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Atlas of Neuroanatomy and Neurophysiology

Selections from the Netter Collection of Medical Illustrations

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Atlas of Neuroanatomy and Neurophysiology
Selections from the Netter Collection of Medical Illustrations

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Foreword

Frank Netter: The Physician, The Artist, The Art

This selection of the art of Dr. Frank H. Netter on neuroanatomy and neurophysiology is drawn from the *Atlas of Human Anatomy* and *Netter's Atlas of Human Physiology*. Viewing these pictures again prompts reflection on Dr. Netter's work and his roles as physician and artist.

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

When Dr. Netter's work is discussed, attention is focused primarily on Netter the artist and only secondarily on Netter the physician. As a student of Dr. Netter's work for more than forty years, I can say that the true strength of a Netter illustration was always established well before brush was laid to paper. In that respect each plate is more of an intellectual than an artistic or aesthetic exercise. It is easy to appreciate the aesthetic qualities of Dr. Netter's work, but to overlook its intellectual qualities is to miss the real strength and intent of the art. This intellectual process requires thorough understanding of the topic, as Dr. Netter wrote: "Strange as it may seem, the hardest part of making a medical picture is not the drawing at all. It is the planning, the conception, the determination of point of view and the approach which will best clarify the subject which takes the most effort."

Years before the inception of "the integrated curriculum," Netter the physician realized that a good medical illustration can include clinical information and physiologic functions as well as anatomy. In pursuit of this principle Dr. Netter often integrates pertinent basic and clinical science elements in his anatomic interpretations. Although he was chided for this heresy by a prominent European anatomy professor, many generations of students training to be physicians rather than anatomists have appreciated Dr. Netter's concept.

The integration of physiology and clinical medicine with anatomy has led Dr. Netter to another, more subtle, choice in his art. Many texts and atlases published during the period of Dr. Netter's career depict anatomy clearly based on cadaver specimens with renderings of shrunken and shriveled tissues and organs. Netter the physician chose to render "live" versions of these structures—not shriveled, colorless, formaldehyde-soaked tissues, but plump, robust organs, glowing with color!

The value of Dr. Netter's approach is clearly demonstrated by the plates in this selection.

John A. Craig, MD
Austin, Texas

This volume brings together two distinct but related aspects of the work of Frank H. Netter, MD, and associated artists. Netter is best known as the creator of the *Atlas of Human Anatomy*, a comprehensive textbook of gross anatomy that has become the standard atlas for students of the subject. But Netter's work included far more than anatomical art. In the pages of *Clinical Symposia*, a series of monographs published over a period of more than 50 years, and in *The Netter Collection of Medical Illustrations*, this premier medical artist created superb illustrations of biological and physiological processes, disease pathology, clinical presentations, and medical procedures.

As a service to the medical community, Novartis Pharmaceuticals has commissioned this special edition of Netter's work, which includes his beautiful and instructive illustrations of nervous system anatomy as well as his depictions of neurophysiological concepts and functions. We hope that readers will find Dr. Netter's renderings of neurological form and function interesting and useful.

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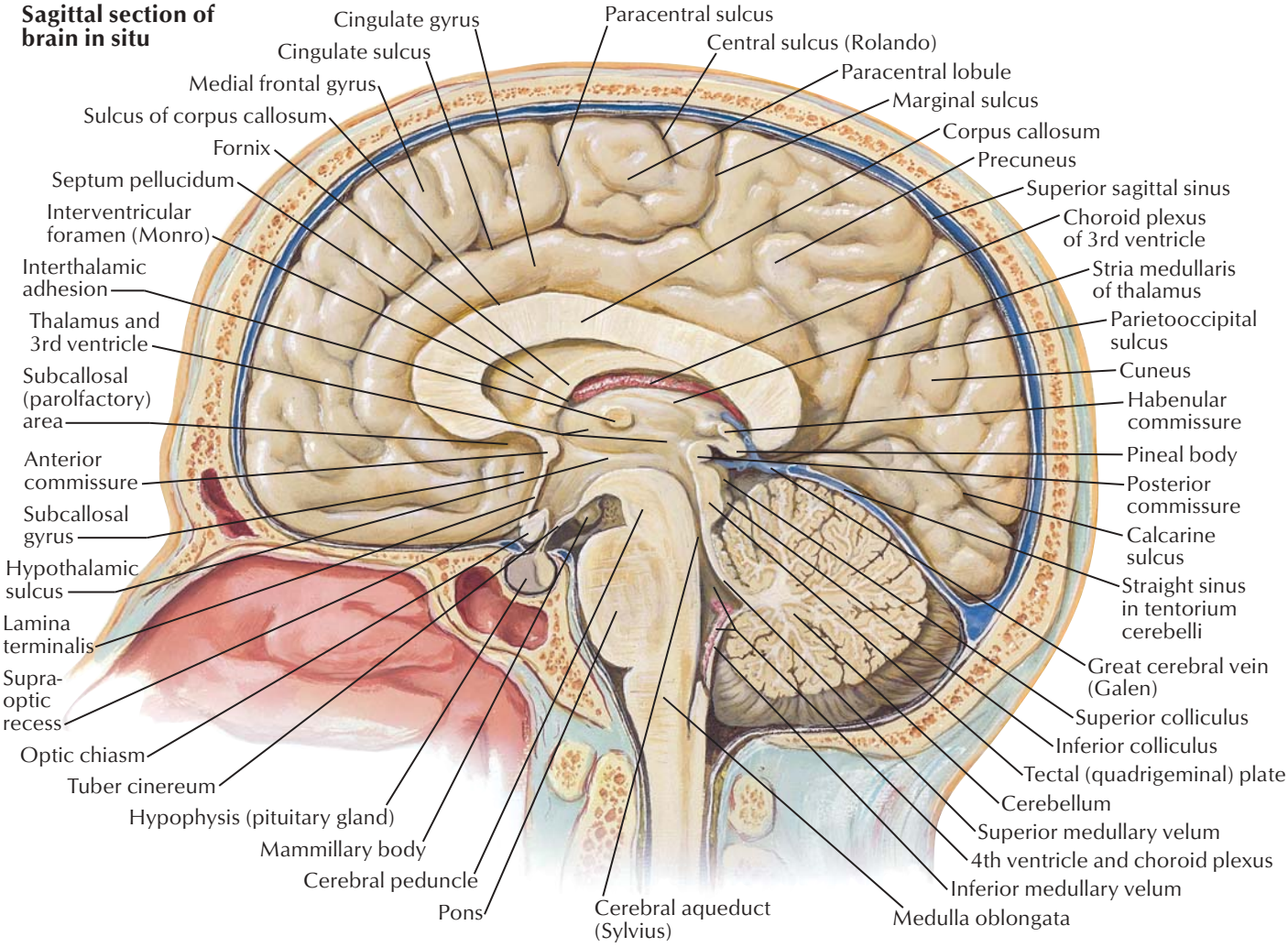


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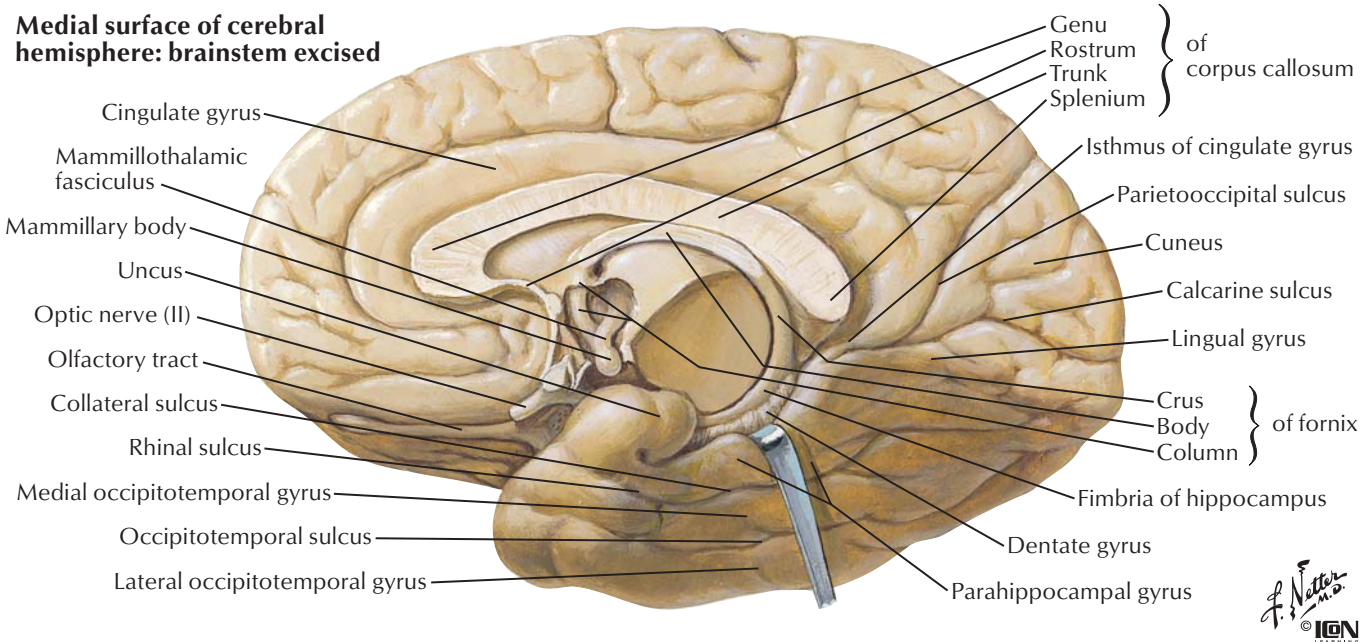
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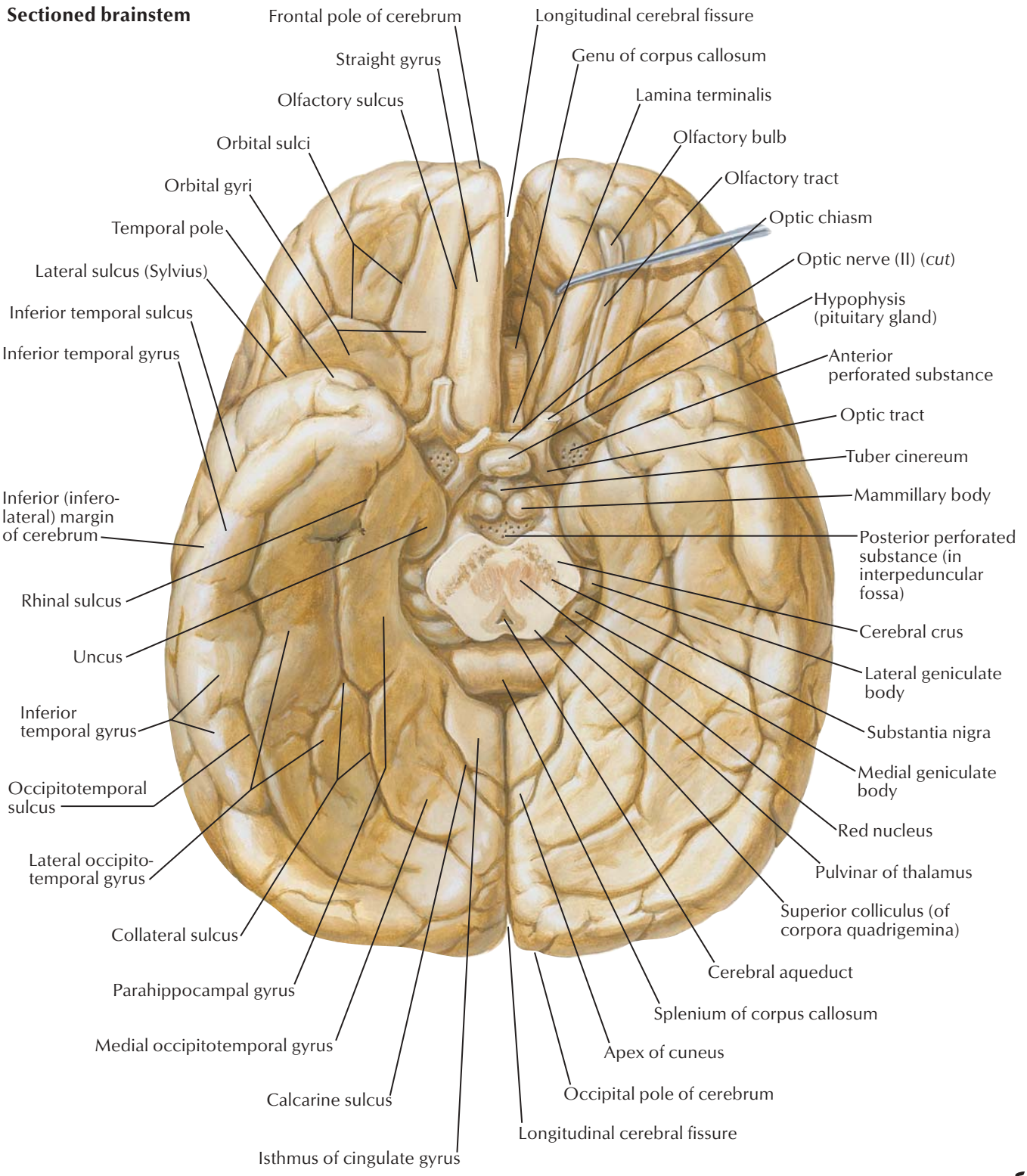
Sagittal section of brain in situ



