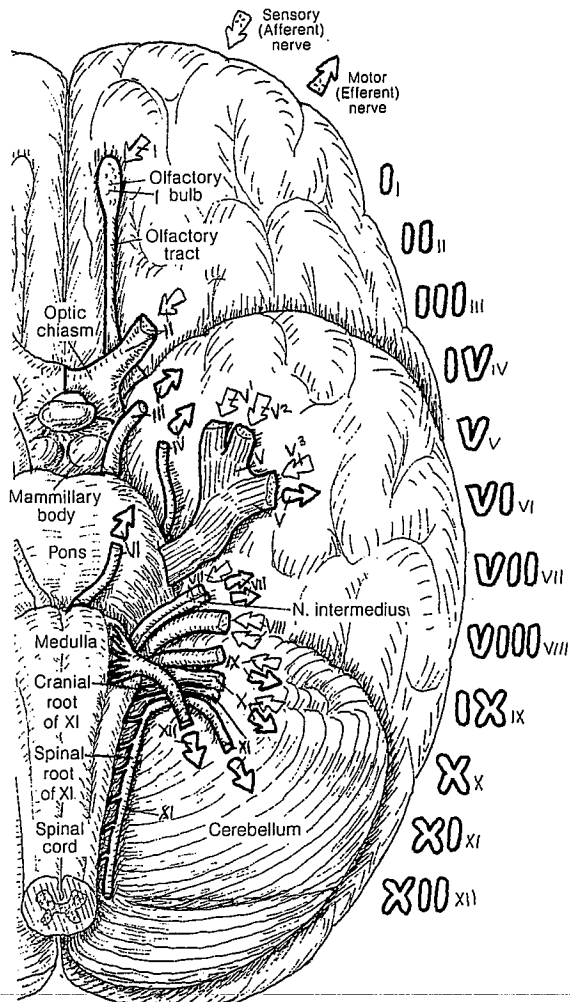
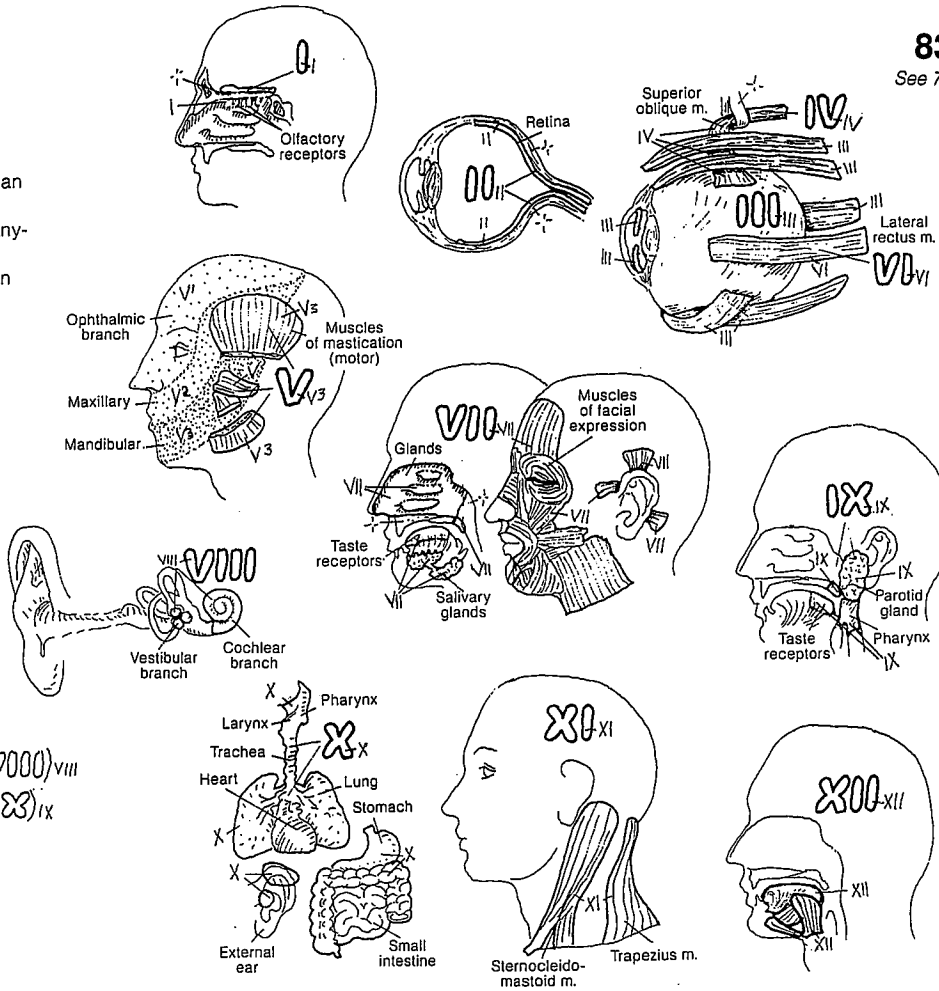


CRANIAL NERVES

CN: Use light colors throughout. (1) Beginning with the first cranial nerve, color the title on the left; the large Roman numeral, the cranial nerve (cut), and the related function arrow at lower left; and the Roman numeral and accompanying illustration at upper right. The illustrations generally depict target organs/areas. (2) Note carefully the direction of the function arrows at lower left (sensory/afferent is incoming; motor/efferent is outgoing). (3) The accessory nerve (XI) has two roots: a spinal root and a cranial root that travels with the vagus nerve (X).

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, brainstem, and cerebellum)

Cranial nerves I and II are derived from the forebrain; all others arise from the brain stem. V = visceral, referring to smooth muscle, glands, and organs with hollow cavities; S = somatic, referring to the skin, eye, skeletal, facial, and skeletal muscles; A = afferent or sensory; E = efferent or motor. All motor nerves depicted include proprioceptive fibers (sensory for muscle, tendon, and joint movement).

- I VA: smell-sensitive (olfactory) receptors in roof/walls of nasal cavity.
- II SA: light-sensitive (visual) receptors in the retina of the eye.
- III SE: to extrinsic eye muscles (exc. lat. rectus and sup. oblique); VE: parasympathetic to ciliary and pupillary sphincter (eye) muscles via ciliary ganglion in the orbit.
- IV SE: to superior oblique muscle of the eye.
- V SA: from face via three divisions indicated; VE: to muscles of mastication, tensor tympani, tensor veli palatini, mylohyoid, and digastric muscles.
- VI SE: to lateral rectus muscle of the eye.
- VII VA: from taste receptors ant. tongue; SA: from ext. ear; VE parasympathetic to 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); VE: to facial muscles, stapedius (mid. ear), stylohyoid, post. digastric muscles.
- VIII SA: cochlear part is sound-sensitive; vestibular part is sensitive to head balance and movement (equilibrium).
- IX VA: from taste receptors post. one-third tongue; SA: from ext. ear and ext. auditory canal; VA: from mucous membranes of posterior mouth, pharynx, auditory tube, and middle ear; from pressure and chemical receptors in carotid body and common carotid artery; VE: to sup. constrictor m. of the pharynx, stylopharyngeus; VE: parasymp. to parotid gland (via otic ganglion in infratemporal fossa).
- X VA: from taste receptors at base of tongue and epiglottis; SA: from ext. ear and ext. aud. canal; VA: from pharynx, larynx, thoracic and abdominal viscera; VE: to muscles of palate, pharynx, and larynx; VE: parasymp. to muscles of thoracic and abdominal viscera (via intramural ganglia).
- XI Cranial root: joins vagus (VA to laryngeal muscles); spinal root (C1-C5): innervates trapezius and sternocleidomastoid muscles.
- XII SE: to extrinsic and intrinsic muscles of tongue.

