lungs via the **pulmonary trunk** at a pressure of about 25 mm Hg (right ventricle), and the left ventricle simultaneously pumps oxygen-rich blood into the **ascending aorta** at a pressure of about 120 mm Hg. This pressure difference is reflected in the thicker walls of the left ventricle compared to the right. The pocket-like **pulmonary** and **aortic semilunar valves** guard the trunk and aorta, respectively. As blood falls back toward the ventricle from the trunk/aorta during the resting phase of the heartbeat (*diastole*), these pockets fill, closing off their respective orifices and preventing reflux into the ventricles.

CHAMBERS OF THE HEART

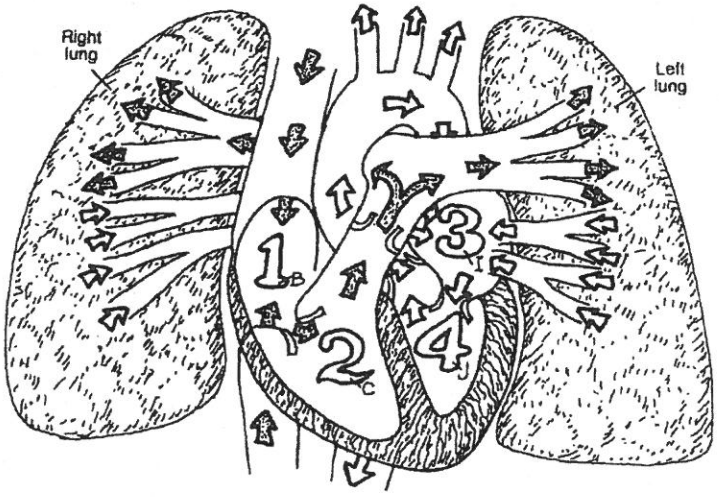
CN: Use blue for A–A^4; dotted arrows represent venous blood flow in both illustrations. Use red for H–H^4; clear arrows represent arterial blood flow in both illustrations. Use light colors for heart cavities B, C, I, and J. (1) Begin with arrows A^4 in the left side of upper drawing above and below the right atrium, B; color A and A^1 In the list of names. Color the structures in the order of the list, A–H^3. (2) Color the circulation chart below, beginning with the arrow A^4 leading into the right atrium (numeral 1). Color the numerals, and their related arrows, in order from 1 to 4. Do not color the chambers or the vessels in the drawing at lower right.

SUPERIOR VENA CAVA$_A$
INFERIOR VENA CAVA$_{A'}$
↓ A^4
RIGHT ATRIUM$_B$
↓
RIGHT VENTRICLE$_C$
A-V TRICUSPID VALVE$_D$
CHORDAE TENDINEAE$_E$
PAPILLARY MUSCLE$_F$
↓
PULMONARY TRUNK$_{A^2}$
PULMONARY SEMILUNAR VALVE$_G$
PULMONARY ARTERY$_{A^3}$
↓ H^4
PULMONARY VEIN$_H$
LEFT ATRIUM$_I$
↓
LEFT VENTRICLE$_J$
A-V BICUSPID (MITRAL) VALVE$_{D'}$
CHORDAE TENDINEAE$_{E'}$
PAPILLARY MUSCLE$_{F'}$
↓
ASCENDING AORTA$_{H'}$
AORTIC SEMILUNAR VALVE$_{G'}$
AORTIC ARCH$_{H^2}$
THORACIC AORTA$_{H^3}$



HEART CHAMBERS & GREAT VESSELS
(Anterior view)

OXYGENATED BLOOD → H^4
DEOXYGENATED BLOOD → A^4



CIRCULATION THROUGH THE HEART
(Diagrammatic)

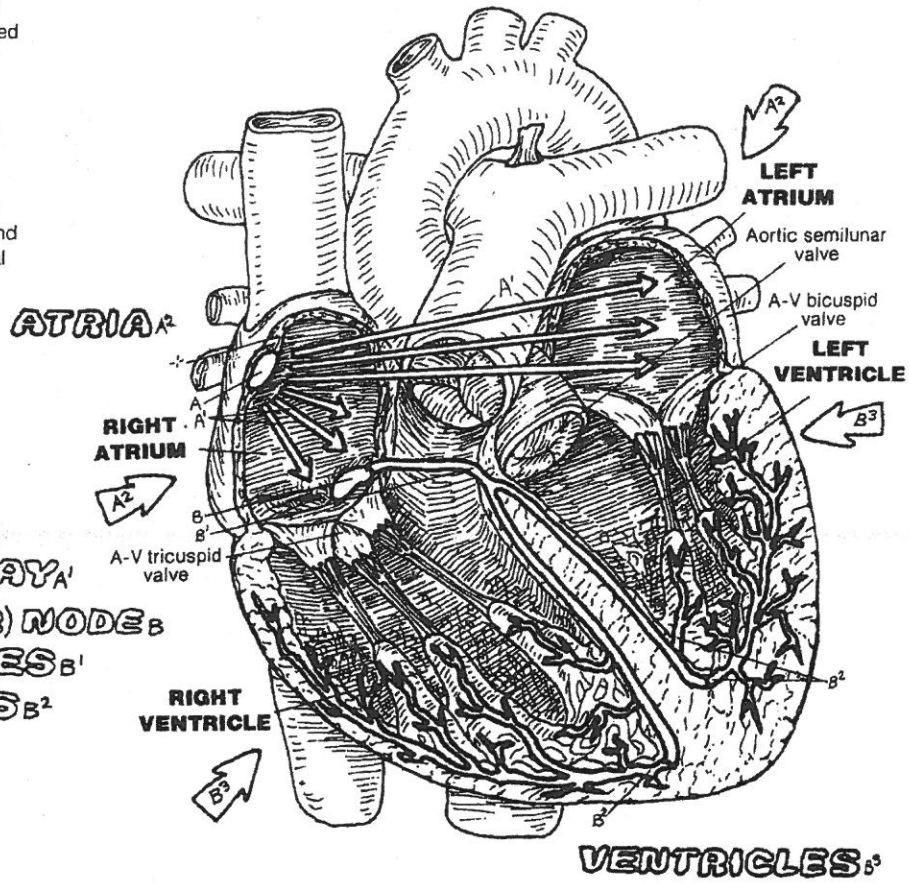
Cardiac muscle cells contract spontaneously. They do not require motor nerves to shorten. However, the intrinsic contraction rate of these cells is too slow and too unorganized for effective pumping of the heart. Happily, groups of more excitable but noncontractile cardiac cells take responsibility for initiating and conducting electrochemical impulses throughout the cardiac musculature. Such cells cause a coordinated, rhythmic sequence of cardiac muscle contractions that result in blood being moved through the cavities of the heart with appropriate volumes and pressures. These cells constitute the **cardiac conduction system**. Impulses generated at the **sinoatrial (SA) node** are distributed throughout the **atria** and to the **atrioventricular (AV) node** by way of nondiscrete **internodal pathways**. Impulses travel from the AV node, down the **AV bundle** and its **branches**, to the **Purkinje plexus** of cells embedded in the ventricular musculature.

The cardiac conduction system generates voltage changes around the heart. Some of these changes can be monitored, assessed, and measured by **electrocardiography (ECG; aka EKG)**. An ECG is essentially a voltmeter reading. It does not measure hemodynamic changes. Electrodes are placed on a number of body points on the skin. Recorded data (various waves of varying voltage over time) are displayed on an oscilloscope or a strip of moving paper. The shape and direction of wave deflections are dependent upon the spatial relationship of the electrodes (leads) on the body surface.

When the SA node fires, excitation/depolarization of the atrial musculature spreads out from the node. This is reflected in the ECG by an upward deflection of the resting (isoelectric) horizontal line (**P wave**). This deflection immediately precedes contraction of the atrial musculature and filling of the ventricles. The **P-Q interval** (**P-R interval** in the absence of a Q wave) reflects conduction of excitation from the atria to the Purkinje cell plexus in the ventricular myocardium. Prolongation of this interval beyond .20 seconds may reflect an AV conduction block. The **QRS complex** reflects depolarization of the ventricular myocardium. The term *complex* here refers to the combination of the three waves (Q, R, and S) immediately preceding ventricular contraction, wherein blood is forced into the pulmonary trunk and ascending aorta. The **S-T segment** reflects a continuing period of ventricular depolarization. Myocardial ischemia may induce a deflection of this normally horizontal segment. The **T wave** is an upward, prolonged deflection and reflects ventricular repolarization (recovery), during which the atria passively fill with blood from the vena cavae and pulmonary veins. The QT interval, corrected for heart rate (QTc), reflects ventricular depolarization and repolarization. Prolongation of this segment may suggest abnormal ventricular rhythms (arrhythmias). In a healthy heart at a low rate of beat, the P-Q, S-T, and **T-P segments** all are isoelectric (horizontal).