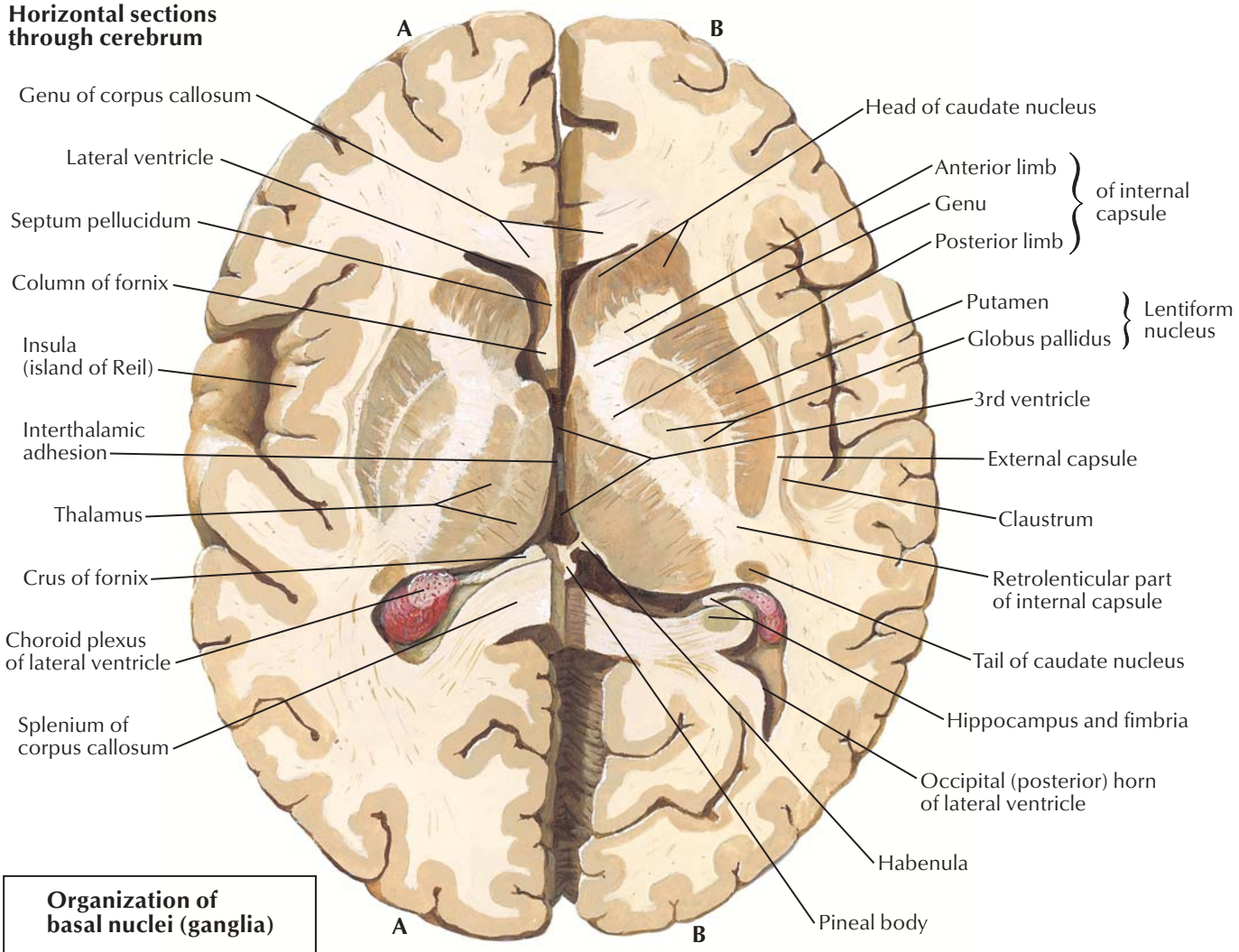
Medial surface of cerebral hemisphere: brainstem excised



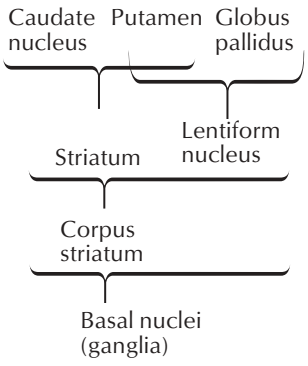
F. Netter M.D. ©ION

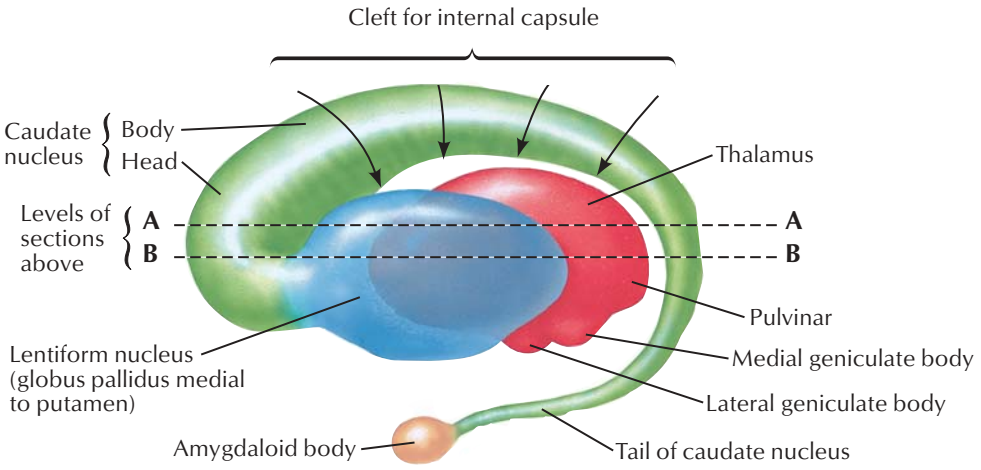

Sectioned brainstem
Frontal pole of cerebrum
Longitudinal cerebral fissure
Straight gyrus
Genu of corpus callosum
Olfactory sulcus
Lamina terminalis
Orbital sulci
Olfactory bulb
Orbital gyri
Olfactory tract
Temporal pole
Optic chiasm
Lateral sulcus (Sylvius)
Optic nerve (II) (cut)
Inferior temporal sulcus
Hypophysis (pituitary gland)
Inferior temporal gyrus
Anterior perforated substance
Optic tract
Tuber cinereum
Inferior (infero-lateral) margin of cerebrum
Mammillary body
Posterior perforated substance (in interpeduncular fossa)
Rhinal sulcus
Cerebral crus
Uncus
Lateral geniculate body
Inferior temporal gyrus
Substantia nigra
Medial geniculate body
Occipitotemporal sulcus
Red nucleus
Lateral occipito-temporal gyrus
Pulvinar of thalamus
Superior colliculus (of corpora quadrigemina)
Collateral sulcus
Cerebral aqueduct
Parahippocampal gyrus
Splenium of corpus callosum
Medial occipitotemporal gyrus
Apex of cuneus
Occipital pole of cerebrum
Calcarine sulcus
Longitudinal cerebral fissure
Isthmus of cingulate gyrus

Horizontal sections through cerebrum



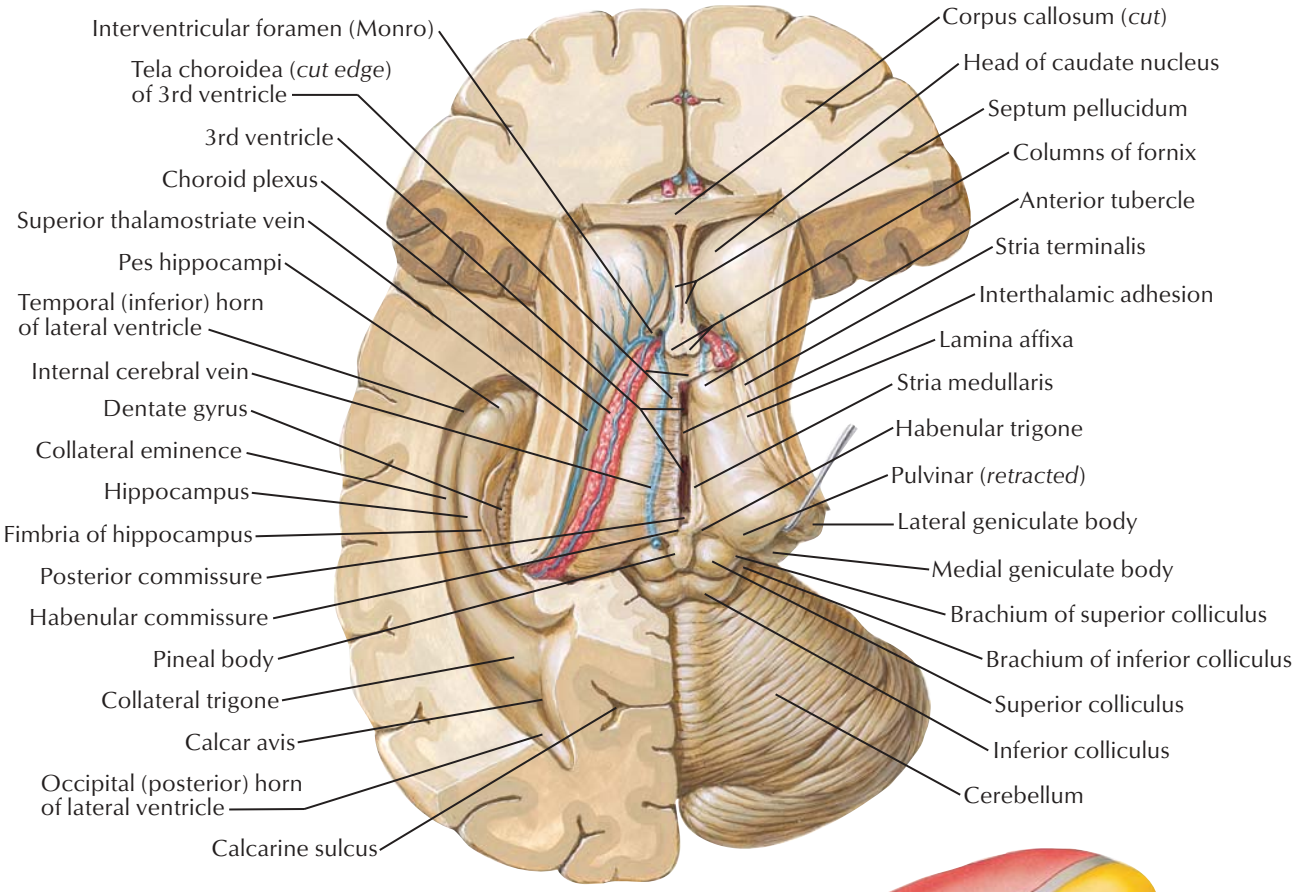
Organization of basal nuclei (ganglia)

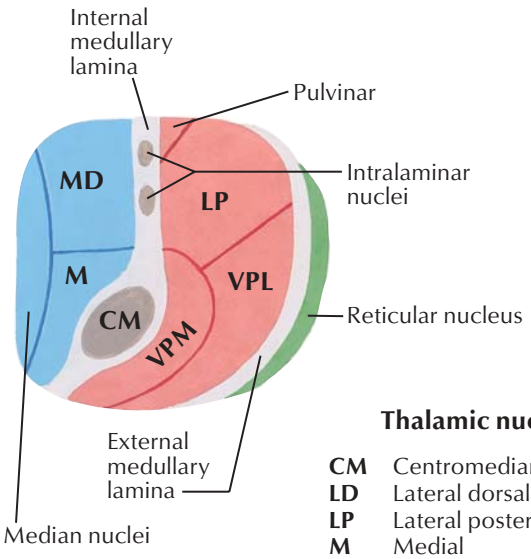




Interrelationship of thalamus, lentiform nucleus, caudate nucleus and amygdaloid body (schema): left lateral view

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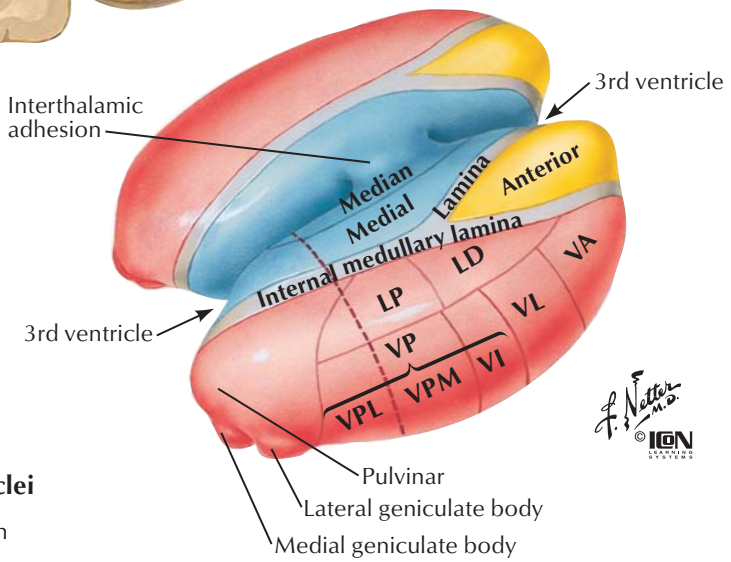




Schematic section through thalamus
(at level of broken line shown in figure at right)