SPINAL NERVES & NERVE ROOTS

CN: Use very light colors for D through G. (1) Begin with the upper illustration. Color all three pairs of spinal nerves as they emerge from the intervertebral foramina (M). (2) Color the cross-sectional view in the center. (3) Color the spinal nerve axons and the arrows representing direction of impulse flow.

SPINAL NERVE ROOT

- POSTERIOR ROOT_A
- SENSORY AXON_B
- CELL BODY_C
- POSTERIOR ROOT GANGLION_D
- ANTERIOR ROOT_E
- MOTOR AXON_F
- CELL BODY_G

SPINAL NERVE_H RAMUS_{H'}

Spinal nerves are collections of axons of sensory and motor neurons located in or adjacent to the spinal cord. They are the spinal equivalent of cranial nerves. Spinal nerves arise from nerve roots that come directly off the spinal cord. The spinal nerves and their roots are arranged segmentally (from cervical to coccygeal) and bilaterally along the length of the spinal cord. The central relations of these spinal nerves/roots can be recalled in Plates 78 and 79. The spinal nerves branch soon after they are formed into *anterior and posterior rami*.

Axons of sensory neurons that form the major part of the *posterior root* are called central processes (see drawing of spinal nerve axons). The cell bodies of these neurons form the posterior root ganglia and are located in or near the intervertebral foramina, except for the sacral and coccygeal nerves, whose ganglia are in the vertebral canal. The peripheral processes of the sensory neurons join with the *axons of motor neurons* to form the spinal nerves.

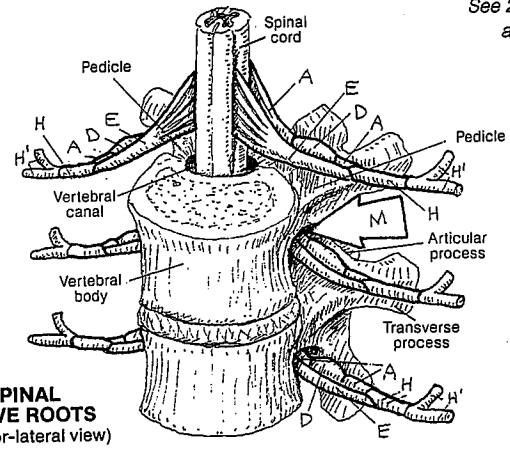
The cell bodies of the motor neurons are multipolar and exist in the anterior horns of the spinal cord. Their axons emerge from the cord to form the anterior roots of the spinal nerves.

The nerve roots join to form the spinal nerves in the region of the *intervertebral foramina*. The nerve roots are progressively longer from cervical to coccygeal regions because the spinal cord does not fill the vertebral canal; it ends at the level of the 1st lumbar vertebra. Thus, some spinal nerve roots are quite long, remaining within the vertebral canal before reaching the lumbar, sacral, and coccygeal intervertebral foramina. The collection of these long nerve roots forms the "cauda equina" (recall Plate 77).

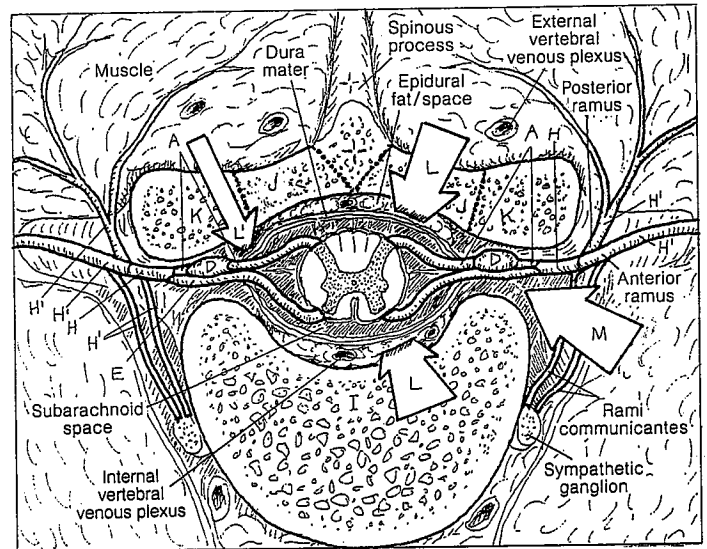
NERVE ROOT RELATIONS

- VERTEBRA
- BODY_I
- LAMINA_J
- ARTICULAR PROCESS_K
- VERTEBRAL CANAL_L
- LATERAL RECESS_{L'}
- INTERVERTEBRAL FORAMEN_M

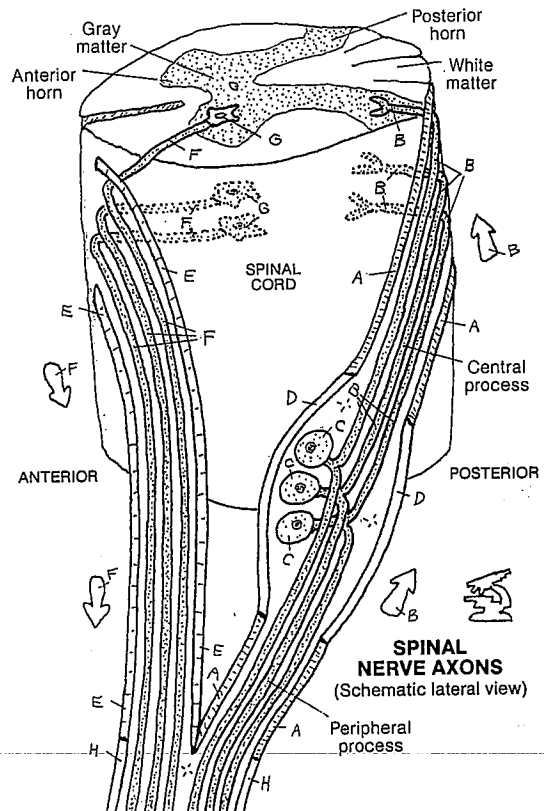
Spinal nerves and their roots have fairly tight quarters. The relations of these nerves and roots can best be appreciated in the cross-sectional view. Nerve roots are vulnerable to irritation (radiculitis) from encroaching, hypertrophic bone in the lateral recesses (degenerative joint disease), from bulging intervertebral discs (degenerative disc disease), or from cysts, meningeal tumors, and so on. With compression of axons or blood vessels supplying the axons, functional deficits can result (radiculopathy: sensory loss, motor loss, and/or tendon reflex change).



SPINAL NERVE ROOTS (Anterior-lateral view)



CROSS SECTION THROUGH T9 (Seen from above)



SPINAL NERVE AXONS (Schematic lateral view)

SPINAL REFLEXES

CN: Use light colors for A and C, and use the same colors you used on Pl. 84 for structures D-F. (1) Color the upper two illustrations simultaneously, in numerical sequence 1-6, including the arrows. The small arrows at the end of the muscle segments indicate contraction or stretch. (2) Color the lower two illustrations similarly. Note that the motor neuron synapsing with the inhibitory interneuron, and the related effector, are not colored.