CARDIAC CONDUCTION SYSTEM & THE ECG

CN: Use blue for D and red for E. Use a very light color for B so that the patterns of dots identifying segments B–B^3 of the ECG remain visible after coloring. The QRS complex and the S-T segment (ECG diagram) are colored similarly; they both reflect ventricular depolarization. (1) Begin at upper right and color the four large arrows identifying the atria, A^2, and ventricles, B^3, as well as their names; do not color the atria and ventricles. Color the internodal and interatrial pathway arrows, A^1. (2) In the middle of the page, color the stages of blood flow through the heart and their related letters; they relate to voltage changes in the ECG below. (3) Color the ECG and related letters, starting at the left. (4) Color the horizontal bar below the time line.

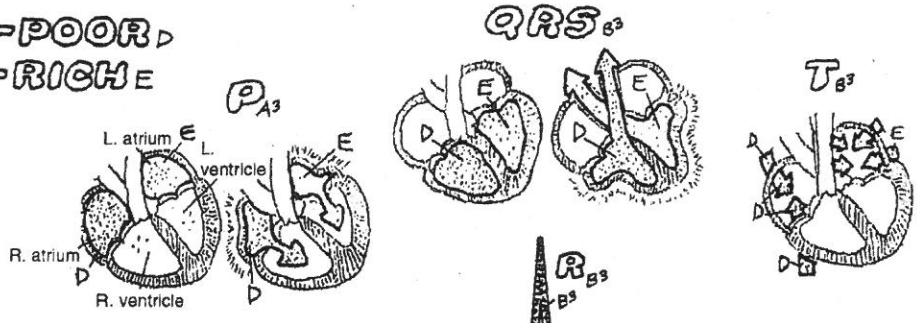


CONDUCTION SYSTEM

SA (SINOATRIAL) NODE A
INTERNODAL PATHWAY A'
AV (ATRIOVENTRICULAR) NODE B
AV BUNDLE/BRANCHES B'
PURKINJE PLEXUS B^2

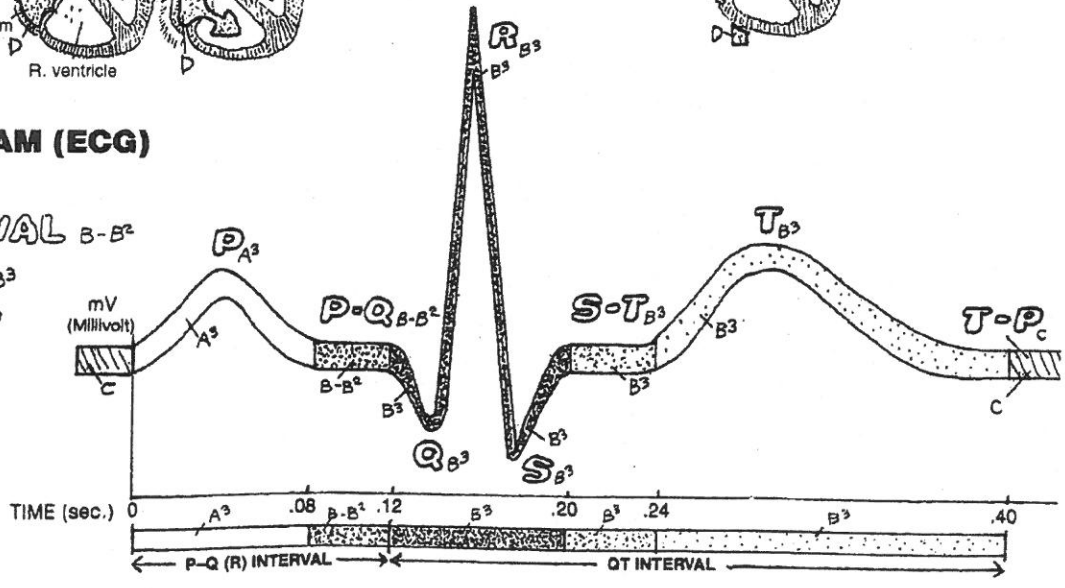
BLOOD FLOW

OXYGEN-POOR D
OXYGEN-RICH E



ELECTROCARDIOGRAM (ECG)

P WAVE A^3
P-Q (P-R) INTERVAL B-B^2
QRS COMPLEX B^3
S-T SEGMENT B^3
T WAVE B^3
T-P SEGMENT C



The lymphoid system is the anatomical component of the immune system. It responds to microorganisms entering the body and to cells/cell parts no longer recognizable as "self." The system provides two forms of immunity: the innate immune response and the adaptive immune response (see page 122). The first is immediately reactive to challenge; it is inborn and it is nonspecific. Its primary vehicle for expression is the inflammatory response (page 122). The second response takes a little longer, as it assesses the chemistry of the pathogen that stimulated the response (**antigen**), but it creates lifelong immunity against each specific challenger with the aid of memory cells. The lymphoid system consists of tissues and organs characterized by collections of uncommitted and committed lymphocytes, phagocytes, fibroblasts in a milieu of extracellular fluid, lymph, and vascular/lymphatic capillaries supported by a meshwork of reticular fibers and reticular cells.

The red **bone marrow** and **thymus** are the primary sources of lymphoid cells that populate lymphoid organs. The bone marrow contains the precursors of all lymphocytes and disburses them into the circulation. It consists largely of various blood cells in different stages of maturation, phagocytes, reticular cells and fibers, and fat cells. Some of the lymphocytes mature and undergo structural and biochemical revision (*differentiation*) in the bone marrow to become B lymphocytes. Large lymphocytes enter the circulation from the bone marrow and function as natural killer (NK) cells.

The thymus is located in the superior and anterior (inferior) mediastinum. It receives uncommitted (*naïve*) lymphocytes from the bone marrow. It is actively engaged in T lymphocyte proliferation and differentiation during embryonic and fetal life and during the first decade of extrauterine life. The thymus begins to undergo degeneration (involution) after puberty.

Secondary lymphoid organs are structures predominantly populated by lymphocytes that migrated from the **primary lymphoid organs**. They range from a diffuse disposition of lymphocytes throughout the loose connective tissues to encapsulated, complex structures (**spleen** and **lymph nodes**).

B lymphocytes (B = bone marrow-derived) differentiate along specific lines, one of which becomes plasma cells. **Plasma cells** secrete protein molecules (**antibodies**) into tissue fluids (humoral immunity). Antibodies interact with and destroy both antigens and free or attached cell parts that elicit activation of the B cells.

T lymphocytes (T = thymus-derived) differentiate into a number of cells, including **helper** (T_H), **cytotoxic** (T_C), and memory cells (not shown). Activated by antigen stimulation, T_H cells stimulate and regulate specific and nonspecific immune operations against cells without necessarily being assisted by B cells. They convey cell-mediated immunity. T_C cells kill cells targeted by other T cells or lymphokines. They do not recirculate through the blood vascular circulation.

Natural killer (NK) cells are essentially undifferentiated lymphocytes; they are part of the innate immune system. They are not activated (adapted) by other cells or lymphokines. NK cells primarily destroy tumor cells and virus-infected cells in association with T_C cells.

Phagocytes are tissue macrophages that destroy antigen and cell debris by phagocytosis. They function as antigen-presenting cells (APC) for T cells. In turn, T cells activate phagocytes.

IMMUNE (LYMPHOID) SYSTEM INTRODUCTION

CN: The thymus, T, shown here is one seen from birth to puberty. It produces the T_H and T_C cells; color these cells the same color as T. Use bright colors for D, E, F, G, Ag, and Ab; use light colors for the cells. M.A.L.T., E, are representations of a continuous array of cells throughout the mucosa of all viscera; for more detailed representations, see page 126. The subscripts of cells listed are abbreviations of the cell name. (1) Color over the entire cells; the identifying symbols in the nuclei of the cells are used universally; see text. (2) Color in the order of the list of names at left. Try to use the same light color for each cell type wherever it appears in pages 122–128. It will help in recall of their names.