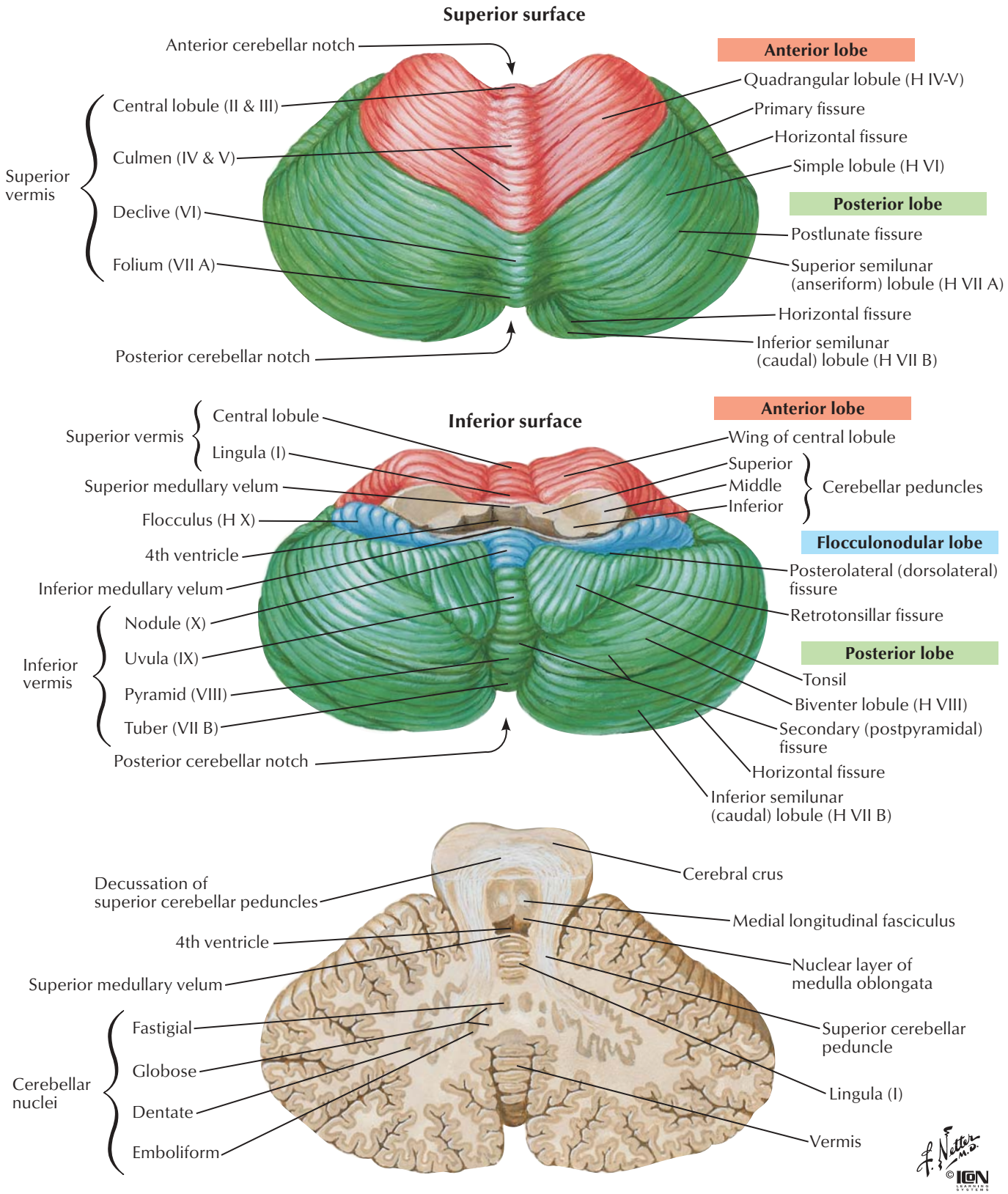
Thalamic nuclei

CM	Centromedian
LD	Lateral dorsal
LP	Lateral posterior
M	Medial
MD	Medial dorsal
VA	Ventral anterior
VI	Ventral intermedial
VL	Ventral lateral
VP	Ventral posterior
VPL	Ventral posterolateral
VPM	Ventral posteromedial

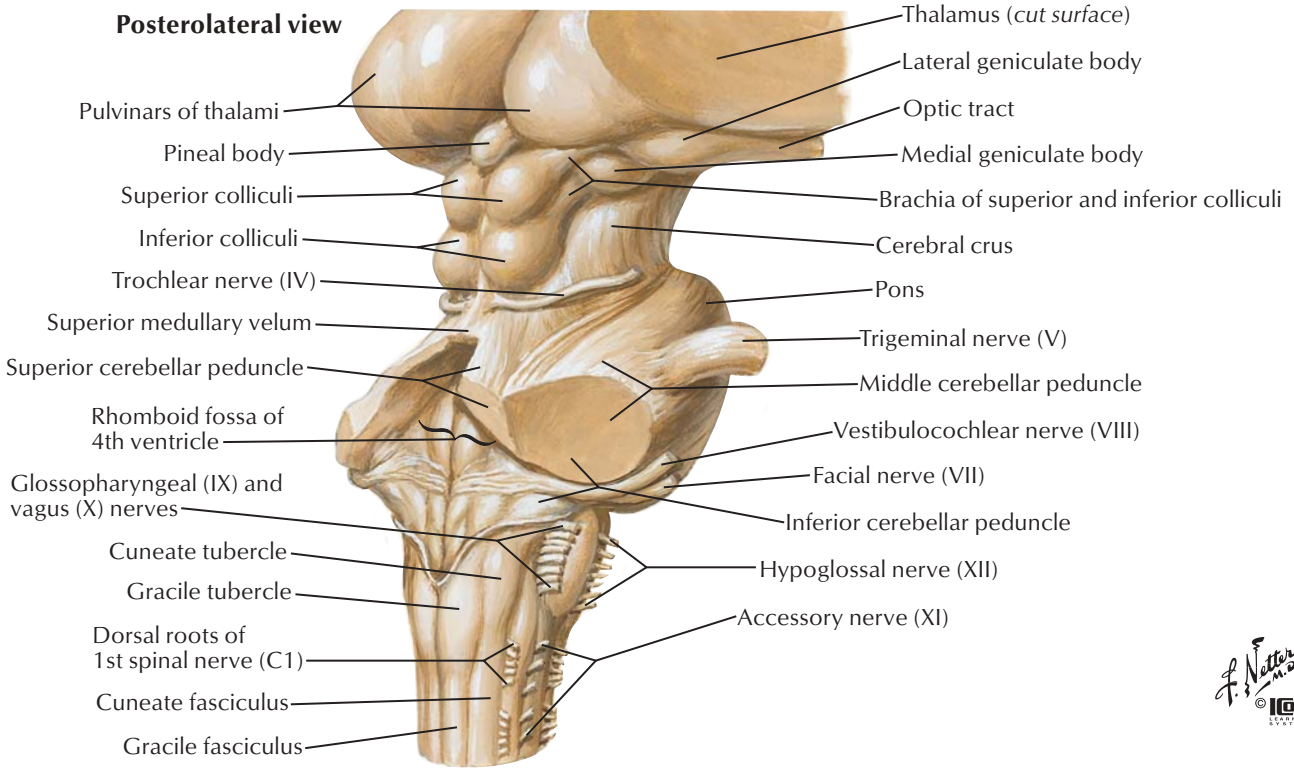


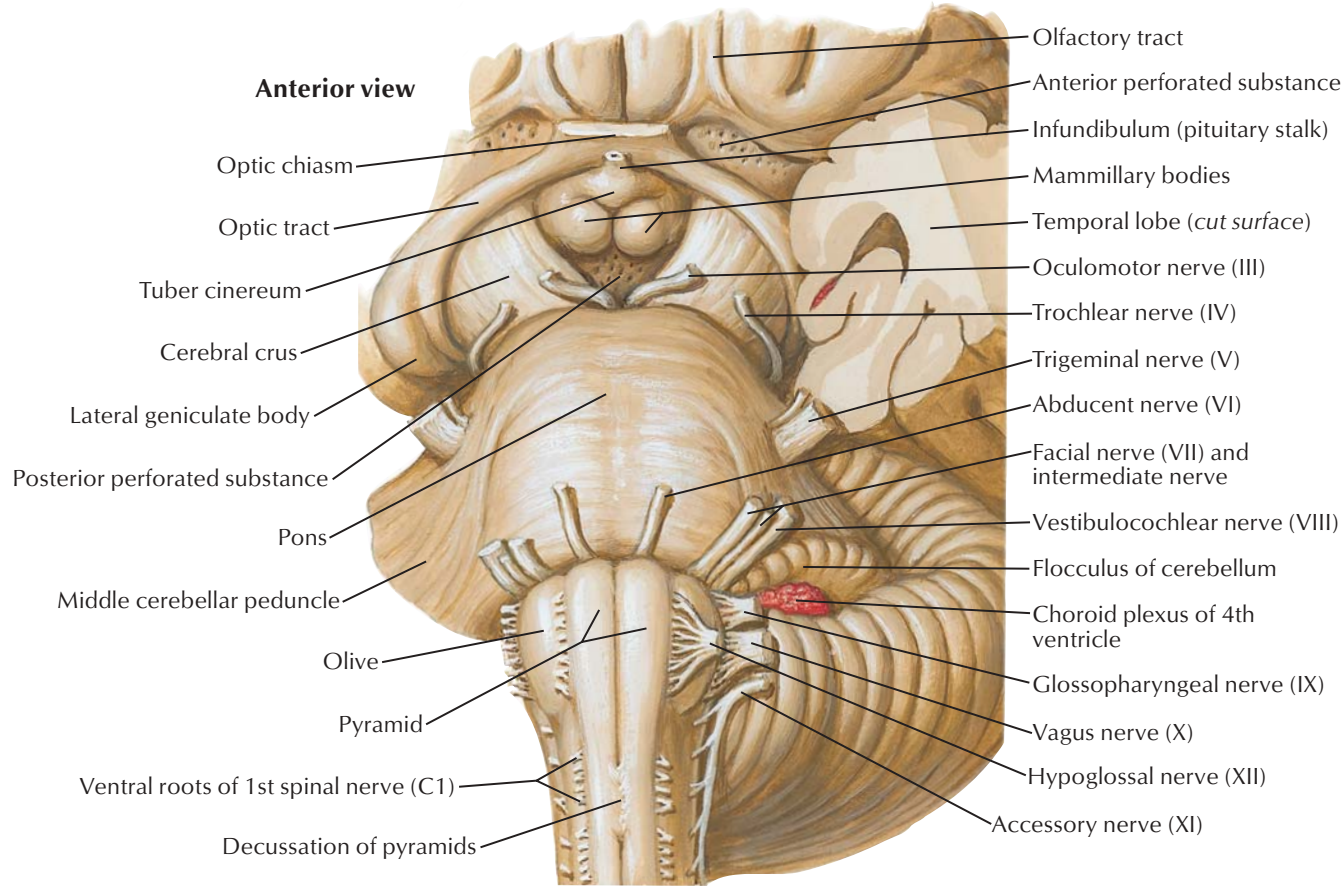
Schematic representation of thalamus
(external medullary lamina and reticular nuclei removed)

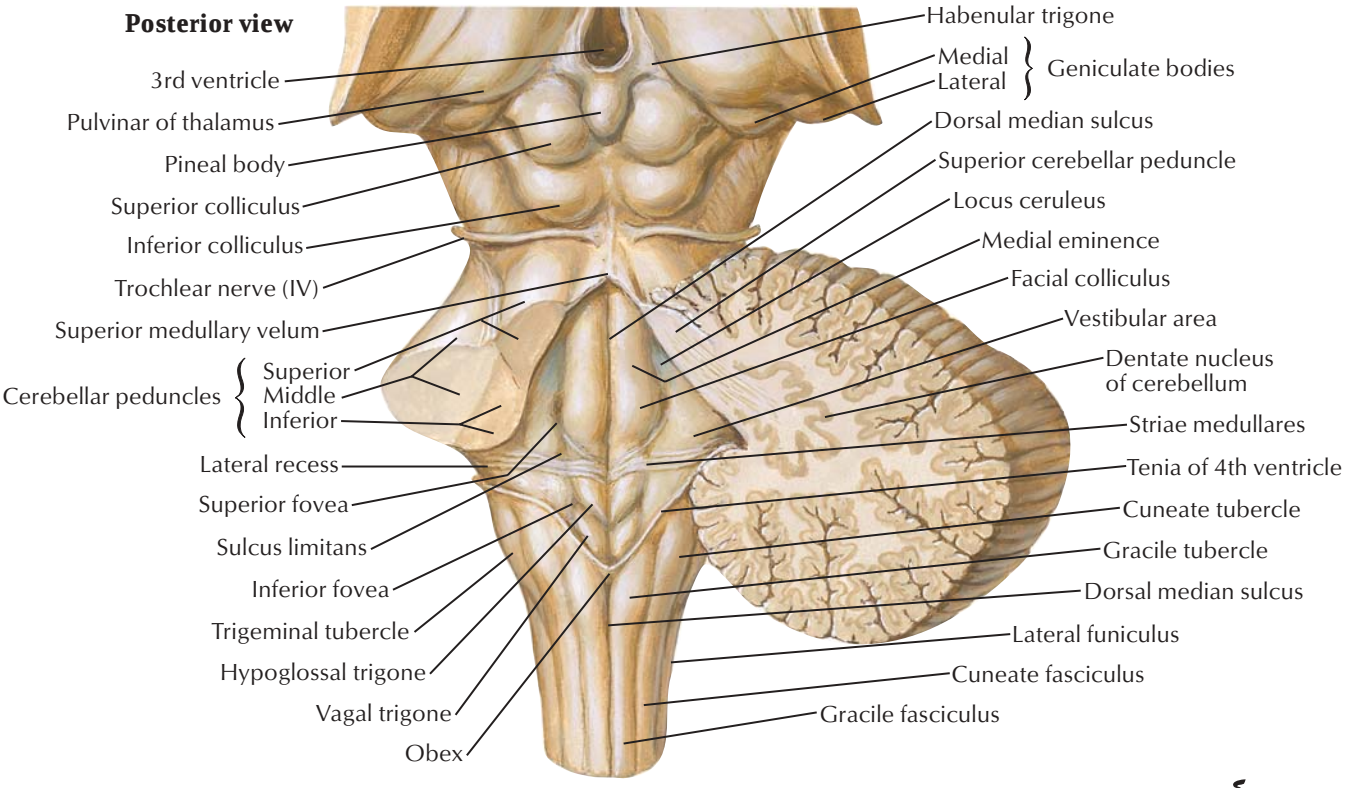
Lateral nuclei
Medial nuclei
Anterior nuclei