MONOSYNAPTIC REFLEX

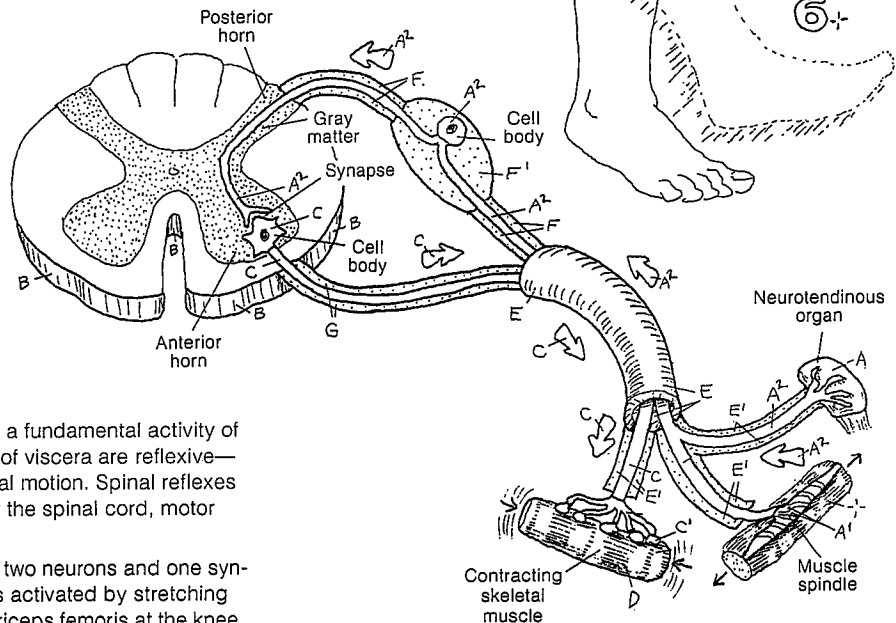
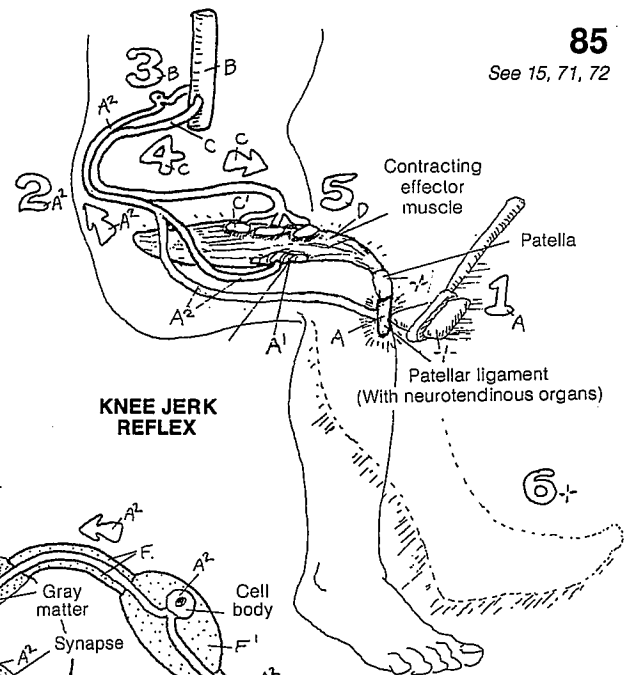
- STRETCH RECEPTOR (N-T ORGAN)_A
- STRETCH RECEPTOR (MUSCLE SPINDLE)_{A'}
- SENSORY NEURON_{A²}
- SPINAL CORD_B
- MOTOR NEURON_C
- END PLATE_{C'}
- EFFECTOR MUSCLE_D

SPINAL NERVES / ROOTS

- SPINAL NERVE_E
- BRANCH_{E'}
- POSTERIOR ROOT_F
- GANGLION_{F'}
- ANTERIOR ROOT_G

A reflex is an involuntary muscle response to a stimulus. It is a fundamental activity of the nervous system; most body movements and movement of viscera are reflexive—e.g., heart rate, respiratory rate, peristalsis of gastrointestinal motion. Spinal reflexes involve sensory receptors, sensory neurons, interneurons of the spinal cord, motor neurons, and effectors.

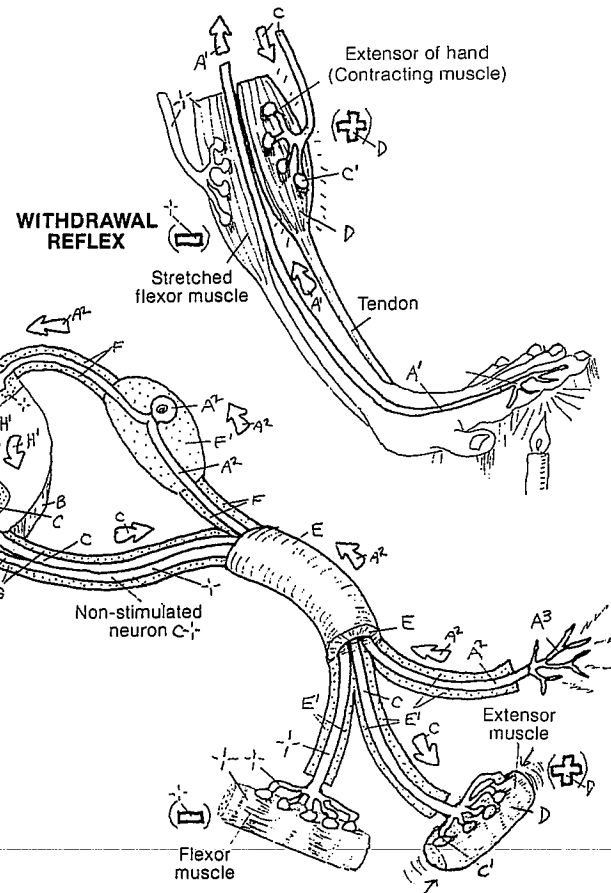
The simplest spinal reflex is a monosynaptic reflex involving two neurons and one synapse (myotatic [stretch] or deep tendon reflex). The reflex is activated by stretching the tendon of a specific muscle, such as the tendon of quadriceps femoris at the knee. This can be done with the sharp tap of a small mallet used for such purposes (or with the 5th-digit side of a hand). The *receptors* responsive to such a stretch are the neurotendinous organs in the patellar ligament and the muscle spindles in the belly of the quadriceps muscle. Muscle spindles are encapsulated, specialized muscle fibers within muscle bellies that have nerve endings sensitive to muscle stretch. Impulses generated in these receptors (1) are conducted by *sensory neurons* (2) to the *spinal cord* (3); these synapse in the gray matter with the anterior horn *motor neurons* (4). The motor neuron conducts impulses to the *end plates* of the *effector muscle* (5). The muscle contracts sufficiently, in the case of the knee reflex ("jerk"), to extend the knee joint momentarily (6).