PRIMARY ORGANS

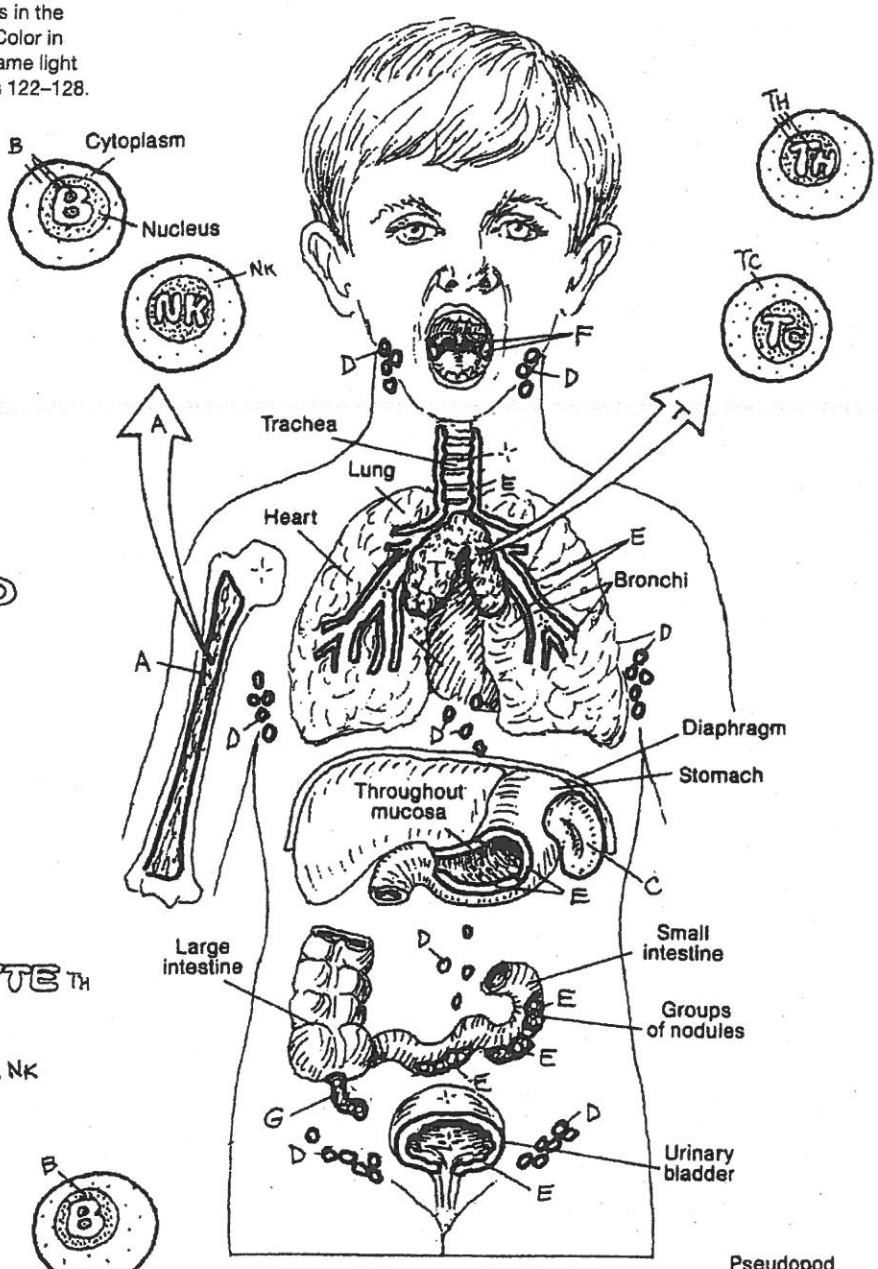
BONE MARROW A
THYMUS T

SECONDARY ORGANS

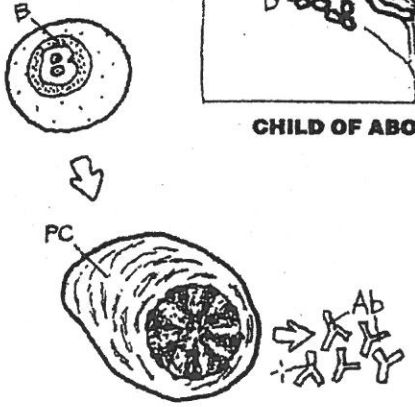
SPLEEN C
LYMPH NODE D
MUCOSAL ASSOCIATED LYMPHOID TISSUE (M.A.L.T.) E
TONSILS F
APPENDIX G

CELLS

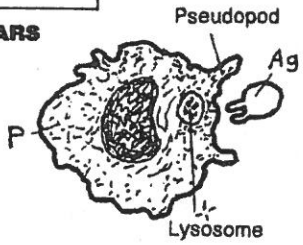
B LYMPHOCYTE B
PLASMA CELL PC
T (HELPER) LYMPHOCYTE TH
T (CYTOTOXIC) CELL TC
NATURAL KILLER CELL NK
PHAGOCYTE P



CHILD OF ABOUT 10 YEARS



ANTIBODY Ab



ANTIGEN Ag

The **lower respiratory tract** consists of the trachea, the **bronchial tree**, and respiratory units. The **trachea** consists of a length of incomplete cartilaginous rings in which each pair is connected by fibroelastic tissue. The ends of each incomplete ring are bound posteriorly by smooth muscle (*trachealis*). The trachea begins at the inferior border of the cricoid cartilage of the larynx at the C6 vertebral level. The trachea continues inferiorly to its *bifurcation*, where it divides into left and right **main (primary) bronchi** at the vertebral level of T4 (level of the aortic arch).

Each main bronchus enters the lung at the *hilum*. The right main bronchus is shorter, more vertical, and wider than the left. The *right* main bronchus generally gives off three **lobar (secondary) bronchi** to three **lobes: superior, middle**, and **inferior**. The *left* main bronchus divides into two lobar bronchi for the superior and inferior lobes. Each lobe is divided by fibrous septa into pyramid-shaped, surgically resectable, anatomical and functional units called **bronchopulmonary segments.** Each segment has one segmental (tertiary) bronchus, and each segment is supplied by a segmental artery and drained by segmental veins and lymphatic vessels.

There can be some variation in the number of lobes and segments of a lung. Here we show the right and left lung each composed of 10 segments. In this case, segments #4 and #5 of the right lung (R. L.) are not located in the same sites in the left lung (L. L.). In some cases, the **apical** and **posterior** segments are combined as one, and the **anterior basal** and **medial basal** segments are also combined, leaving 8 segments in the left lung (not shown).

Knowledge of the tridimensional arrangement of segments is of special significance to pulmonary surgeons and clinicians seeking a precise localization of a lesion in the lung.

Within each bronchopulmonary segment, a segmental bronchus branches into several **bronchioles**, each less than 1 mm in diameter, absent cartilage, and supported by smooth muscle. These bronchioles branch into smaller terminal bronchioles, characterized by ciliated cuboidal cells *without glands*. If gland (goblet) cells were to exist below the level of cilia, fluid would accumulate in the air cells—not a healthy situation. The terminal bronchioles represent the end of the air-conducting pathway.

Each terminal bronchiole divides into two or more **respiratory bronchioles**, characterized by occasional alveolar sacs on their walls. Each respiratory bronchiole supplies a **respiratory unit**, a discrete group of air cells (**alveoli**) arranged in **alveolar sacs** and fed by **alveolar ducts.** Extending from its source bronchiole, each respiratory bronchiole extending inferiorly has more and more alveolar sacs. The walls of the alveoli, composed of simple squamous epithelia and supported by thin interwoven layers of elastic and reticular fibers, are surrounded by capillaries that arise from **pulmonary arterioles** and become the tributaries of **pulmonary venules**. The walls of these capillaries merge with the structurally similar alveoli. Oxygen and carbon dioxide rapidly diffuse through these walls secondary to pressure gradients.