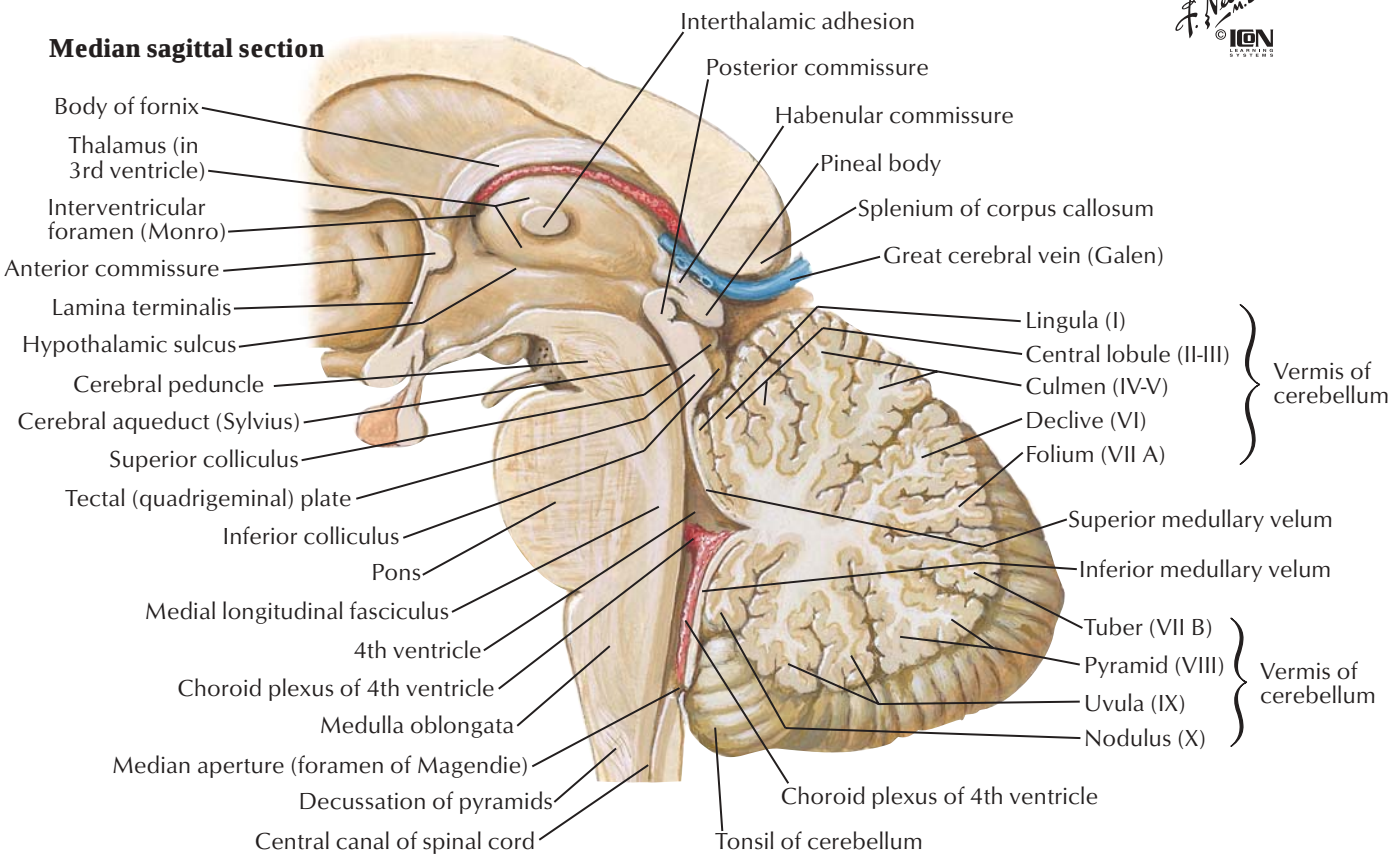


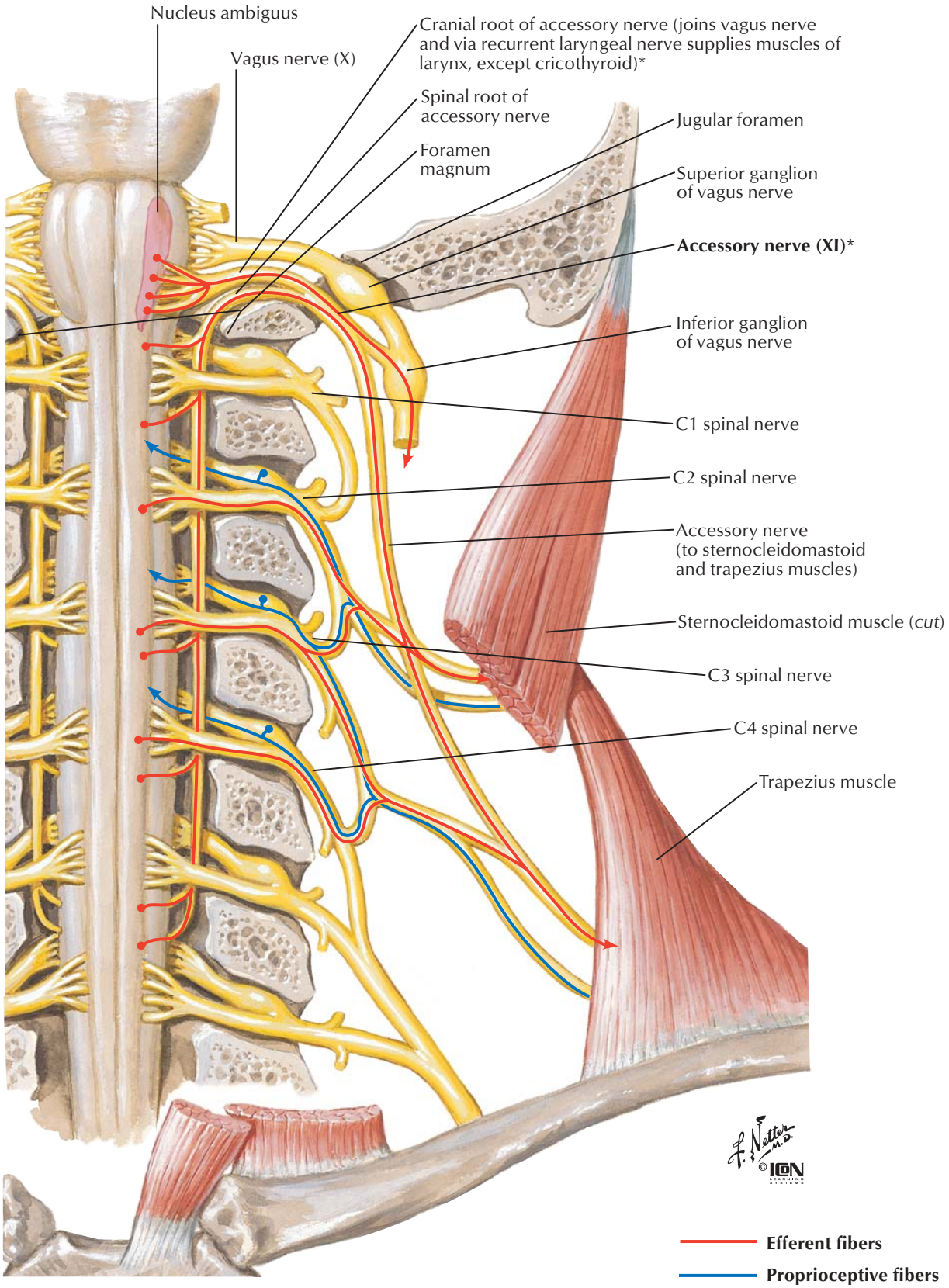
Section in plane of superior cerebellar peduncle


Posterolateral view
Thalamus (cut surface)
Lateral geniculate body
Optic tract
Medial geniculate body
Brachia of superior and inferior colliculi
Cerebral crus
Pons
Trigeminal nerve (V)
Middle cerebellar peduncle
Vestibulocochlear nerve (VIII)
Facial nerve (VII)
Inferior cerebellar peduncle
Hypoglossal nerve (XII)
Accessory nerve (XI)
Pulvinars of thalami
Pineal body
Superior colliculi
Inferior colliculi
Trochlear nerve (IV)
Superior medullary velum
Superior cerebellar peduncle
Rhomboid fossa of 4th ventricle
Glossopharyngeal (IX) and vagus (X) nerves
Cuneate tubercle
Gracile tubercle
Dorsal roots of 1st spinal nerve (C1)
Cuneate fasciculus
Gracile fasciculus

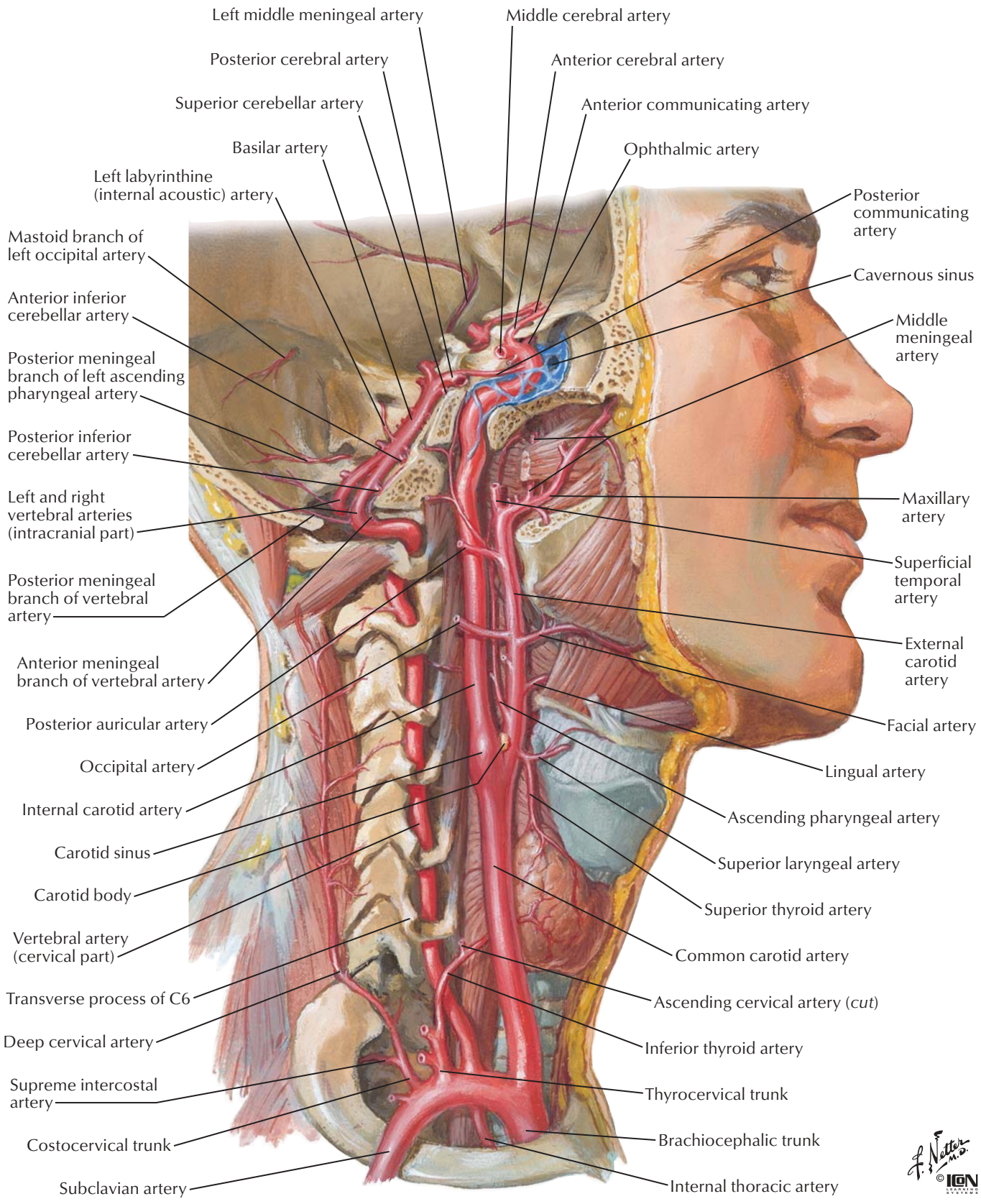

Anterior view
Olfactory tract
Anterior perforated substance
Infundibulum (pituitary stalk)
Mammillary bodies
Temporal lobe (cut surface)
Oculomotor nerve (III)
Trochlear nerve (IV)
Trigeminal nerve (V)
Abducent nerve (VI)
Facial nerve (VII) and intermediate nerve
Vestibulocochlear nerve (VIII)
Flocculus of cerebellum
Choroid plexus of 4th ventricle
Glossopharyngeal nerve (IX)
Vagus nerve (X)
Hypoglossal nerve (XII)
Accessory nerve (XI)
Optic chiasm
Optic tract
Tuber cinereum
Cerebral crus
Lateral geniculate body
Posterior perforated substance
Pons
Middle cerebellar peduncle
Olive
Pyramid
Ventral roots of 1st spinal nerve (C1)
Decussation of pyramids