POLYSYNAPTIC REFLEX

- PAIN RECEPTOR_{A^B}
- SENSORY NEURON_{A²}
- INTERNEURON_H
- FACILITATORY (+)_{H'}
- INHIBITORY (-)_{H²-1'}
- (+)₁ MOTOR NEURON_C / EFFECTOR_D
- (-)₂ MOTOR NEURON_{C²} / EFFECTOR_{D²}

Polysynaptic reflexes range from simple withdrawal reflexes to complex reflexes involving several segments of the spinal cord and brain. The complexity of a polysynaptic reflex relies on the number of interneurons in the reflex and the number of synaptic contacts. In this case, temperature and pain receptors respond to a sharp increase in heat; sensory neurons conduct the impulse 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 2nd motor neuron (C₂), and the antagonist flexor muscle is stretched without contracting, permitting the fingers to be withdrawn from the flame.



DISTRIBUTION OF SPINAL NERVES & THORACIC SPINAL NERVE

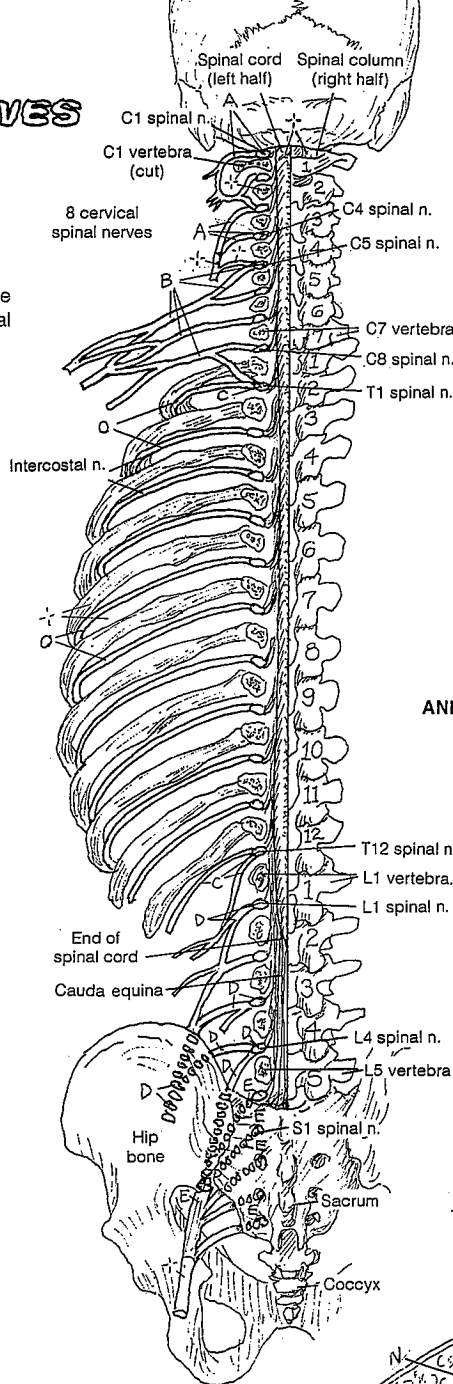
CN: (1) Begin with the upper illustration, which is an introduction to the major nerve plexuses (detailed on the following three plates) formed by spinal nerves. Note that each nerve (shown emerging from the left half of the spinal cord) receives the color of the plexus to which it contributes; exceptions are nerves T1 and L4, which make two contributions but receive the color of their main grouping. Thoracic nerves (C) give rise to intercostal nerves (O), represented above in the company of each rib and treated in more detail below. (2) Color the example of nerve coverings, taken from a cutaneous nerve (F¹) in the cross-sectional view to the right. (3) Color the larger view and review the introduction to these structures on Plate 84.

Thirty-one pairs of spinal nerves supply the body structure with sensory and motor innervation, except for areas covered by cranial nerves. From above to below, there are 8 cervical spinal nerves (C1-C8), 12 thoracic (T1-T12), 5 lumbar (L1-L5), 5 sacral (S1-S5), and one coccygeal (Co1). There is one more nerve than vertebrae in the cervical spine; C1 passes above the C1 vertebra, C8 passes below the C7 vertebra. Thus, spinal nerves after C6 pass below the vertebra of the same number; above C7 they pass above the vertebra of the same number.

Spinal nerves arise from roots; once formed, they split into rami (see Plate 84 and the cross section below right). The anterior rami of all spinal nerves (except thoracic) form interconnecting networks or plexuses outside the vertebral column. The posterior rami do not contribute to plexuses. Peripheral nerves are branchings from the plexuses and are directed to geographically related parts of the body. The nerves of the cervical plexus (C1-C4) can be colored in Plate 87, the nerves of the brachial plexus (C5-T1) in Plate 88, and the nerves of the lumbar plexus (L1-L4) and sacral plexus (S1-S4) in Plate 89. The coccygeal plexus (S4, S5, Co1) is not shown.

The anterior rami of thoracic spinal nerves form intercostal nerves, not plexuses (see Plate 50), although T1 contributes a branch to the brachial plexus. An idealized cross section through the thorax reveals the ring-like distribution of a "typical" thoracic spinal nerve (see below right). The anterior ramus of one thoracic nerve supplies a segment of the cutaneous, subcutaneous, and musculoskeletal areas of the torso, and the smaller posterior rami (along with posterior rami of cervical and lumbar spinal nerves) supplies its posterior wall and that of the neck. Note the formation of the cutaneous branches to appreciate the innervation of the skin around the body (see also Plate 90).

A cross section through any nerve reveals coverings similar to those of muscle (Plate 44). These fibrous envelopes ensure physical security for the individual axons (endoneurium), fascicles of neurons (perineurium), and the entire nerve (epineurium continuous with deep fascia). These coverings also physically secure the vessels (vasa vasorum) and nerves (vasa nervosum) supplying the axons.



CERVICAL PLEXUS (C1-C4)^A

BRACHIAL PLEXUS (C5-T1)^B

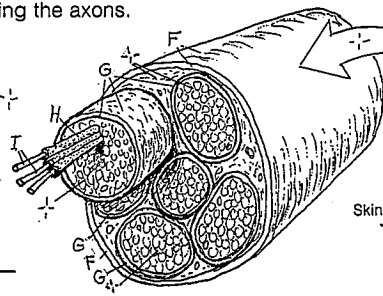
THORACIC NERVES (T1-T12)^C

SPINAL NERVES AND NERVE PLEXUSES (Posterior view)