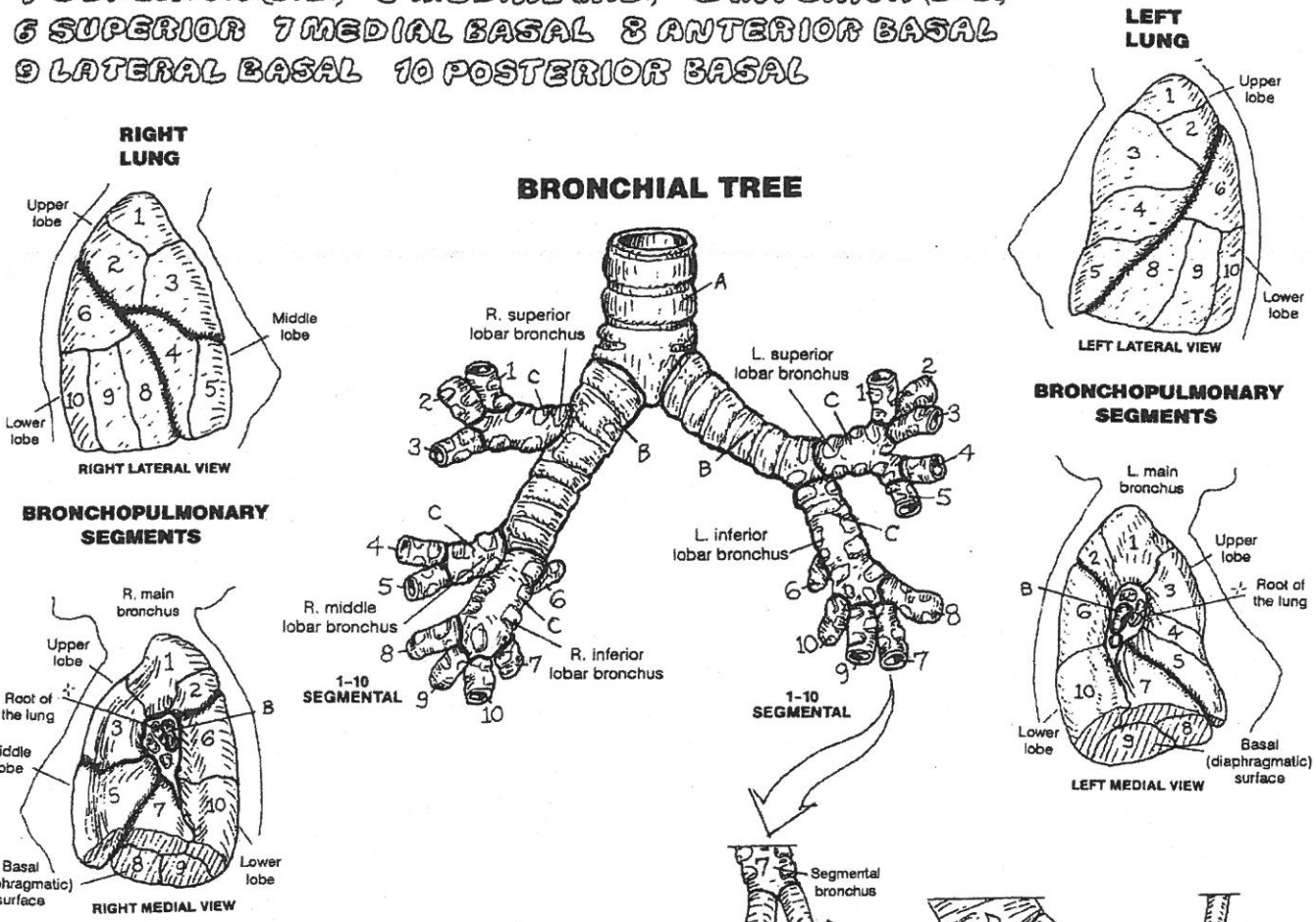
LOWER RESPIRATORY TRACT

See 127

CN: Save blue for H, purple for I, and red for J. (1) Use 10 different colors for the segments of both lungs, and key those colors to the 10 segmental bronchi of each lung. (2) Follow the arrows to the respiratory unit. Use one light color for the alveoli, G¹, and the alveolar sacs, G. In the gas exchange diagram, note that red blood cells in the capillary I receive three different colors according to their stage of oxygenation.

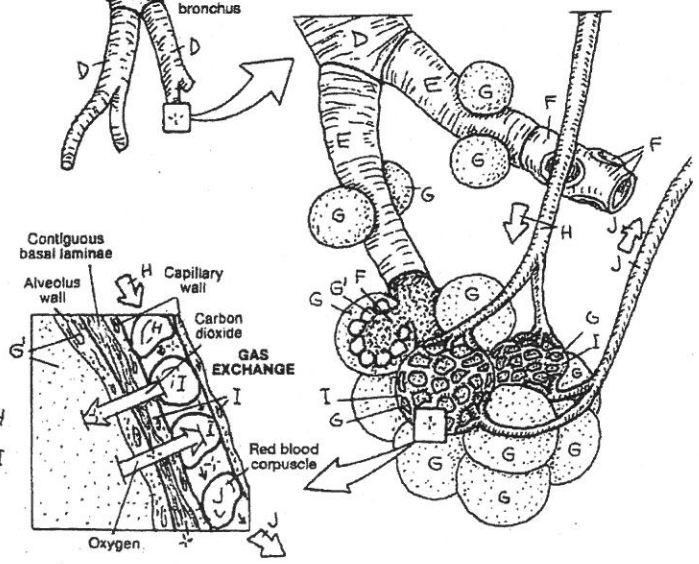
TRACHEA A
MAIN PRIMARY BRONCHUS B
LOBAR (SECONDARY) BRONCHUS C

1 APICAL 2 POSTERIOR 3 ANTERIOR 4 LATERAL (R.L.)
4 SUPERIOR (L.L.) 5 MEDIAL (R.L.) 5 INFERIOR (L.L.)
6 SUPERIOR 7 MEDIAL BASAL 8 ANTERIOR BASAL
9 LATERAL BASAL 10 POSTERIOR BASAL



TERMINAL RESPIRATORY UNIT

BRONCHIOLE D
RESPIRATORY BRONCHIOLE E
ALVEOLAR DUCT F
ALVEOLAR SAC G
ALVEOLUS G¹
PULMONARY ARTERIOLE H
CAPILLARY NETWORK I
PULMONARY VENULE J



The digestive system consists of an **alimentary canal** with **accessory organs**. The canal begins with the **oral cavity**, where the **teeth** pulverize ingested food while it is softened and partly digested by **salivary gland** secretions. The **tongue** aids in mechanical manipulation of the food (bolus) and literally flips the food into the fibromuscular **pharynx** during swallowing.

The **esophagus** moves the bolus along to the **stomach** by peristaltic muscular contractions. There, the bolus is treated to mechanical and chemical digestion, then passed into the highly coiled **small intestine** for more enzymatic and mechanical digestive processes. Bile, produced by the **liver** and stored in the **gallbladder**, is discharged into the **duodenum** by a **bile duct**. It assists in the breakdown of fats. Digestive enzymes from the **pancreas** enter the duodenum as well. Nutrients of molecular size are extracted primarily from the lumen of the small intestine, absorbed by lining cells, and transferred to blood and lymph capillaries for eventual delivery to the liver for processing. The **large intestine** is concerned with absorption of minerals and water (proximal half) and storage. Undigested, unabsorbed material continues to the **rectum** for discharge through the **anal canal** and anus.

DIGESTIVE SYSTEM OVERVIEW

CN: Use your lightest colors for D, E, T, V, and W. When organs or structures overlap each other, each overlapping portion receives the color of both. (1) After coloring the alimentary canal, review the structures before completing the accessory organs. The central section of the transverse colon, J, has been removed to show deeper structures. (2) Color gray the diagrammatic depiction of the alimentary canal in relation to the body in the upper right corner.

ALIMENTARY CANAL

ORAL CAVITY A
PHARYNX B
ESOPHAGUS C
STOMACH D

SMALL INTESTINE

DUODENUM E
JEJUNUM F
ILEUM G

LARGE INTESTINE

CECUM H
VERMIFORM APPENDIX H'