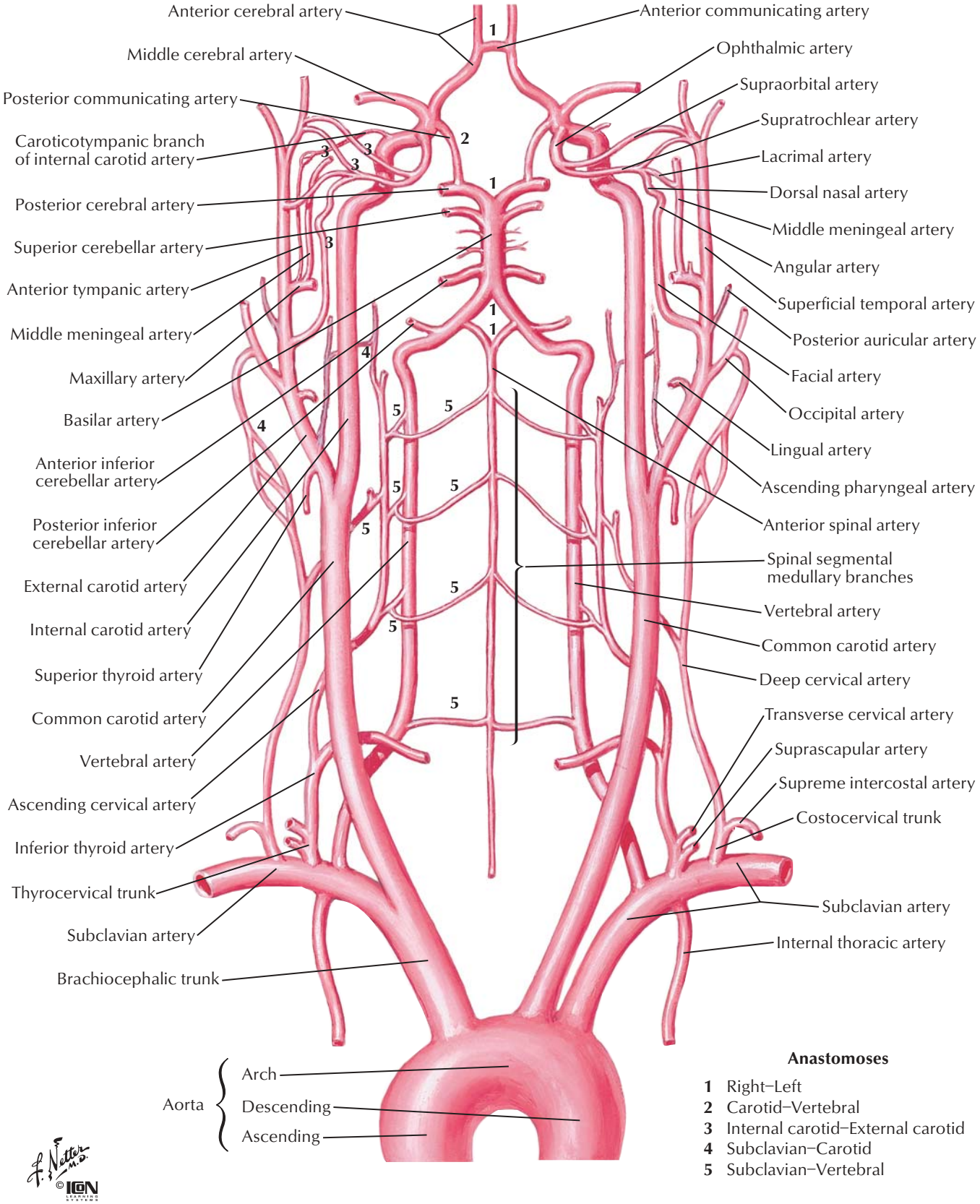

Posterior view
3rd ventricle
Pulvinar of thalamus
Pineal body
Superior colliculus
Inferior colliculus
Trochlear nerve (IV)
Superior medullary velum
Cerebellar peduncles
Superior
Middle
Inferior
Lateral recess
Superior fovea
Sulcus limitans
Inferior fovea
Trigeminal tubercle
Hypoglossal trigone
Vagal trigone
Obex
Habenular trigone
Medial
Lateral
Geniculate bodies
Dorsal median sulcus
Superior cerebellar peduncle
Locus ceruleus
Medial eminence
Facial colliculus
Vestibular area
Dentate nucleus of cerebellum
Striae medullares
Tenia of 4th ventricle
Cuneate tubercle
Gracile tubercle
Dorsal median sulcus
Lateral funiculus
Cuneate fasciculus
Gracile fasciculus

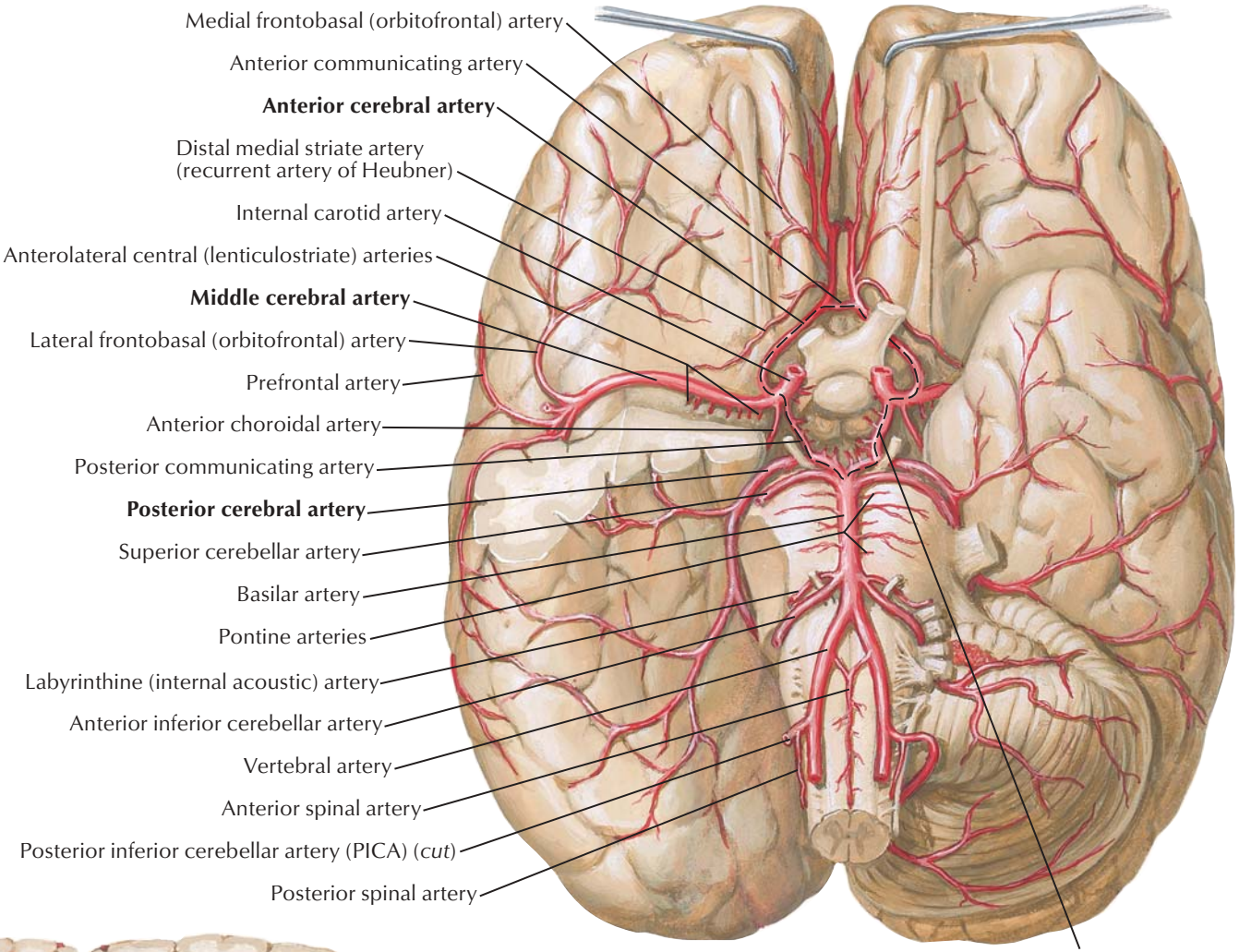

Median sagittal section
Body of fornix
Thalamus (in 3rd ventricle)
Interventricular foramen (Monro)
Anterior commissure
Lamina terminalis
Hypothalamic sulcus
Cerebral peduncle
Cerebral aqueduct (Sylvius)
Superior colliculus
Tectal (quadrigeminal) plate
Inferior colliculus
Pons
Medial longitudinal fasciculus
4th ventricle
Choroid plexus of 4th ventricle
Medulla oblongata
Median aperture (foramen of Magendie)
Decussation of pyramids
Central canal of spinal cord
Interthalamic adhesion
Posterior commissure
Habenular commissure
Pineal body
Splenium of corpus callosum
Great cerebral vein (Galen)
Lingula (I)
Central lobule (II-III)
Culmen (IV-V)
Declive (VI)
Folium (VII A)
Vermis of cerebellum
Superior medullary velum
Inferior medullary velum
Tuber (VII B)
Pyramid (VIII)
Uvula (IX)
Nodulus (X)
Vermis of cerebellum
Choroid plexus of 4th ventricle
Tonsil of cerebellum

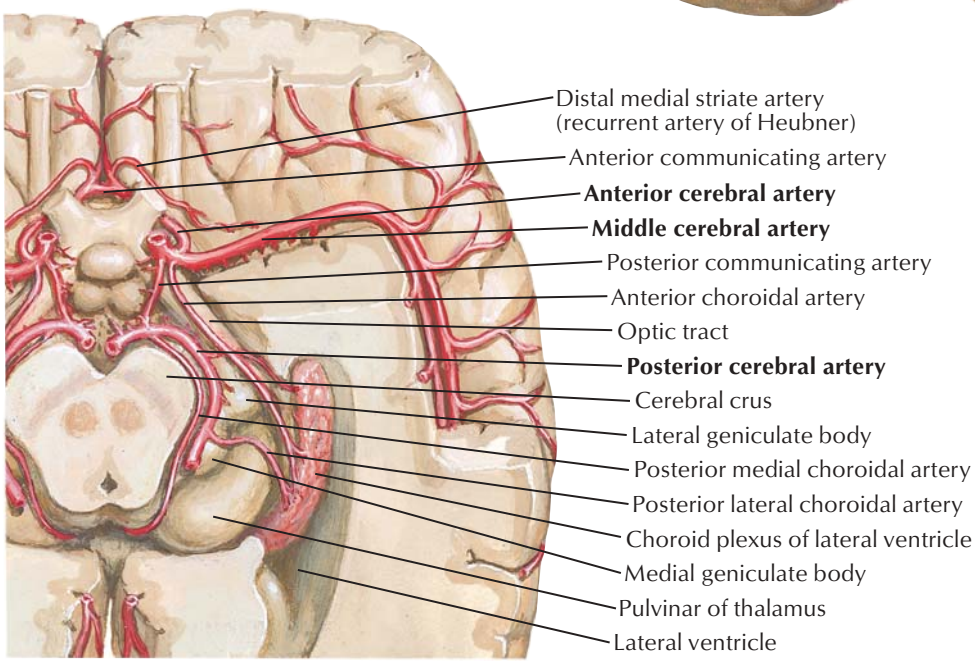


*Recent evidence suggests that the accessory nerve lacks a cranial root and has no connection to the vagus nerve. Verification of this finding awaits further investigation.