LUMBAR PLEXUS (L1-L4)^D

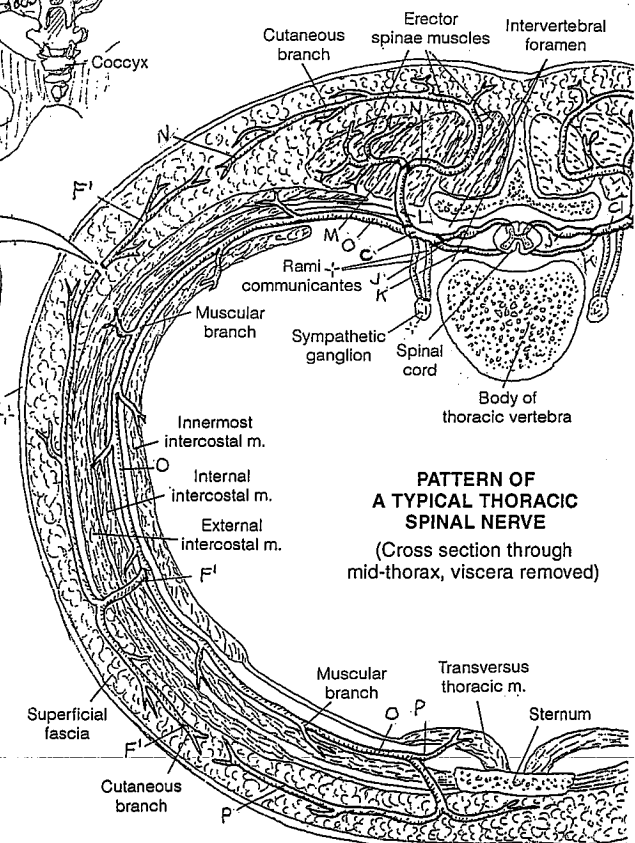
SACRAL PLEXUS (L4, L5-S4)^E

NERVE COVERINGS
EPINEURIUM
PERINEURIUM_c
ENDONEURIUM_H
AXON_I



POSTERIOR ROOT
ANTERIOR ROOT_K
THORACIC SPINAL NERVE_C
POSTERIOR RAMUS_L
LATERAL (MUSCULAR) BRANCH_M
MEDIAL (CUTANEOUS) BRANCH_N
ANTERIOR RAMUS_O
(INTERCOSTAL NERVE)_O
LAT. CUTANEOUS BR._{F¹}
ANT. CUTANEOUS BR._{O, P}

NERVE SECTION



PATTERN OF A TYPICAL THORACIC SPINAL NERVE
 (Cross section through mid-thorax, viscera removed)

BRACHIAL PLEXUS & NERVES TO THE UPPER LIMB

CN: Use light colors for A-D. (1) In the upper illustration, color the letters and numbers identifying the five roots of the brachial plexus. Note but do not color the small branches of the plexus as you color the plexus itself. Note in the lower illustration that the entire plexus is colored gray. (2) As you color each of the major nerves arising from the plexus, color it in the lower illustration as well. As you color each nerve, try to visualize it on your own limb.

BRACHIAL PLEXUS & MAJOR BRANCHES

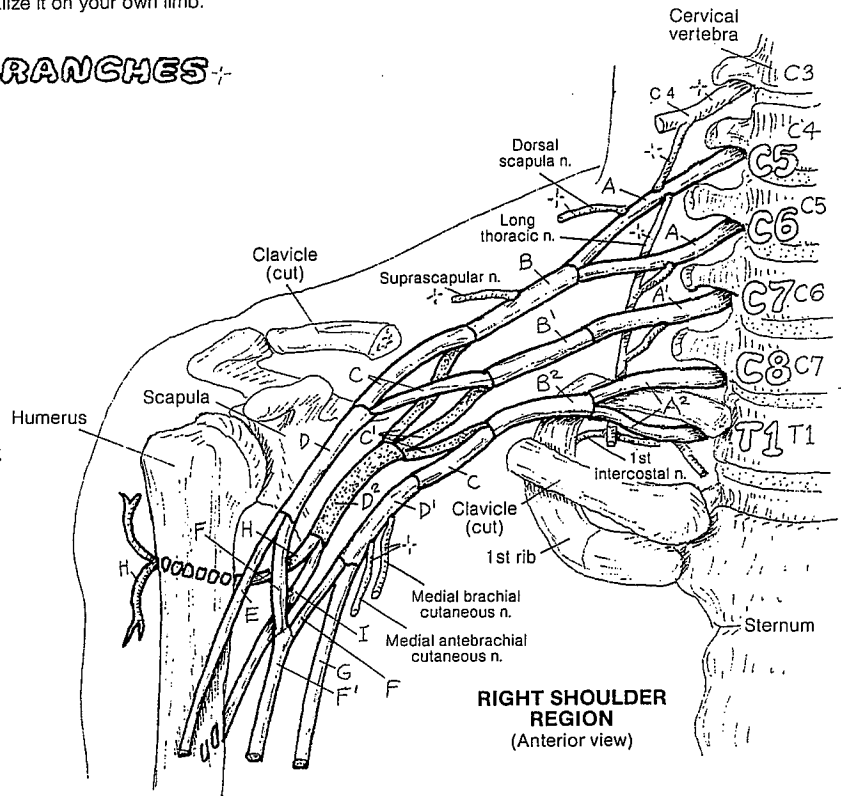
ROOTS C5, C6^A
UPPER TRUNK^B

ROOT C7^{A'}
MIDDLE TRUNK^{B'}

ROOTS C8, T1^{A²}
LOWER TRUNK^{B²}

ANTERIOR DIVISION^C
LATERAL CORD (C5-C7)^D
MUSCULOCUTANEOUS N.^E
BR. TO MEDIAN N.^F
MEDIAL CORD (C8-T1)^{D'}
BR. TO MEDIAN N.^F
MEDIAN N.^{F'}
ULNAR N.^G

POSTERIOR DIVISION (C5-T1)^{C'}
POSTERIOR CORD^{D²}
AXILLARY N. (C5-C6)^H
RADIAL N. (C5-T1)^I



RIGHT SHOULDER REGION (Anterior view)

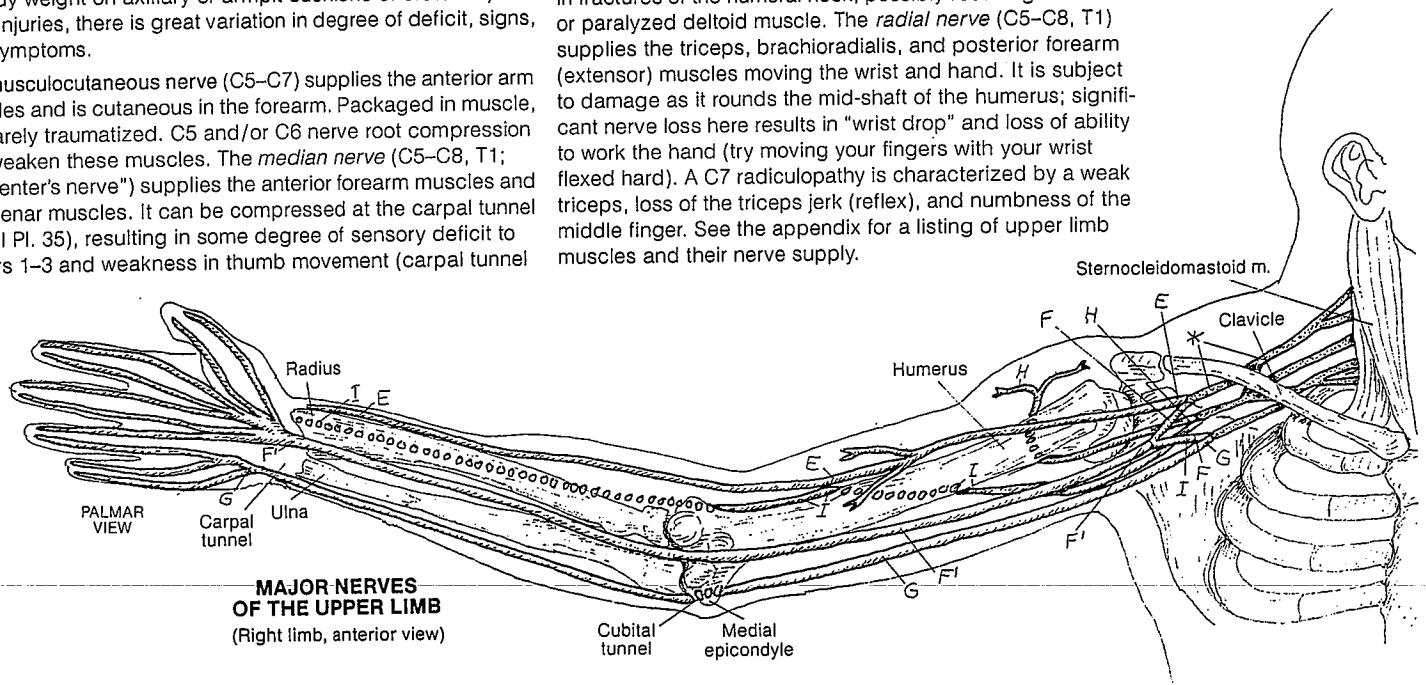
The major nerves to the structures of the upper limb arise from the brachial plexus, formed from the anterior rami of spinal nerves C5-T1 (plus or minus one level). These rami form the *roots of the plexus*. In the pattern illustrated, further branching and joining of fibers in the neck, supraclavicular area, and axilla result in the formation of the five major nerves of the upper limb.