COLON

ASCENDING COLON I
TRANSVERSE COLON J
DESCENDING COLON K
SIGMOID COLON L

RECTUM M
ANAL CANAL N

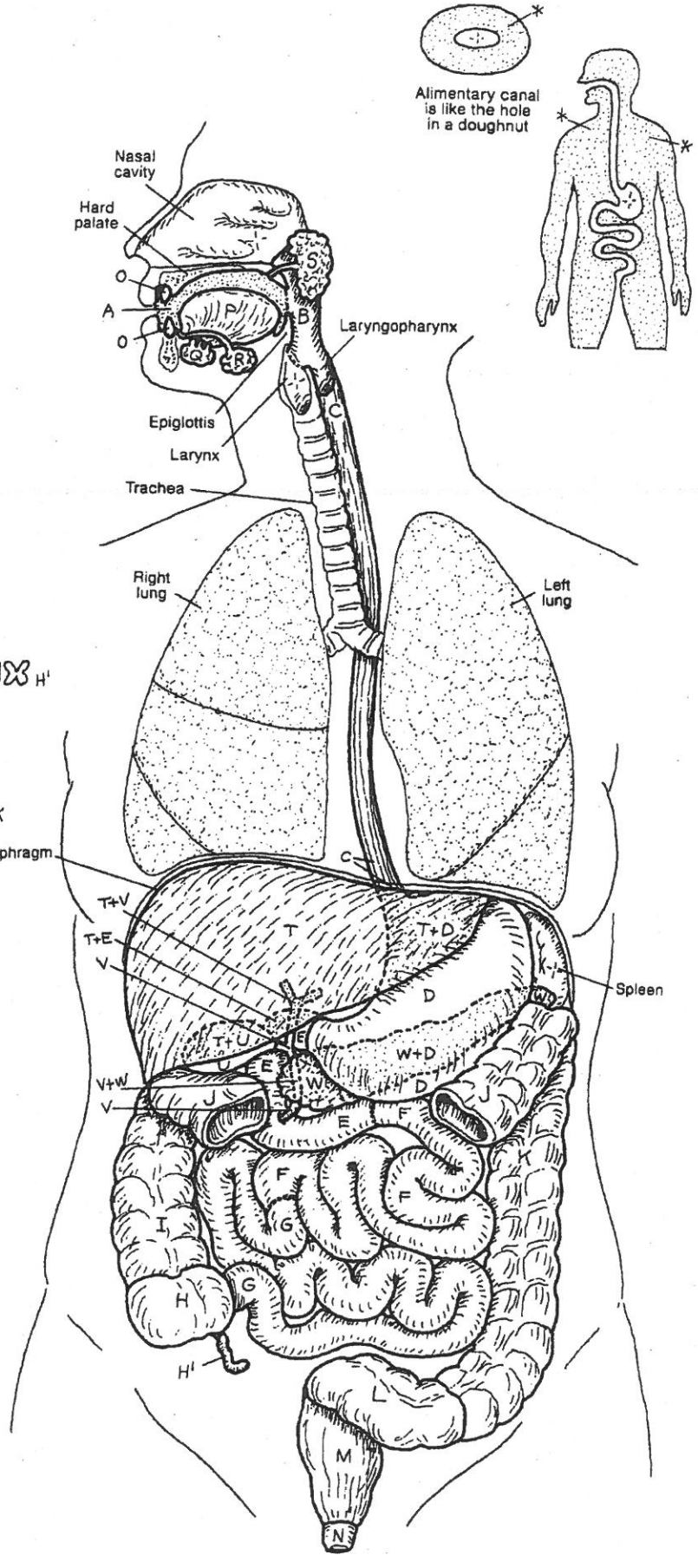
ACCESSORY ORGANS

TEETH O
TONGUE P

SALIVARY GLANDS

SUBLINGUAL Q
SUBMANDIBULAR R
PAROTID S

LIVER T
GALLBLADDER U
BILE DUCTS V
PANCREAS W



The **biliary system** consists of an arrangement of ducts transporting bile from the liver cells that manufacture it to the gallbladder, for storage and release, and the second part of the duodenum.

Bile is formed in the liver (not the gallbladder!). It is a fluid consisting largely of water (97%), with bile salts and pigments (from the breakdown products of hemoglobin in the spleen). Once formed, bile is discharged from **hepatic cells** (hepatocytes) into surrounding bile canaliculi. These small canals merge to form bile ductules that join the converging bile ducts traveling in company with the intrahepatic branches of the portal vein and hepatic artery. The bile is brought out of the liver by the **right** and **left hepatic ducts** that merge at the porta hepatis to form the **common hepatic duct**. That duct descends between the layers of the lesser omentum and receives the 4-cm-long **cystic duct** from the gallbladder. The gallbladder is pressed against the visceral surface of the right lobe of the liver, which is covered with visceral peritoneum. The **bile duct** is formed by the cystic and common hepatic ducts. About 8 cm long, it descends behind the first part of the duodenum, deep to or through the head of the pancreas. It usually joins with the main **pancreatic duct**, forming an ampulla in the wall of the second part of the duodenum. There, the duct opens into the lumen of the duodenum. There can be variations in the union of these two ducts.

The **gallbladder** serves as a storage chamber for bile discharged from the liver. Bile is concentrated here several times. This fact is reflected in the multiple microvilli on the luminal surfaces of the simple columnar epithelial cells that absorb water from the dilute bile. In response to the gastric or duodenal presence of fat, secretion of cholecystokinin is induced, which stimulates the gallbladder to discharge its contents into the cystic duct. Peristaltic contractions of the duct musculature squirt bile into the duodenal lumen through the ampullary sphincter. Bile saponifies and emulsifies fats, making them water soluble and amenable to digestion by enzymes (lipases).

The **pancreas** is a gland in the retroperitoneum, consisting of a head, neck, body, and tail. Most of the pancreas consists of sac-like (acinar) exocrine glands that secrete enzymes and sodium bicarbonate, at a rate of about 2,000 mL per day, into the tributaries of the pancreatic duct and into the duodenum through one or two papillae, guarded by an ampullary sphincter. These enzymes are responsible for a major part of the chemical digestion in the small intestine (to name a few: lipase for fat, trypsin for protein, amylase for carbohydrates, and others). Pancreatic secretion is regulated by hormones (primarily cholecystokinin and secretin) from entero-endocrine cells and by the vagus nerves (acetylcholine). The endocrine function of the pancreas is covered on page 154.

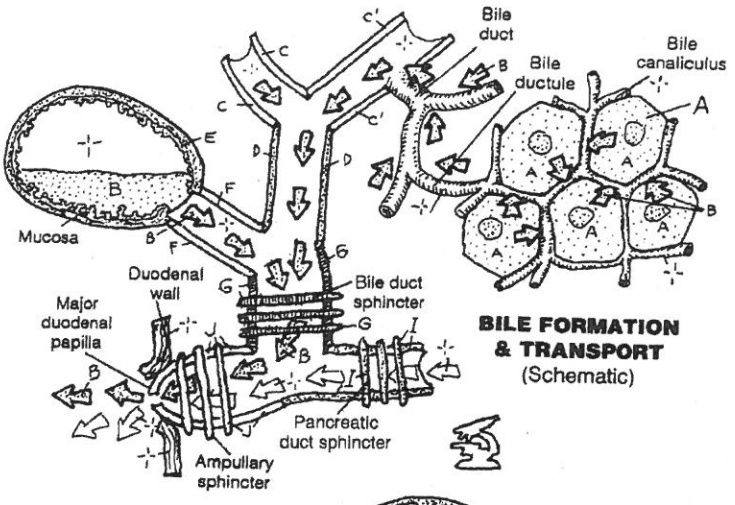
BILIARY SYSTEM & PANCREAS

See 142, 154

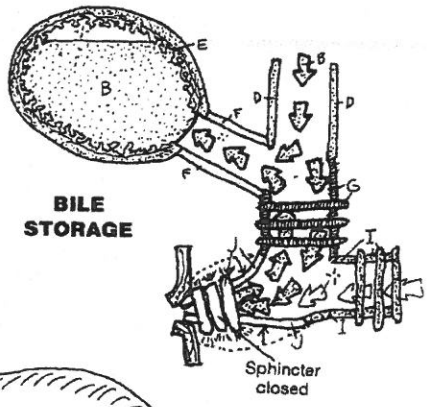
CN: Use the same colors as you used on page 142 for the hepatic cells and bile ducts, and a very light color for H. (1) Color simultaneously the diagram of bile formation/transport and the large central illustration. Avoid coloring but note the duodenum, spleen, and background vessels. (2) Color the diagram describing bile storage.

HEPATIC CELL A
BILE B
RIGHT HEPATIC DUCT C
LEFT HEPATIC DUCT C'
COMMON HEPATIC DUCT D
GALLBLADDER E
CYSTIC DUCT F
BILE DUCT G