Left middle meningeal artery
Middle cerebral artery
Posterior cerebral artery
Anterior cerebral artery
Superior cerebellar artery
Anterior communicating artery
Basilar artery
Ophthalmic artery
Left labyrinthine (internal acoustic) artery
Posterior communicating artery
Mastoid branch of left occipital artery
Cavernous sinus
Anterior inferior cerebellar artery
Middle meningeal artery
Posterior meningeal branch of left ascending pharyngeal artery
Posterior inferior cerebellar artery
Left and right vertebral arteries (intracranial part)
Maxillary artery
Superficial temporal artery
Posterior meningeal branch of vertebral artery
External carotid artery
Anterior meningeal branch of vertebral artery
Facial artery
Posterior auricular artery
Lingual artery
Occipital artery
Ascending pharyngeal artery
Internal carotid artery
Superior laryngeal artery
Carotid sinus
Superior thyroid artery
Carotid body
Common carotid artery
Vertebral artery (cervical part)
Ascending cervical artery (cut)
Transverse process of C6
Inferior thyroid artery
Deep cervical artery
Thyrocervical trunk
Supreme intercostal artery
Brachiocephalic trunk
Costocervical trunk
Internal thoracic artery
Subclavian artery

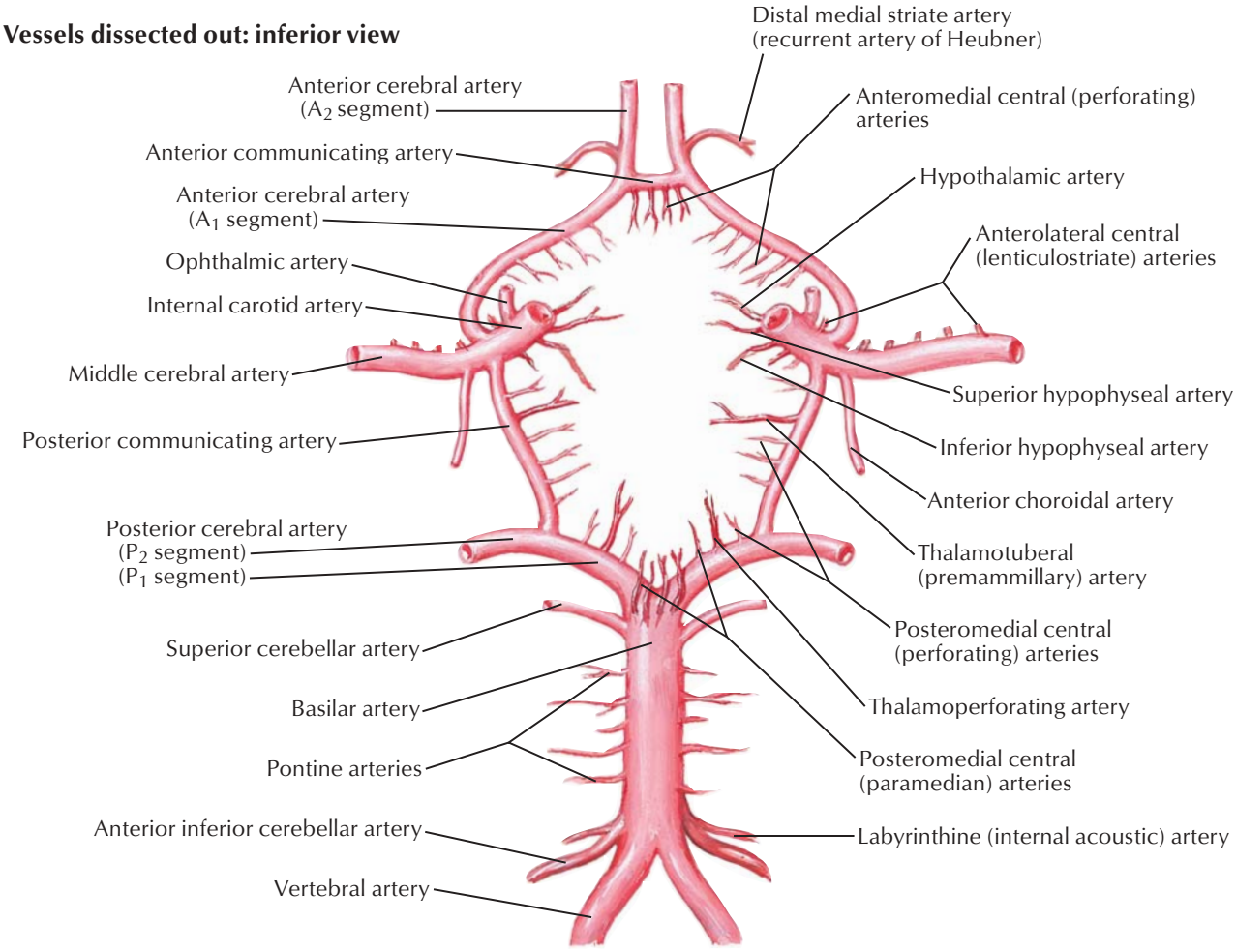

Anterior cerebral artery
Middle cerebral artery
Posterior communicating artery
Caroticotympanic branch of internal carotid artery
Posterior cerebral artery
Superior cerebellar artery
Anterior tympanic artery
Middle meningeal artery
Maxillary artery
Basilar artery
Anterior inferior cerebellar artery
Posterior inferior cerebellar artery
External carotid artery
Internal carotid artery
Superior thyroid artery
Common carotid artery
Vertebral artery
Ascending cervical artery
Inferior thyroid artery
Thyrocervical trunk
Subclavian artery
Brachiocephalic trunk
Aorta
Arch
Descending
Ascending
Anterior communicating artery
Ophthalmic artery
Supraorbital artery
Supratrochlear artery
Lacrimal artery
Dorsal nasal artery
Middle meningeal artery
Angular artery
Superficial temporal artery
Posterior auricular artery
Facial artery
Occipital artery
Lingual artery
Ascending pharyngeal artery
Anterior spinal artery
Spinal segmental medullary branches
Vertebral artery
Common carotid artery
Deep cervical artery
Transverse cervical artery
Suprascapular artery
Supreme intercostal artery
Costocervical trunk
Subclavian artery
Internal thoracic artery
1
2
3
4
5
Anastomoses
1 Right–Left
2 Carotid–Vertebral
3 Internal carotid–External carotid
4 Subclavian–Carotid
5 Subclavian–Vertebral



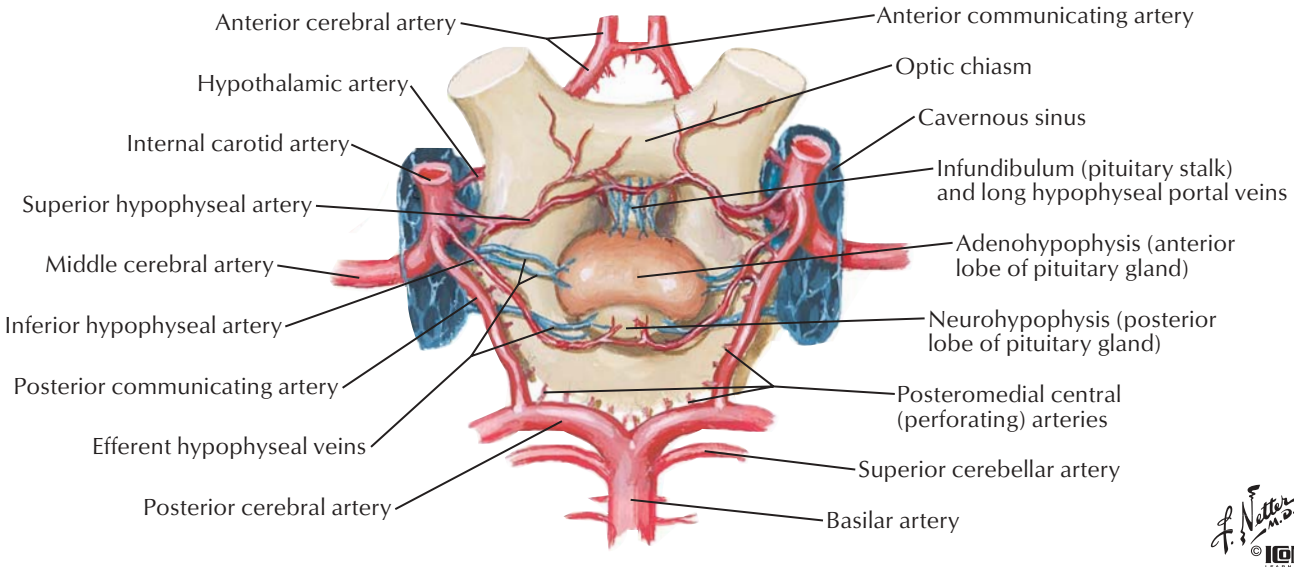


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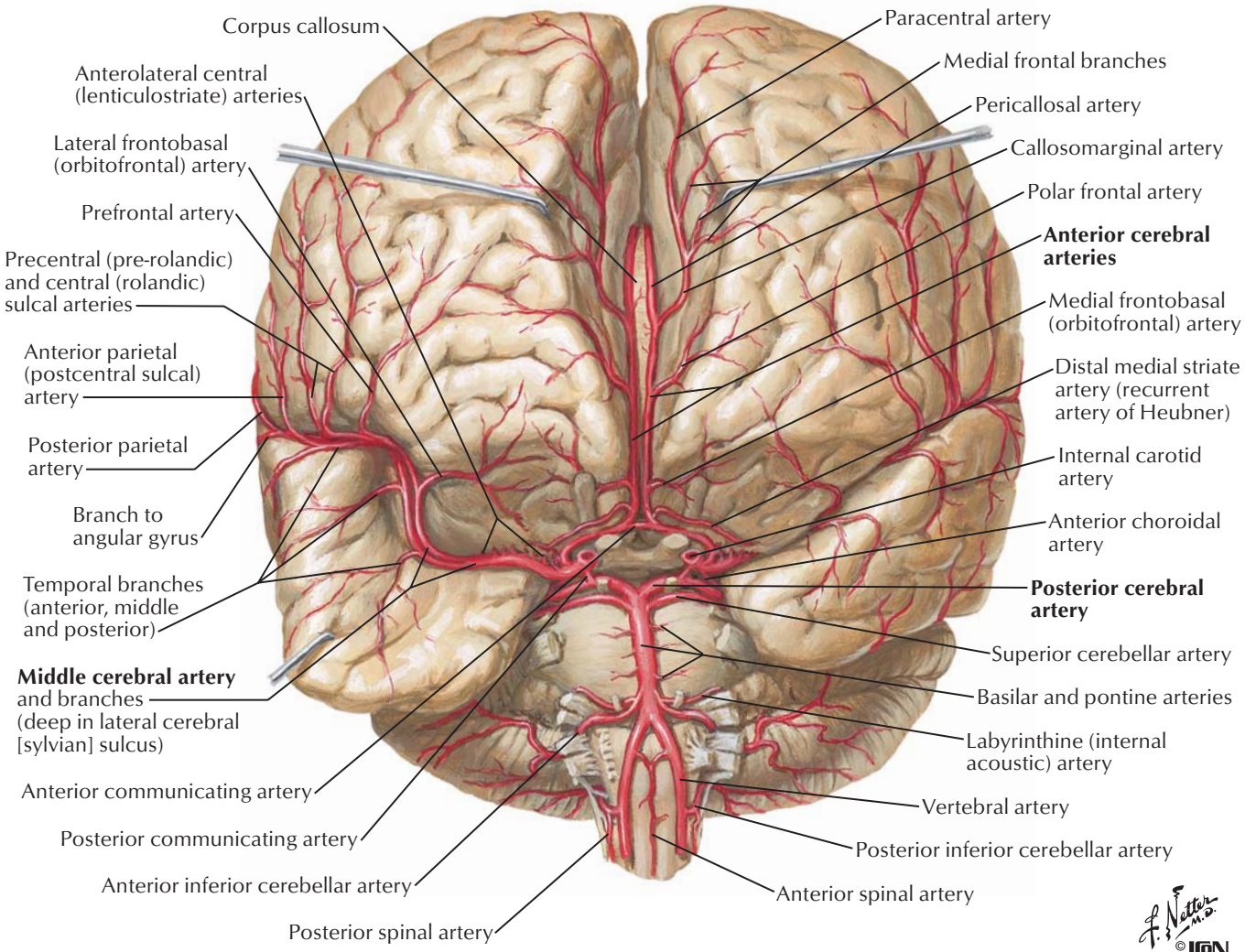
Vessels dissected out: inferior view