The brachial plexus is subject to injury (plexopathy) from excessive stretching or traction (e.g., rapid, forceful pulling of the upper limb) and compression (e.g., long-term placement of body weight on axillary or armpit cushions of crutches). In such injuries, there is great variation in degree of deficit, signs, and symptoms.

The musculocutaneous nerve (C5-C7) supplies the anterior arm muscles and is cutaneous in the forearm. Packaged in muscle, it is rarely traumatized. C5 and/or C6 nerve root compression can weaken these muscles. The *median nerve* (C5-C8, T1; "carpenter's nerve") supplies the anterior forearm muscles and the thenar muscles. It can be compressed at the carpal tunnel (recall Pl. 35), resulting in some degree of sensory deficit to fingers 1-3 and weakness in thumb movement (carpal tunnel

syndrome). Similar complaints can be associated with a C6 nerve root compression.

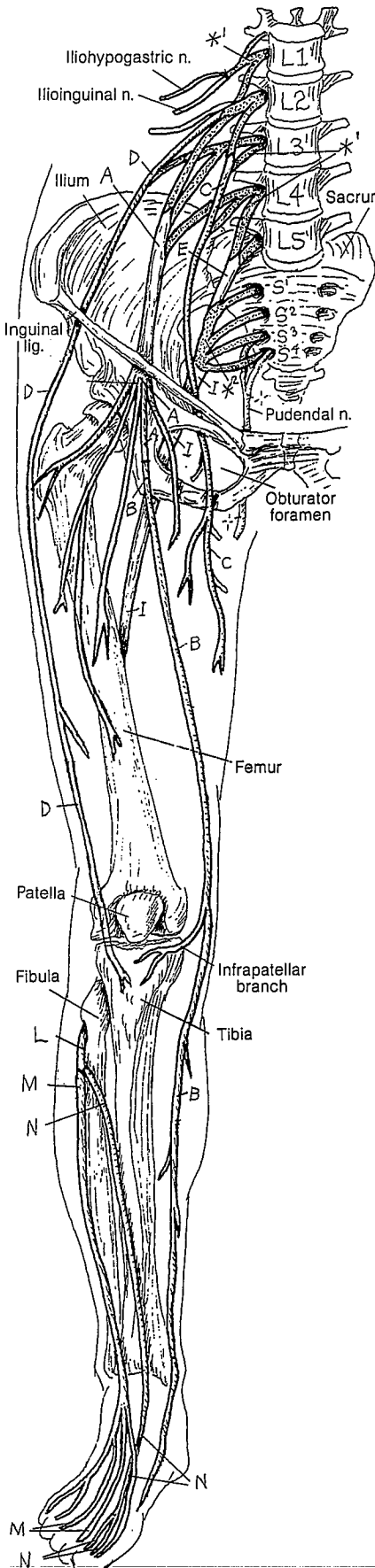
The ulnar nerve (C8-T1; "musician's nerve") supplies certain muscles of the forearm and most intrinsic muscles of the hand. It is subject to trauma as it rounds the elbow in the cubital tunnel, possibly resulting in ulnar-side finger pain, hand weakness, or abnormal little finger position. Similar complaints can be associated with a C8 nerve root compression. The *axillary nerve* (C5-C6) wraps around the neck of the humerus to supply deltoid and teres minor. It is vulnerable in fractures of the humeral neck, possibly resulting in a weak or paralyzed deltoid muscle. The *radial nerve* (C5-C8, T1) supplies the triceps, brachioradialis, and posterior forearm (extensor) muscles moving the wrist and hand. It is subject to damage as it rounds the mid-shaft of the humerus; significant nerve loss here results in "wrist drop" and loss of ability to work the hand (try moving your fingers with your wrist flexed hard). A C7 radiculopathy is characterized by a weak triceps, loss of the triceps jerk (reflex), and numbness of the middle finger. See the appendix for a listing of upper limb muscles and their nerve supply.



MAJOR NERVES OF THE UPPER LIMB (Right limb, anterior view)

LUMBAR PLEXUS & NERVES TO THE LOWER LIMB

CN: Use a bright color for J. (1) Begin with the anterior view. Color the lumbar and sacral plexuses gray; note that they have been dotted for easy identification. Note the longest branch of the femoral nerve: saphenous nerve. (2) Color the posterior view, which includes almost entirely the sciatic nerve and its branches. The heel of the foot has been lifted to view the plantar nerves.