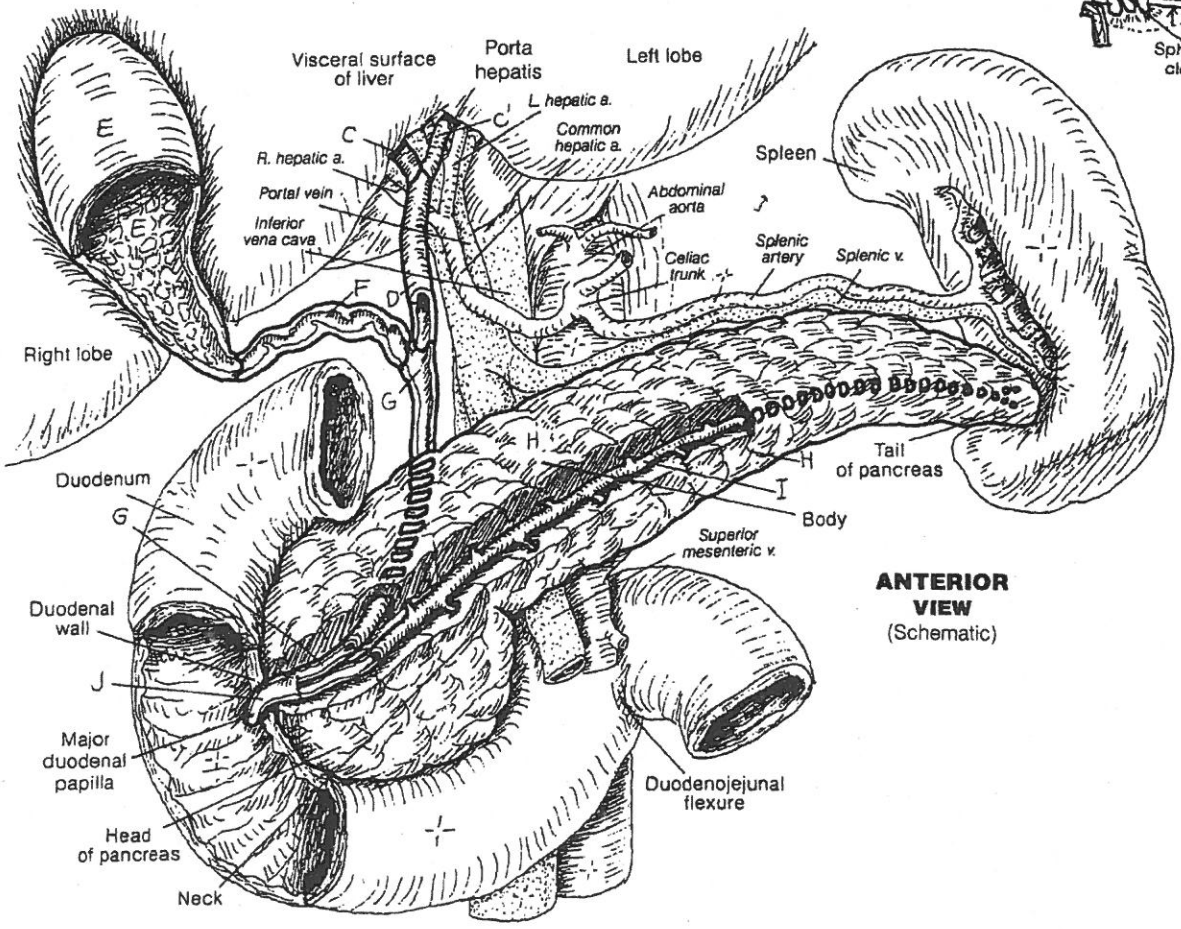
PANCREAS H
PANCREATIC DUCT I
HEPATO-DUODENAL AMPULLA J



BILE FORMATION & TRANSPORT
(Schematic)



BILE STORAGE



ANTERIOR VIEW
(Schematic)

The **urinary tract** consists of paired kidneys and ureters in the retroperitoneum, a single urinary bladder, and a urethra. The urinary tract represents a pathway for the elimination of metabolic byproducts and toxic and other nonessential molecules, all dissolved in a small volume of water (*urine*). The **kidneys** are not simply instruments of excretion; they function in the conservation of water and maintenance of acid–base balance in the blood. The process is dynamic; that which is excreted as waste in one second may be retained as precious in the next.

The **ureters** are fibromuscular tubes, lined by a transitional epithelial layer of a highly convoluted mucosa like that of the esophagus (recall page 8). The muscular layer deep to the mucosa is thicker than the mucosa itself. Each ureter has an adventitial layer as well. Three areas of the ureters are relatively narrow and prone to being obstructed by mineralized concretions (*stones*) from the kidney (see arrows).

The fibromuscular **urinary bladder** lies in the true pelvis, its superior surface covered with peritoneum. The mucosa is lined with transitional epithelium. The bladder may contain as little as 50 mL of urine, but can hold as much as 700 to1,000 mL without injury. As it distends, it rises into the abdominal cavity and bulges posteriorly. The mucosal area between the two ureteral orifices and the urethral orifice is called the *trigone*.

The fibromuscular, glandular **urethra**, lined with transitional epithelium except near the skin, is larger in males (20 cm) than in females (4 cm). Hence, urethritis is more common in men, cystitis more common in women. In males, the urethra is described in three parts: prostatic, membranous, and spongy. The ductus deferens and ducts of the seminal vesicles join the **prostatic urethra**, though the latter may join the former before entering the urethra. The **membranous urethra**, secured among muscle layers in the urogenital diaphragm, is short and vulnerable to rupture with trauma to the low anterior pelvis. The **spongy urethra** in the body of the penis is about 15 cm long and lined with stratified columnar or pseudostratified columnar epithelium. It opens to the outside at the urinary meatus (external urethral orifice).

In the female, the urethra immediately enters the deep perineal space after leaving the bladder. It enters the superficial perineal space between the vestibular bulbs and opens to the outside.

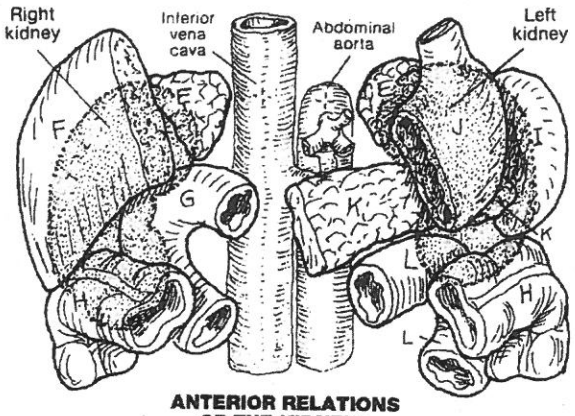
CN: Use very light colors on this page. (1) Color the three views of the urinary tract together. Color the kidneys in the anterior view in relation to the organ contact areas shown above. The kidneys in that upper view are shown as underlying, shaded silhouettes and receive no color. (2) Note and color the openings of the ureters, B, into the bladder in the anterior view. (3) Color gray the three arrows marking sites of potential ureteric obstruction by "stones."

URINARY TRACT

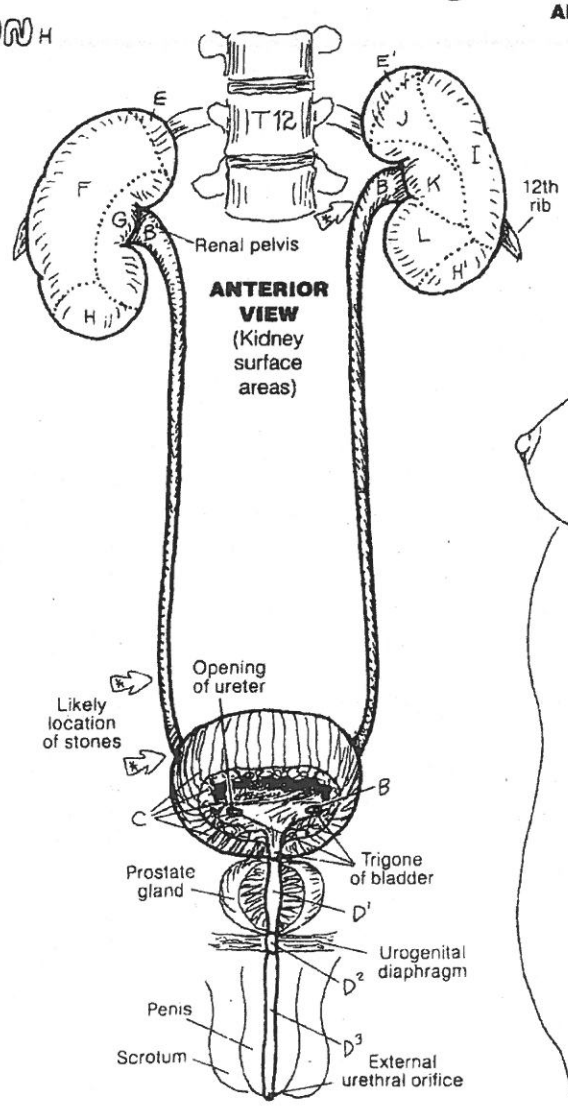
KIDNEY A
URETER B
URINARY BLADDER C
URETHRA D
PROSTATIC U. (MALE) D'
MEMBRANOUS U. (MALE) D²
SPONGY U. (MALE) D³