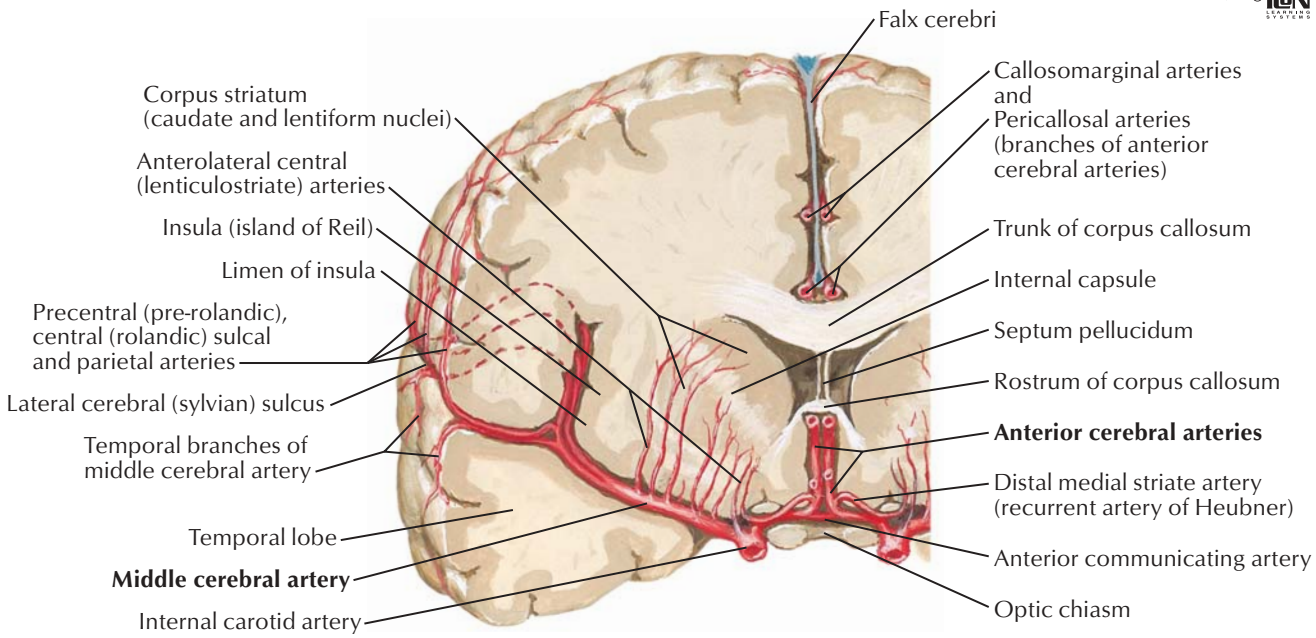


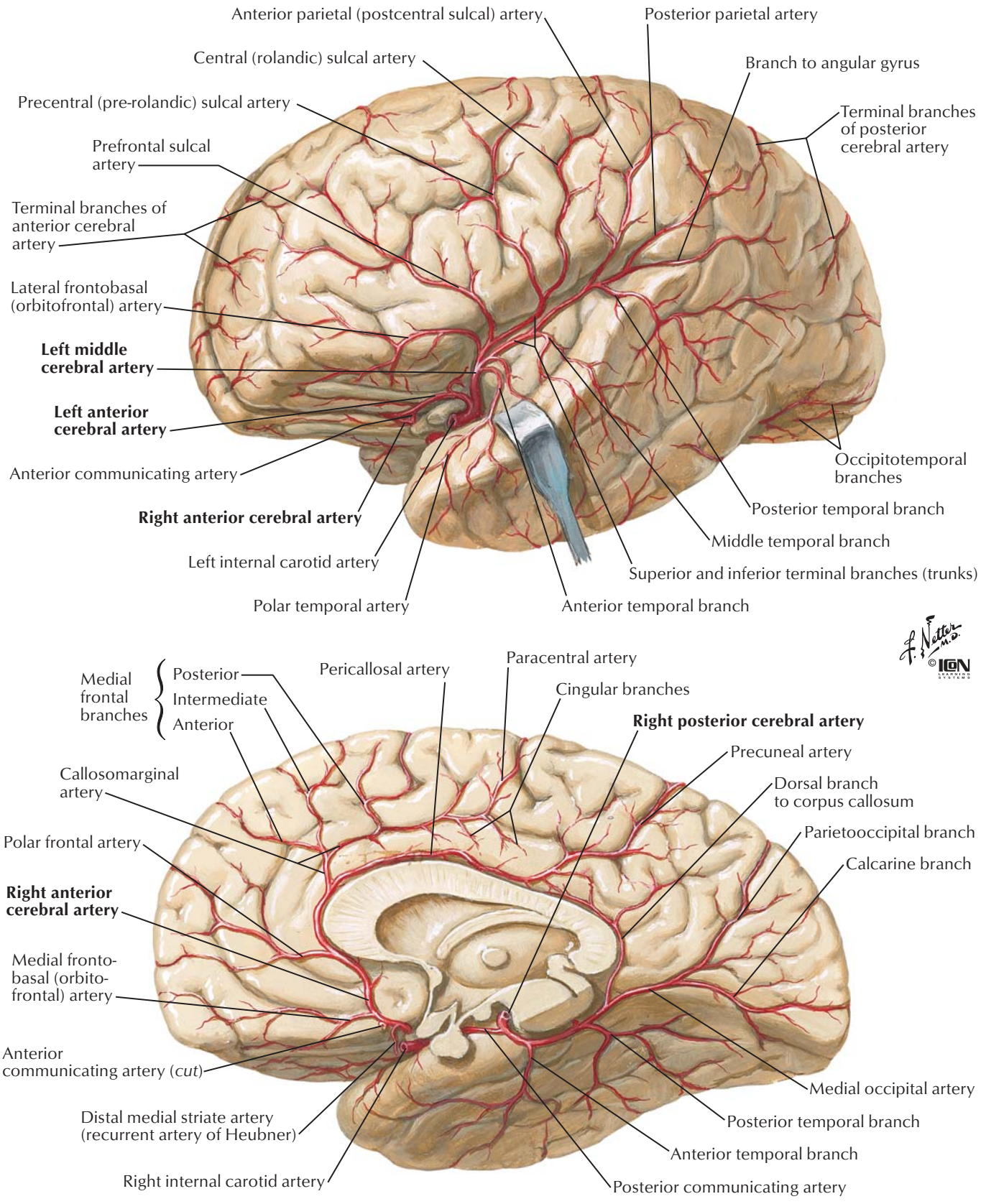
Vessels in situ: inferior view



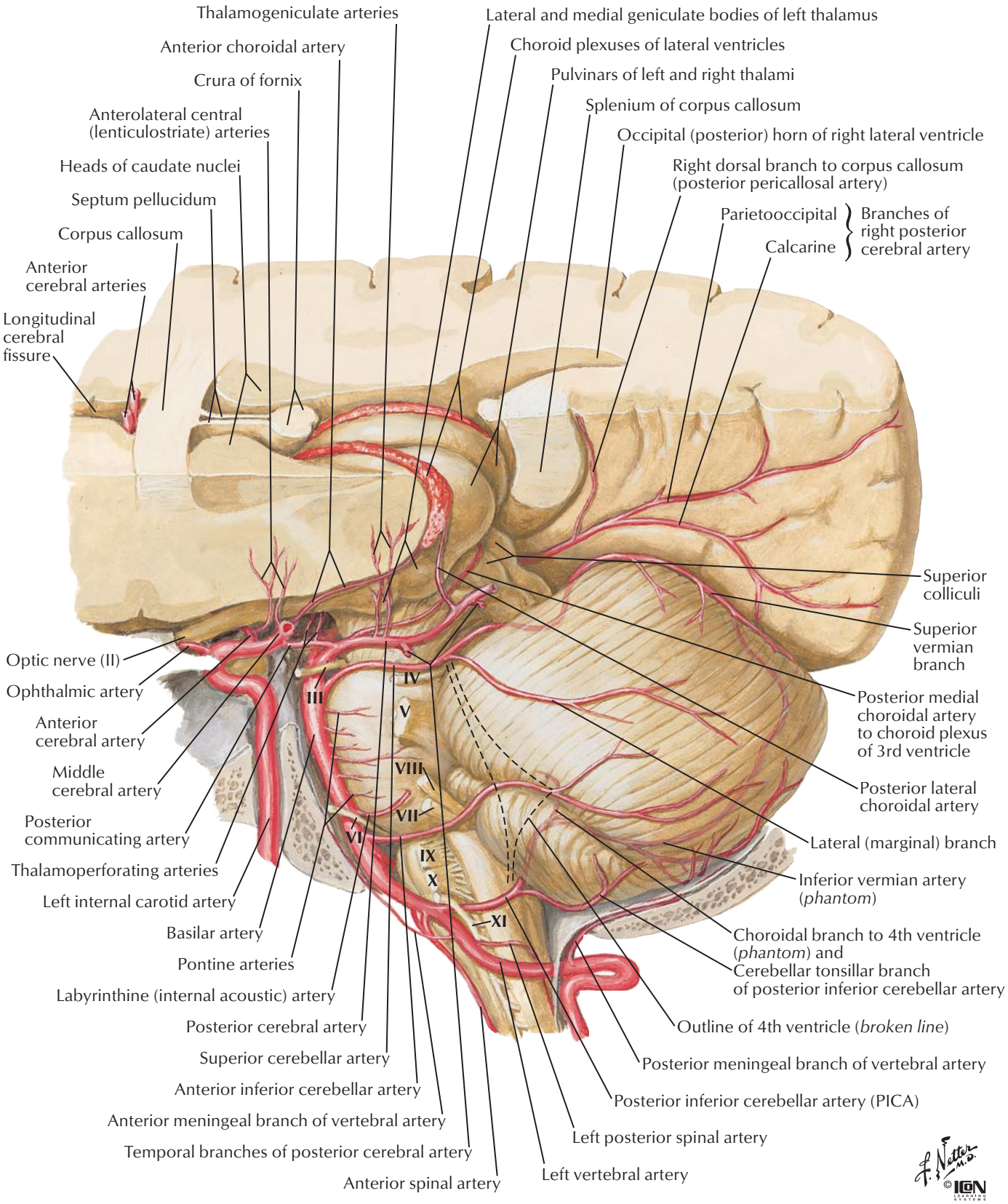
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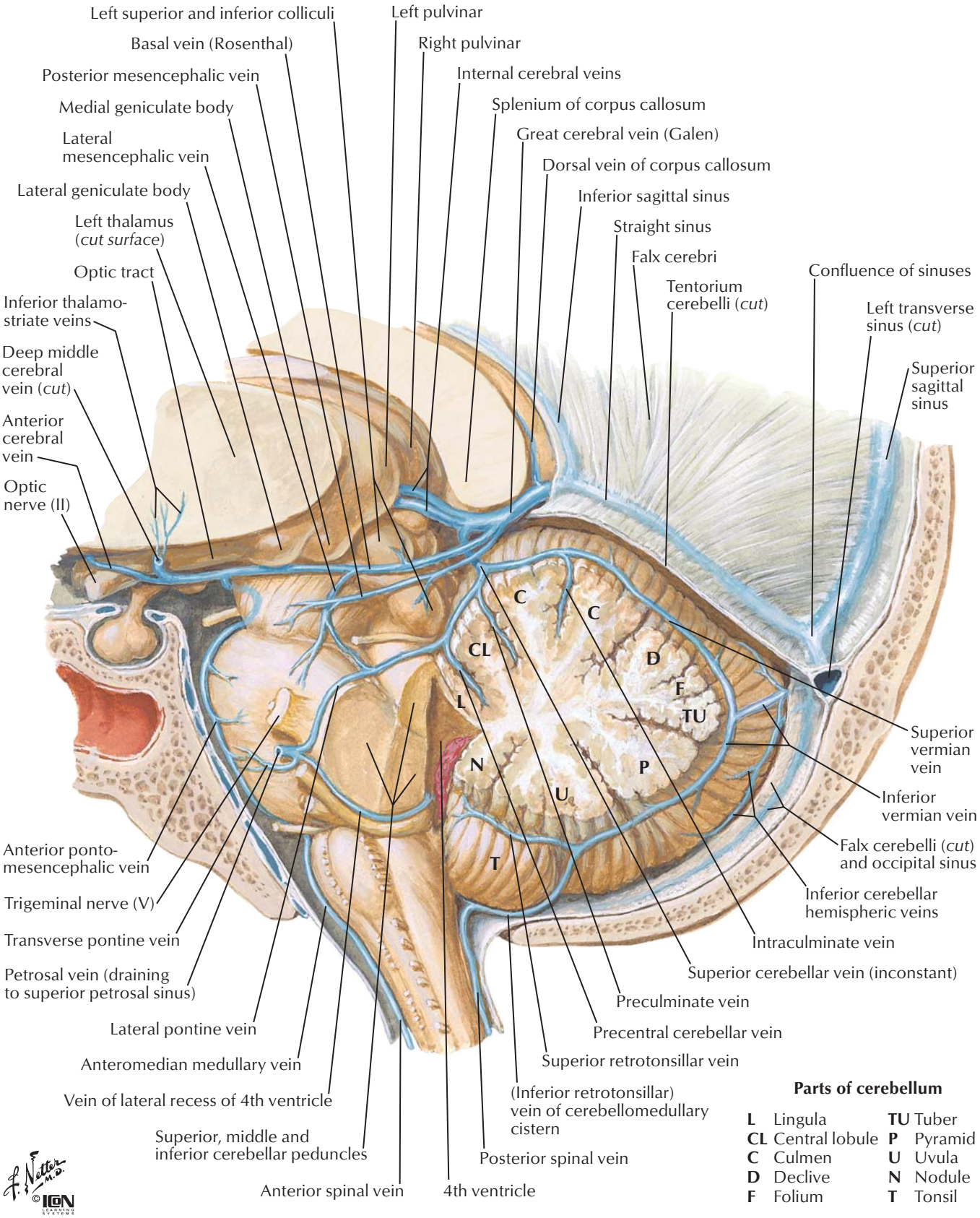

Corpus callosum
Anterolateral central (lenticulostriate) arteries
Lateral frontobasal (orbitofrontal) artery
Prefrontal artery
Precentral (pre-rolandic) and central (rolandic) sulcal arteries
Anterior parietal (postcentral sulcal) artery
Posterior parietal artery
Branch to angular gyrus
Temporal branches (anterior, middle and posterior)
Middle cerebral artery and branches (deep in lateral cerebral [sylvian] sulcus)
Anterior communicating artery
Posterior communicating artery
Anterior inferior cerebellar artery
Posterior spinal artery
Paracentral artery
Medial frontal branches
Pericallosal artery
Callosomarginal artery
Polar frontal artery
Anterior cerebral arteries
Medial frontobasal (orbitofrontal) artery
Distal medial striate artery (recurrent artery of Heubner)
Internal carotid artery
Anterior choroidal artery
Posterior cerebral artery
Superior cerebellar artery
Basilar and pontine arteries
Labyrinthine (internal acoustic) artery
Vertebral artery
Posterior inferior cerebellar artery
Anterior spinal artery