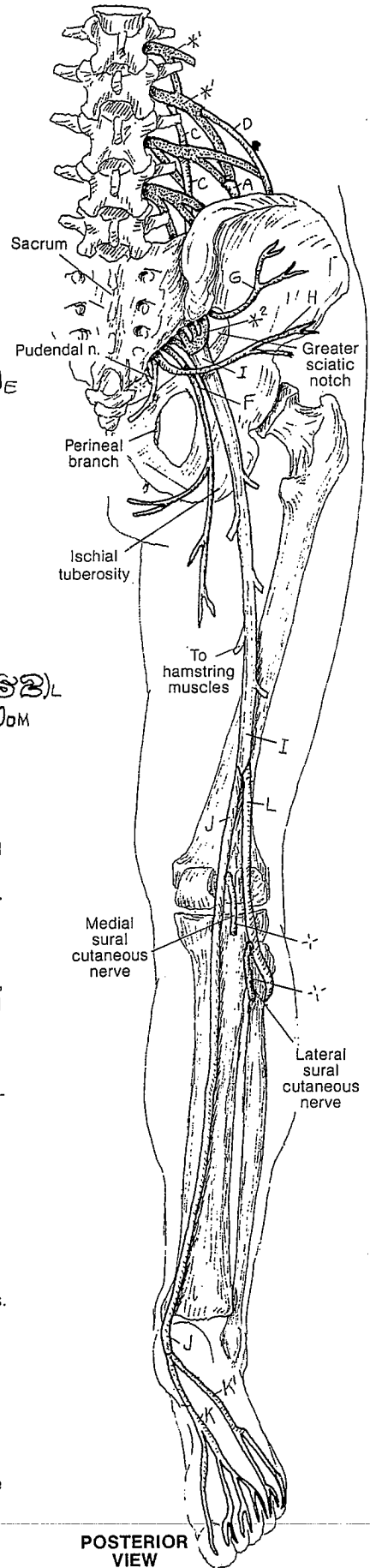
ANTERIOR VIEW

- LUMBAR PLEXUS (L1-L4) ***
- FEMORAL N. _A**
- SAPHENOUS N. _B**
- OBTURATOR N. _C**
- LAT. FEMORAL CUTAN. N. _D**
- LUMBOSACRAL TRUNK (L4-L5) _E**
- SACRAL PLEXUS (L4-S4) *²**
- POST. FEMORAL CUTAN. N. _F**
- SUPERIOR GLUTEAL N. _G**
- INFERIOR GLUTEAL N. _H**
- SCIATIC N. (L4-S3) _I**
- TIBIAL N. (L4-S3) _J**
- MED. LAT. PLANTAR N. _K**
- COMMON FIBULAR N. (L4-S2) _L**
- SUPERFICIAL FIBULAR N. _M**
- DEEP FIBULAR N. _N**

The lumbar plexus, formed from the anterior rami of L1-L4 spinal nerves, is located against the muscles of the posterior abdominal wall. The *femoral nerve* (L2-L4) passes through the psoas major muscle in its descent, emerging lateral to the muscle in the pelvis. As the nerve passes under the inguinal ligament, it lies on the muscle's anterior surface. The femoral nerve breaks up into a leash of nerves in the proximal thigh, supplying the four heads of the quadriceps femoris muscle and the sartorius muscle. Medially, the cutaneous *saphenous nerve* descends to the medial knee and beyond to the ankle. In mid-thigh, it passes through the adductor canal into the posterior femoral compartment, with the femoral artery and vein (recall Plate 63). The *obturator nerve* (L2-L4) passes along the lateral pelvic wall on the obturator internus muscle. It penetrates the obturator foramen to enter the medial thigh, supplying the adductor muscles. Both femoral and obturator nerves are subject to trauma or compression within the pelvis.

The lumbosacral trunk (L4, L5) joins with the sacral spinal nerves to form the *sacral plexus* (L4-S4). From this plexus, the *superior gluteal nerve* (L4, L5, S1) passes through the greater sciatic foramen, above the piriformis muscle, to supply gluteus medius (and sometimes minimus). The *inferior gluteal nerve* (L5, S1, S2) comes into the gluteal region above piriformis to supply gluteus maximus.

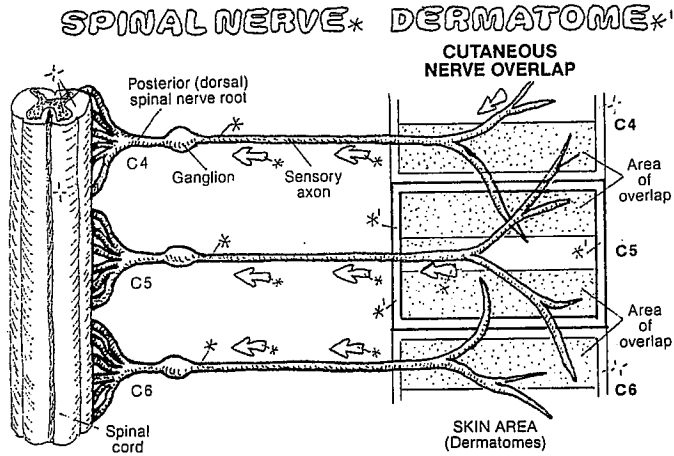
The sciatic nerve joins the posterior femoral cutaneous nerve and the inferior gluteal nerve to pass through the greater sciatic foramen under the piriformis muscle, deep to gluteus maximus (but not innervating it). It descends between the ischial tuberosity and the greater trochanter of the femur. Within the posterior femoral compartment, above the knee, the sciatic nerve splits into the tibial and common fibular (*peroneal*) nerves. The *tibial nerve* supplies the posterior leg muscles and the plantar muscles of the foot. The common fibular nerve supplies the lateral leg muscles (superficial fibular nerve) and the muscles of the anterolateral leg compartment (deep fibular nerve).