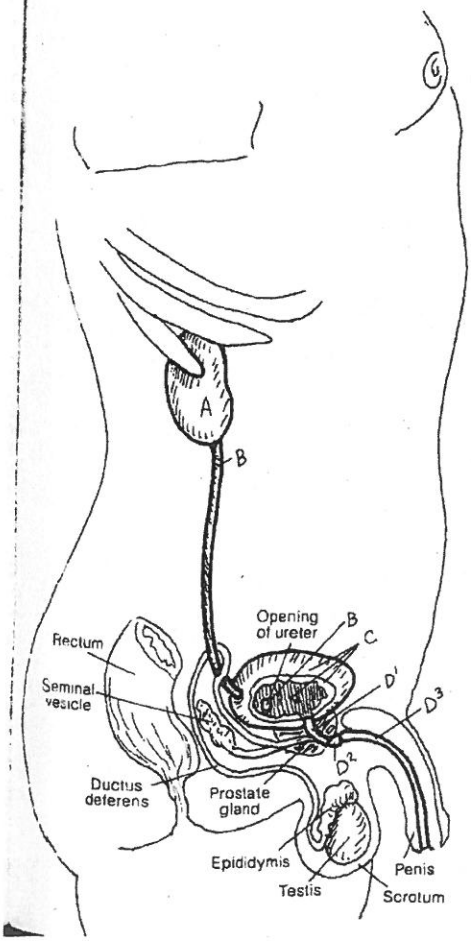
KIDNEY RELATIONS

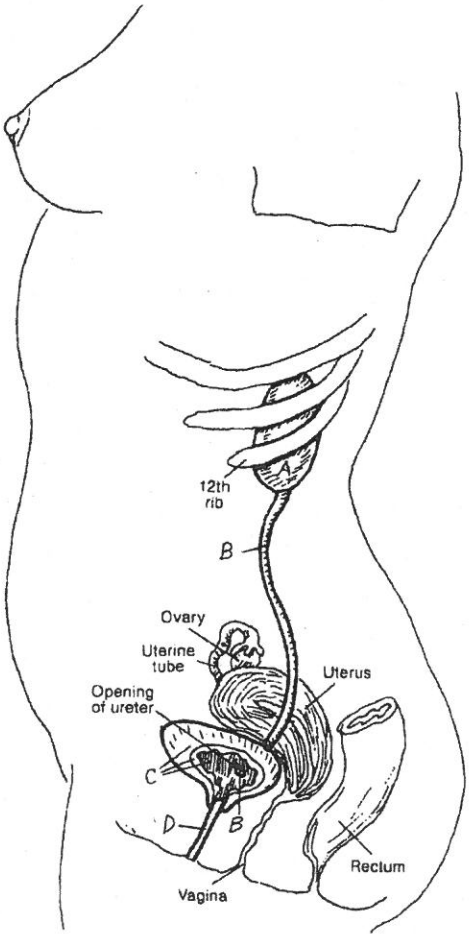
SUPRARENAL GLAND E
LIVER F
DUODENUM G
TRANSVERSE COLON H
SPLEEN I
STOMACH J
PANCREAS K
JEJUNUM L



ANTERIOR RELATIONS OF THE KIDNEYS







The primary functional unit of the kidney is the **nephron**, consisting of the **renal corpuscle**, and the proximal/distal convoluted and straight tubules and **loop of Henle** (**renal tubule**). The nephron ends as it joins the **collecting tubule/duct**.

The renal corpuscles occupy the cortex; **juxtamedullary nephrons** are more deeply set in the cortex than **cortical nephrons**, which are reported to be the more common (about 70–80%) of the two. Note that the thin straight tubules of the juxtamedullary nephrons are significantly longer and dip deeper into the medulla than those of the cortical nephrons. The functional difference between them is expressed in different degrees of **urine** concentration in the loop of Henle (see page 148).

The renal corpuscle is composed of an encapsulated cluster of porous (*fenestrated*), specialized capillaries, called the **glomerulus**, fed by an **afferent arteriole** on one side and drained by an **efferent arteriole** on the same side. Phagocytic mesangial cells share space at the vascular pole (not shown).

Each glomerulus is developmentally pushed into a blind capsule, invaginating it (see text, page 103). This capsule is the **glomerular capsule** (*capsule of Bowman*). The side of the capsule into which the glomerulus invaginated is called the *vascular pole*. See now the cross section of the renal corpuscle at the lower part of the page; note that the side opposite the vascular pole (the urinary pole) opens into the **proximal convoluted tubule** (first part of the renal tubule).

The cavity created by invagination of the glomerulus into the capsule is the **capsular space**. It receives the plasma filtrate from the glomerular capillaries. The outer wall of the capsule is the **parietal layer**. The inner wall is the **visceral layer**, composed of elongated, octopus-like epithelial cells (**podocytes**) with long extensions reaching along a length of capillary and multiple short finger-like processes on one or both sides (*pedicels*) that reach out to attach to the underlying capillary. The plasma passes through the capillary fenestrations between pedicels and enters the capsule through these minute passageways (*filtration sites*). This fluid in the capsule is now *filtrate*.

The cells of the renal tubules of the nephron function to (1) *reabsorb* certain substances from the tubular lumen, as well as the interstitial fluid and local capillaries, such as sodium, potassium, bicarbonate, calcium, other electrolytes, and water; (2) *secrete* (return) certain substances from the tubular cells into the tubular lumen; and (3) *excrete* (transport) the constantly varying amount of leftovers (urine) through collecting ducts for eventual storage. In this way the tubules keep a neutral acid–base balance in the body fluids and concentrate the filtrate passing through the tubules, minute by minute, to retain body water. On average, 99% of the filtrate is reabsorbed by the tubules of the nephron and the collecting ducts and returned to the fluid spaces of the body. In this function, the distal convoluted and straight tubules and the collecting ducts play a most important role.

THE NEPHRON

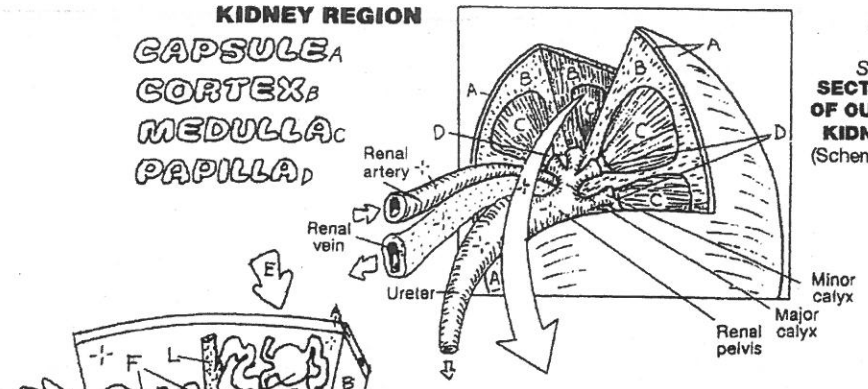
CN: Use red for G and G^1; use the colors you used on the previous page for similar structures which may have different labels. (1) Begin by coloring the "Kidney Region" at the top of the page. (2) Color the two types of nephrons in the smaller wedge. (3) Color the detailed view of the cortical nephron. (4) At the bottom of the page, color the cross section of the renal corpuscle on the right. The capsular space, H^3, is to be left uncolored. (5) At lower left, color the podocytes around the glomerular capillary at left, relating it to the glomerulus at right.

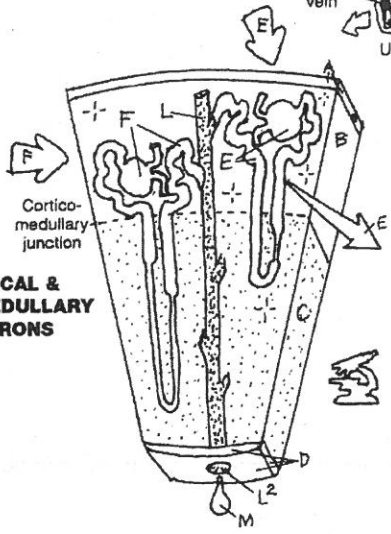
See 148

SECTION OF OUTER KIDNEY (Schematic)

KIDNEY REGION

CAPSULE A
CORTEX B
MEDULLA C
PAPILLA D





CORTICAL & JUXTAMEDULLARY NEPHRONS

NEPHRON

CORTICAL NEPHRON E
JUXTAMEDULLARY NEPHRON F

RENAL CORPUSCLE

AFFERENT ARTERIOLE G
GLOMERULUS G^1
GLOMERULAR CAPSULE H
PARIETAL LAYER H^1
VISCERAL LAYER (PODOCYTE) H^2
CAPSULAR SPACE H^3
EFFERENT ARTERIOLE G^2