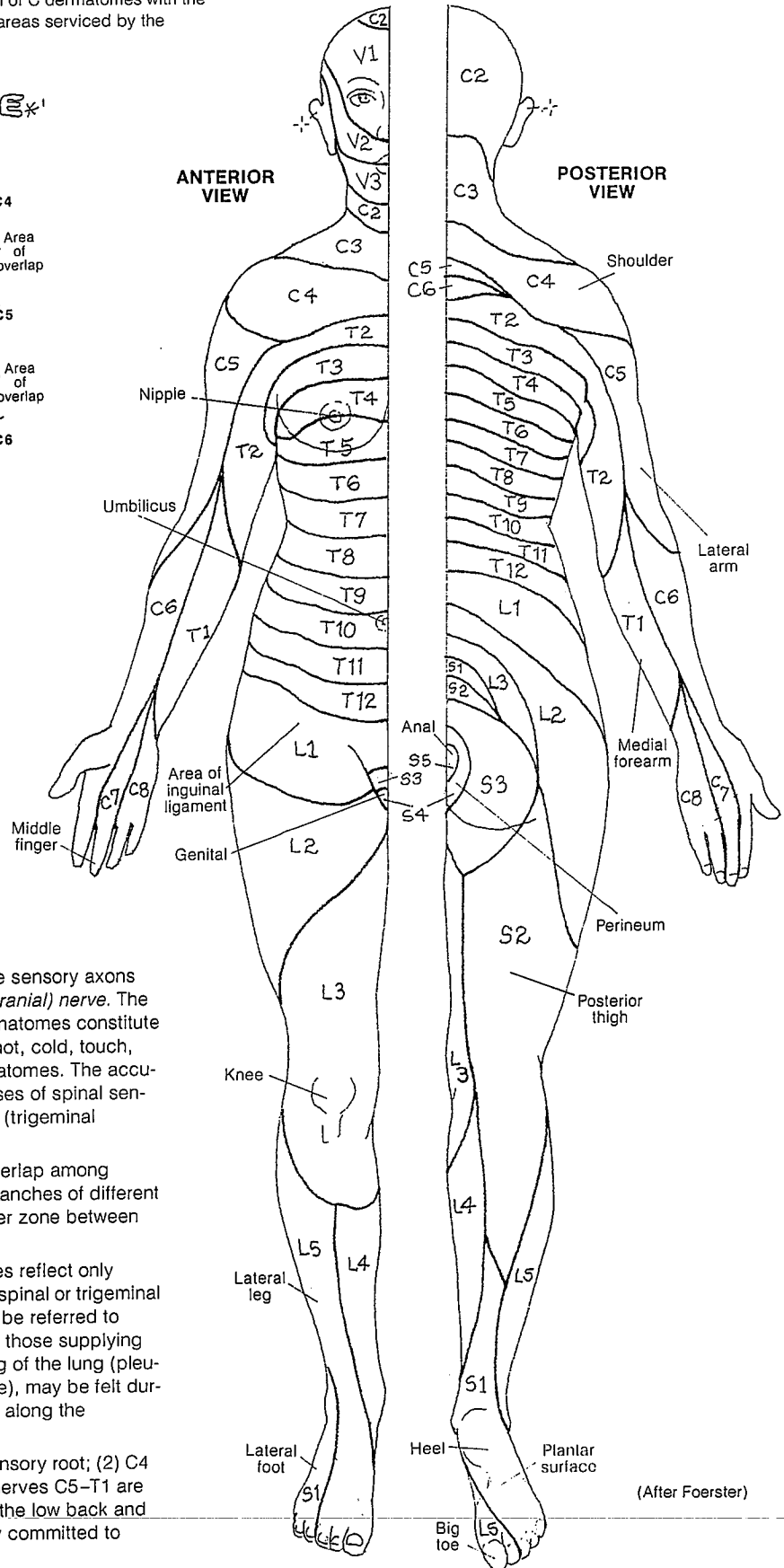
POSTERIOR VIEW

DERMATOMES

CN: (1) Begin with the diagram at left, depicting sensory innervation of an area of skin (dermatome) and the degree of overlap among contiguous spinal nerve cutaneous branches and the dermatomes they supply. Color gray the three spinal nerves and the rectangular borders of the related dermatomes. Note the overlap. (2) Use very light colors for the five groups of dermatomes. Use one color for all dermatomes with the letter V, another color for the dermatomes marked with a C, and so on with T, L, and S. Suggestion: carefully outline the collection of C dermatomes with the color used for C, then color in the enclosed area, focusing on the skin areas serviced by the related spinal nerve; repeat with T, L, and S dermatomes.



- DERMATOMES OF**
- TRIGEMINAL NERVE_V**
V₁-V₃_V
 - CERVICAL NERVES_A**
C₂-C₈_A
 - THORACIC NERVES_B**
T₁-T₁₂_B
 - LUMBAR NERVES_C**
L₁-L₅_C
 - SACRAL NERVES_D**
S₁-S₅_D



A dermatome is an area of skin (cutaneous area) supplied by the sensory axons of a single spinal nerve or a single division of the trigeminal (V cranial) nerve. The body surface is globally covered by sensory receptors. The dermatomes constitute a map of cutaneous innervation. Testing of general sensations (hot, cold, touch, pressure) and pain can help determine deficits in specific dermatomes. The accuracy of dermatomal representation has been corroborated in cases of spinal sensory root/nerve deficit (radiculopathy), trigeminal nerve irritation (trigeminal neuralgia), and spinal cord deficits (myelopathy).

In the case of spinal nerves and the trigeminal nerve, there is overlap among cutaneous branches of neighboring sensory axons. Thus, two branches of different spinal nerves or divisions of the trigeminal nerve cover the border zone between pairs of contiguous dermatomes.

In the case of pain, it is important to understand that dermatomes reflect only cutaneous pain and pain referred to the skin (e.g., visceral pain, spinal or trigeminal sensory nerve root pain). Commonly, pain of visceral origin may be referred to cutaneous areas served by the same spinal sensory nerve(s) as those supplying the visceral structure. For example, the pain of an inflamed lining of the lung (pleurisy), which is innervated by C3-C5 spinal nerves (phrenic nerve), may be felt during deep inspiration in the cervical dermatomes C3-C5 (usually along the supraclavicular nerve distribution).

Finally, note that (1) C1 has no dermatome because it has no sensory root; (2) C4 and T2 dermatomes overlap the chest wall because the spinal nerves C5-T1 are largely committed to the upper limb; and (3) the same is true in the low back and perineum with respect to spinal nerves L4-S2, which are largely committed to the lower limb.

(After Foerster)

SENSORY RECEPTORS

CN: Use your lightest colors for A and E. (1) Begin with the overview of a sensory pathway. (2) Color the general exteroceptors. Note that each receptor is connected to a sensory neuron (B) of a different color. (3) Color the proprioceptors in the lower illustration. Color over the entire muscle spindle, but not the surrounding muscle fibers.

Sensory receptors provide information to the brain about the internal and external environment of the body. Most receptors are transducers: they convert mechanical, chemical, electrical, or light stimuli to electrochemical impulses that can be conducted by the nervous system. Once generated, informational or sensory impulses travel to the CNS via sensory neurons, ultimately reaching the thalamus. Here impulses are relayed to the sensory cortex (conscious interpretation) or to motor centers for appropriate (reflexive) response.

EXTEROCEPTORS

SPECIAL N.S.

GENERAL (CUTANEOUS)

FREE NERVE ENDINGS / AXON

MERKEL (TACTILE) CELL / AXON

ENCAPSULATED ENDINGS

MEISSNER (TACTILE) CORPUSCLE / AXON

RUFFINI (DEFORMATION) ENDINGS / AXON

Exteroceptors are located near the body surface. Special exteroceptors (not shown) include photoreceptors of the retina (light stimuli; Plate 95), taste receptors (chemical stimuli; Plate 100), and auditory receptors (sound stimuli; Plate 98). General exteroceptors are cutaneous sensory endings. They are either encapsulated or free. Free nerve endings, either single or in networks, are found in the epidermis and virtually all of the connective tissues of the body. Free endings may serve as thermoreceptors (heat/cold), mechanoreceptors (light touch), or pain receptors (nociceptors). Free endings may be specialized, as with the Merkel cell endings (see Plate 18) and the spiral endings around hair follicles sensitive to hair movement.

PROPRIOCEPTORS

PACINIAN (PRESSURE) CORPUSCLE / AXON

MUSCLE SPINDLE / MIXED AXONS

NEUROTENDINOUS ORGAN / AXON

Proprioceptors are found in deeper tissues (e.g., superficial fascia, deep fascia, tendons, ligaments, muscles, joint capsules) of the musculoskeletal system. They are sensitive to stretch, movement, pressure, and changes in position. The *Pacinian corpuscles* are large lamellar bodies acting as mechanoreceptors: distortion of their onion skin-like lamellae induces generation of an electrochemical impulse. *Muscle spindles*, sensitive to stretch, consist of two types of special muscle fibers (nuclear bag and nuclear chain) entwined with spiral or flower-spray sensory endings. Stretch of these spindles (and the skeletal muscle in which they are located) induces discharge in the sensory fibers. These impulses reach the cerebellum. Reflexive motor commands tighten the special muscle fibers and increase resistance of the skeletal muscle to stretch. By these spindles, the CNS controls muscle tone and muscle contraction. *Neurotendinous organs* (Golgi) are nerve endings enclosed in capsules located at muscle/tendon junctions or in tendons. They are induced to generate electrochemical impulses in response to tendon deformation or stretch.

INTEROCEPTORS

Interoceptors (not shown) are free or encapsulated nerve endings, often in association with special epithelial cells, located in the walls of vessels and viscera. These receptors include chemoreceptors, baroreceptors (pressure), and nociceptors. They are not usually sensitive to the stimuli to which exteroceptors react.

SENSORY CORTEX