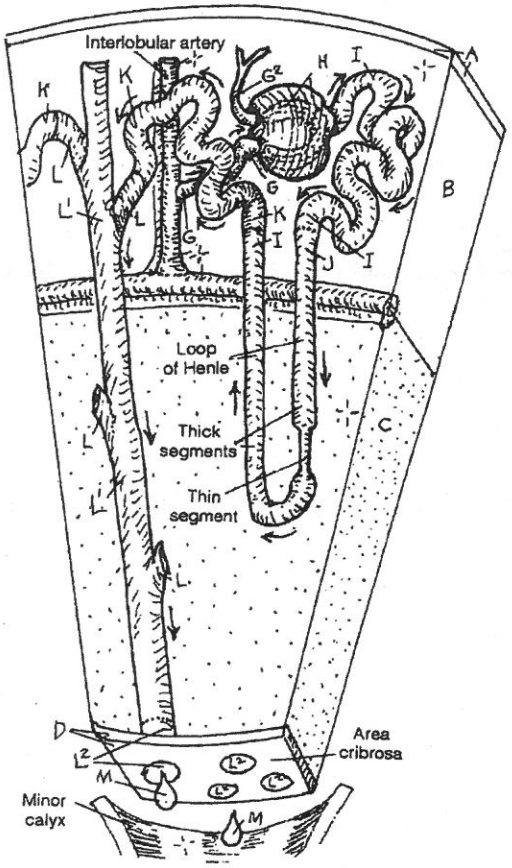
RENAL TUBULE

PROXIMAL CONVOLUTED TUBULE I
LOOP OF HENLE J
DISTAL CONVOLUTED TUBULE K

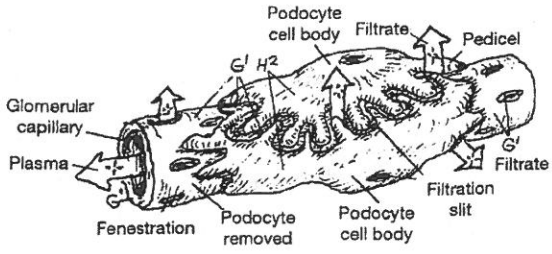
COLLECTING TUBULE L
COLLECTING DUCT L^1
PAPILLARY DUCT L^2

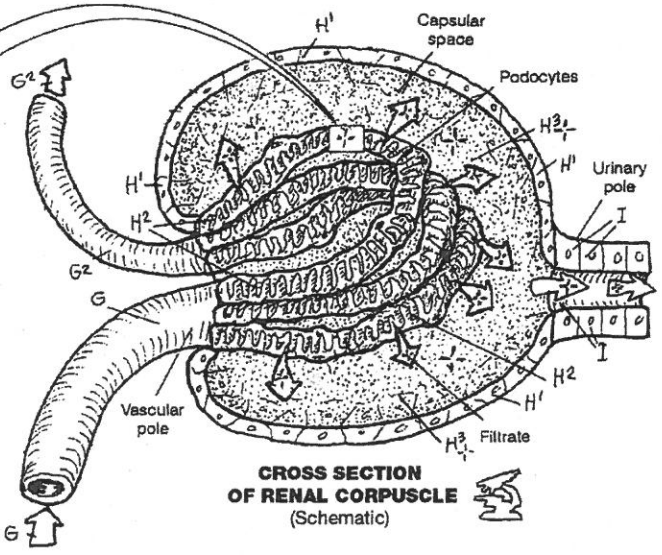
URINE M

CORTICAL NEPHRON E



PODOCYTE





CROSS SECTION OF RENAL CORPUSCLE (Schematic)

Classically, **endocrine glands** and **tissues** are discrete masses of secretory cells and their supporting tissues in close proximity to blood capillaries into which these cells secrete their hormones. *Hormones* are chemical agents usually effective among cells (**target organs**) located some distance from their source. **Hormonal secretion** results in positive or negative feedback control mechanisms in the target tissue(s). In the broader scope, in the face of current and recent past research, it is generally agreed that the classical definition may have to be expanded to accommodate new findings with regard to *local* chemical control. Chemical agents that are effective in the same fluid environment as the cells that secreted them (local "target" cells) are known as *paracrines*. There are also cells that secrete chemical agents outside the cell's membrane and induce a response among receptors in or on the same cell (*autocrines*). Such cells, at least in part, are self-regulatory.

Hormonal activity results in growth, reproduction, and metabolic stability in the internal (chemical) environment. In this internal environment, cells, tissues, and organs contribute and respond to chemical input results in stabilizing influences on cellular activity under a broad set of conditions, and maintains a long-lasting "normal" environment called *homeostasis* (*homeo*, normal; *stasis*, a state of equilibrium among opposing forces or tendencies).

The classical endocrine glands shown here are presented on the following pages, with the exception of the **pineal gland** (see page 75) and the **thymus** (see page 123). In addition to the classical endocrine glands, a few of the myriad tissues/cells that secrete chemical agents influential in cellular activities are listed here.

The atria of the **heart** secrete atrial natriuretic peptide (ANP) during periods of heightened blood pressure. The effect of this chemical agent is to limit the influence of the renin-angiotensin-aldosterone mechanism and permit increased excretion of water and sodium.

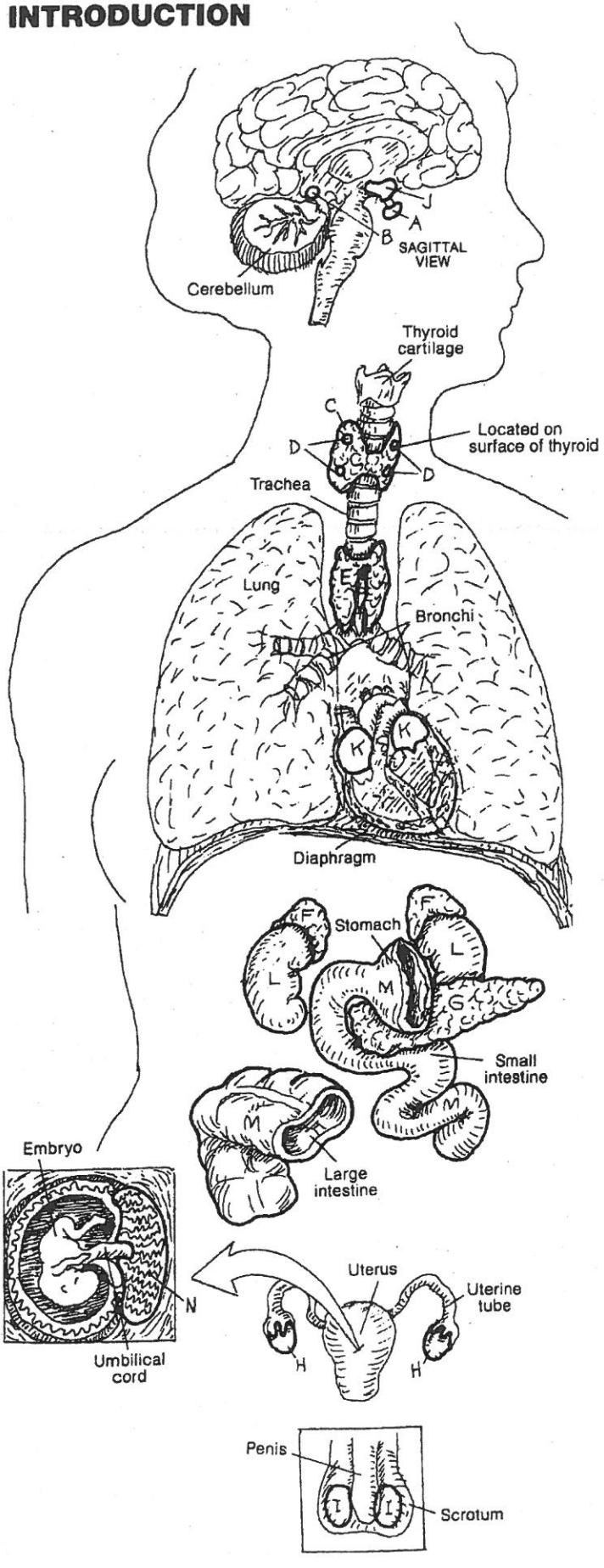
The juxtaglomerular cells of the **kidney** (see page 148) secrete renin, an enzyme that converts angiotensinogen to angiotensin I and indirectly induces increased blood pressure and conservation of body fluids, such as during hemorrhage.

The cells of the **gastrointestinal tract** secrete numerous endocrine factors that influence intestinal motility and enzyme secretion.

The **placenta** secretes many hormones, including human chorionic gonadotropin (hCG), estrogen, progesterone, lactotropic (breast development and milk production support) hormones, and relaxin. During the first 90 days after fertilization, hCG contributes to the support of embryonic growth by stimulating the growth of the corpus luteum.

INTRODUCTION

CN: Use a very light color for the thyroid, C, and a darker one for the parathyroids, D (actually located on the posterior surface of the thyroid). After coloring the endocrine glands and tissues, color the functional scheme at lower right.



ENDOCRINE GLANDS

HYPOPHYSIS (PITUITARY) A
PINEAL B
THYROID C
PARATHYROID (4) D
THYMUS E
ADRENAL (SUPRARENAL) (2) F
PANCREAS G
OVARY (2) H
TESTIS (2) I

ENDOCRINE TISSUES

HYPOTHALAMUS J
HEART K
KIDNEY (2) L
GASTROINTESTINAL TRACT M
PLACENTA N

ENDOCRINE FUNCTION

ENDOCRINE GLAND O
HORMONAL SECRETION P
TARGET ORGAN Q