Falx cerebri
Corpus striatum (caudate and lentiform nuclei)
Anterolateral central (lenticulostriate) arteries
Insula (island of Reil)
Limen of insula
Precentral (pre-rolandic), central (rolandic) sulcal and parietal arteries
Lateral cerebral (sylvian) sulcus
Temporal branches of middle cerebral artery
Temporal lobe
Middle cerebral artery
Internal carotid artery
Callosomarginal arteries and Pericallosal arteries (branches of anterior cerebral arteries)
Trunk of corpus callosum
Internal capsule
Septum pellucidum
Rostrum of corpus callosum
Anterior cerebral arteries
Distal medial striate artery (recurrent artery of Heubner)
Anterior communicating artery
Optic chiasm



Note: Anterior parietal (postcentral sulcal) artery also occurs as separate anterior parietal and postcentral sulcal arteries

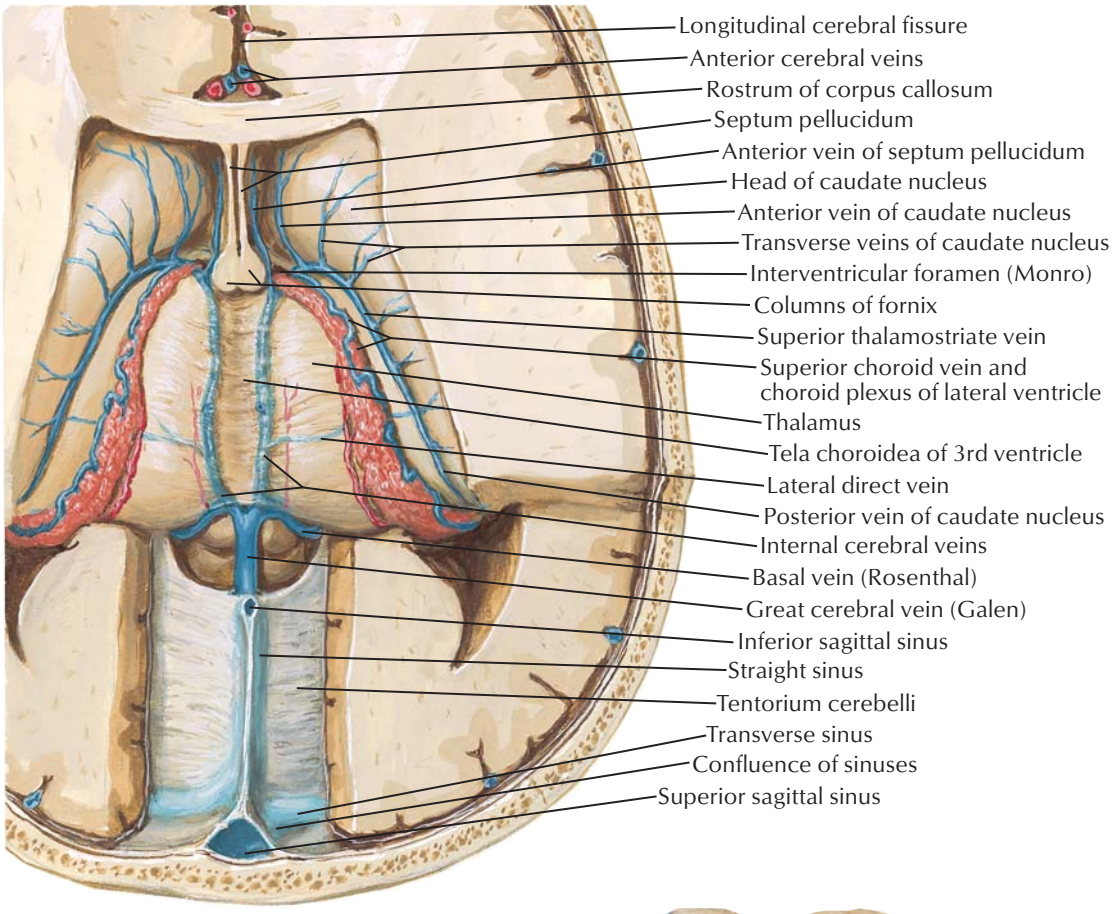

Thalamogeniculate arteries
Anterior choroidal artery
Crura of fornix
Anterolateral central (lenticulostriate) arteries
Heads of caudate nuclei
Septum pellucidum
Corpus callosum
Anterior cerebral arteries
Longitudinal cerebral fissure
Lateral and medial geniculate bodies of left thalamus
Choroid plexuses of lateral ventricles
Pulvinars of left and right thalami
Splenium of corpus callosum
Occipital (posterior) horn of right lateral ventricle
Right dorsal branch to corpus callosum (posterior pericallosal artery)
Parietooccipital
Calcarine
Branches of right posterior cerebral artery
Superior colliculi
Superior vermian branch
Posterior medial choroidal artery to choroid plexus of 3rd ventricle
Posterior lateral choroidal artery
Lateral (marginal) branch
Inferior vermian artery (phantom)
Choroidal branch to 4th ventricle (phantom) and Cerebellar tonsillar branch of posterior inferior cerebellar artery
Outline of 4th ventricle (broken line)
Posterior meningeal branch of vertebral artery
Posterior inferior cerebellar artery (PICA)
Left posterior spinal artery
Left vertebral artery
Anterior spinal artery
Optic nerve (II)
Ophthalmic artery
Anterior cerebral artery
Middle cerebral artery
Posterior communicating artery
Thalamoperforating arteries
Left internal carotid artery
Basilar artery
Pontine arteries
Labyrinthine (internal acoustic) artery
Posterior cerebral artery
Superior cerebellar artery
Anterior inferior cerebellar artery
Anterior meningeal branch of vertebral artery
Temporal branches of posterior cerebral artery
III
IV
V
VI
VII
VIII
IX
X
XI
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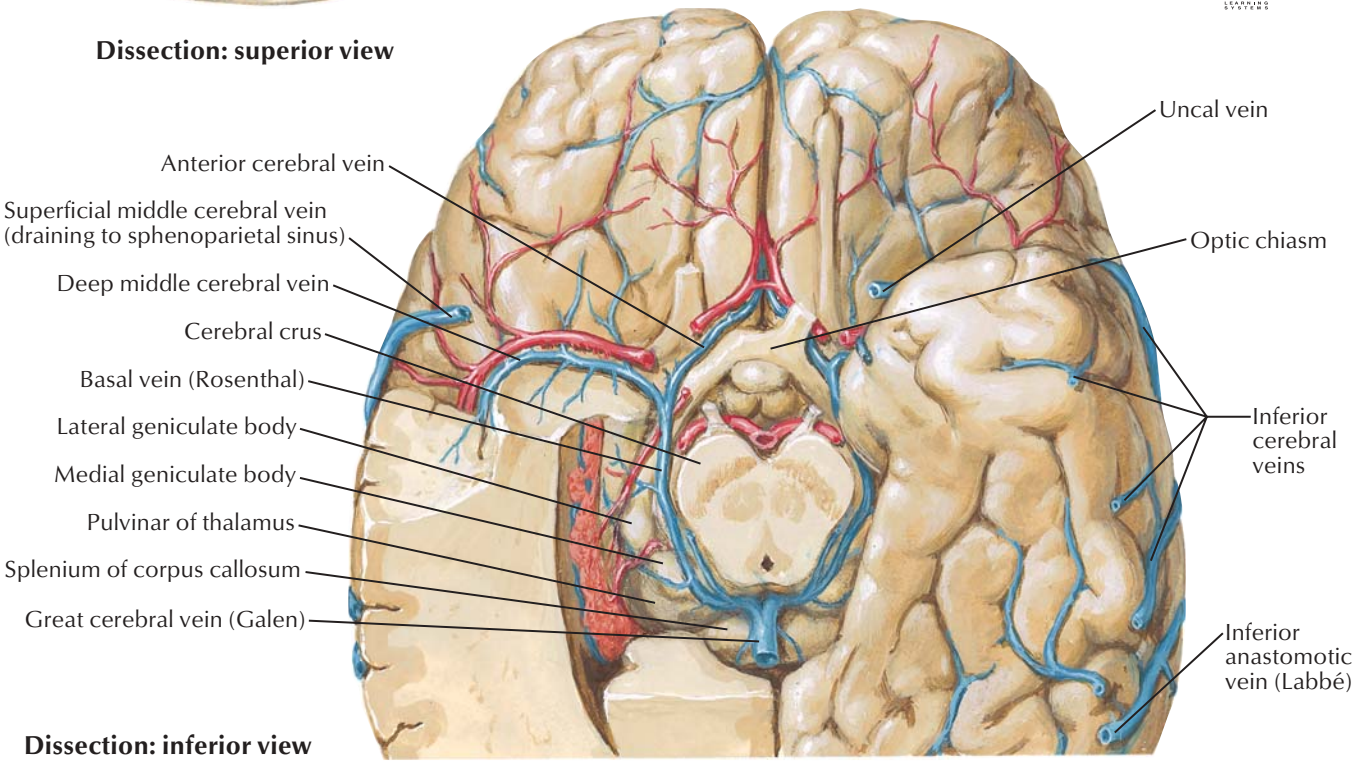
Parts of cerebellum

L	Lingula	**TU**	Tuber
CL	Central lobule	**P**	Pyramid
C	Culmen	**U**	Uvula
D	Declive	**N**	Nodule
F	Folium	**T**	Tonsil

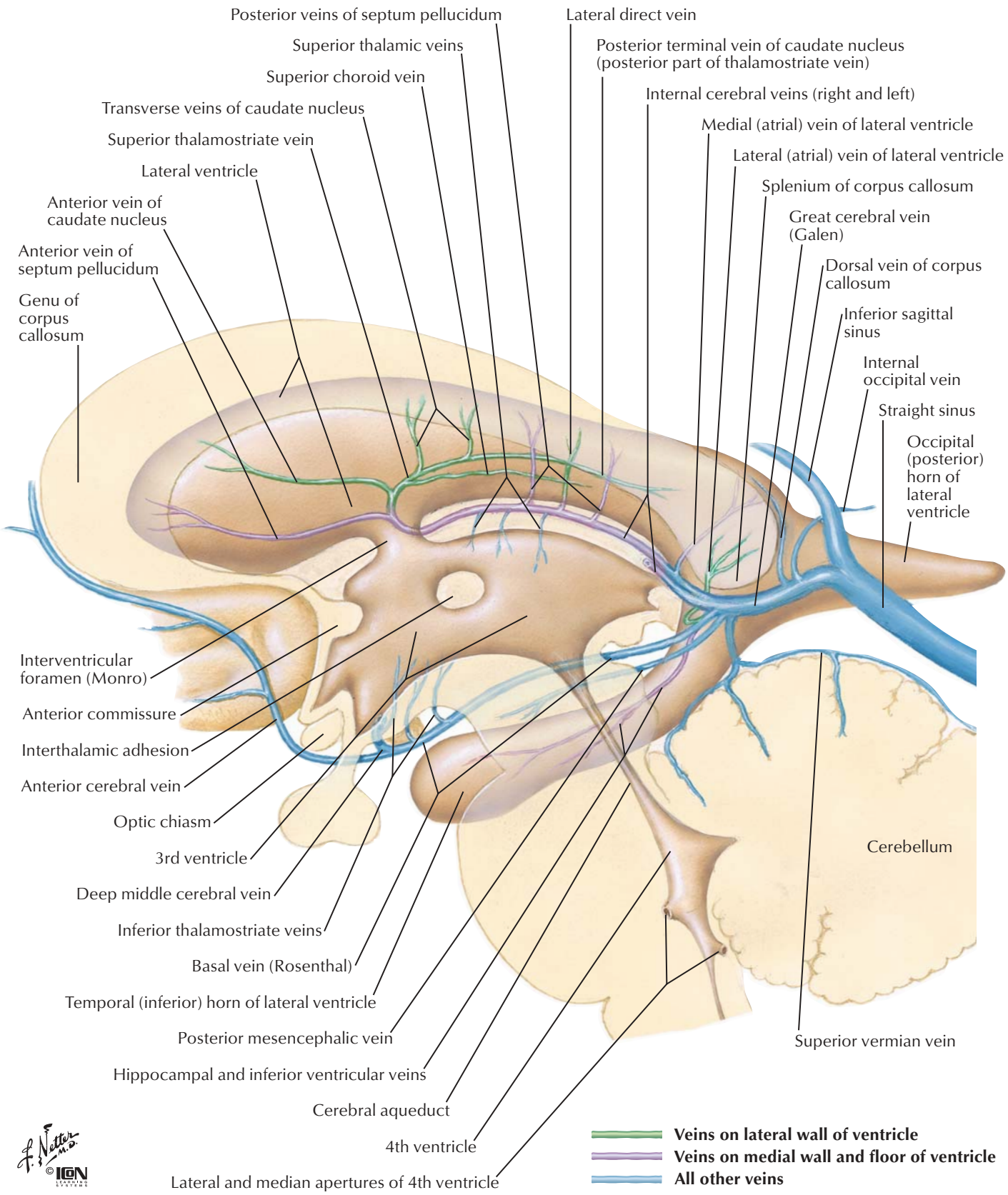
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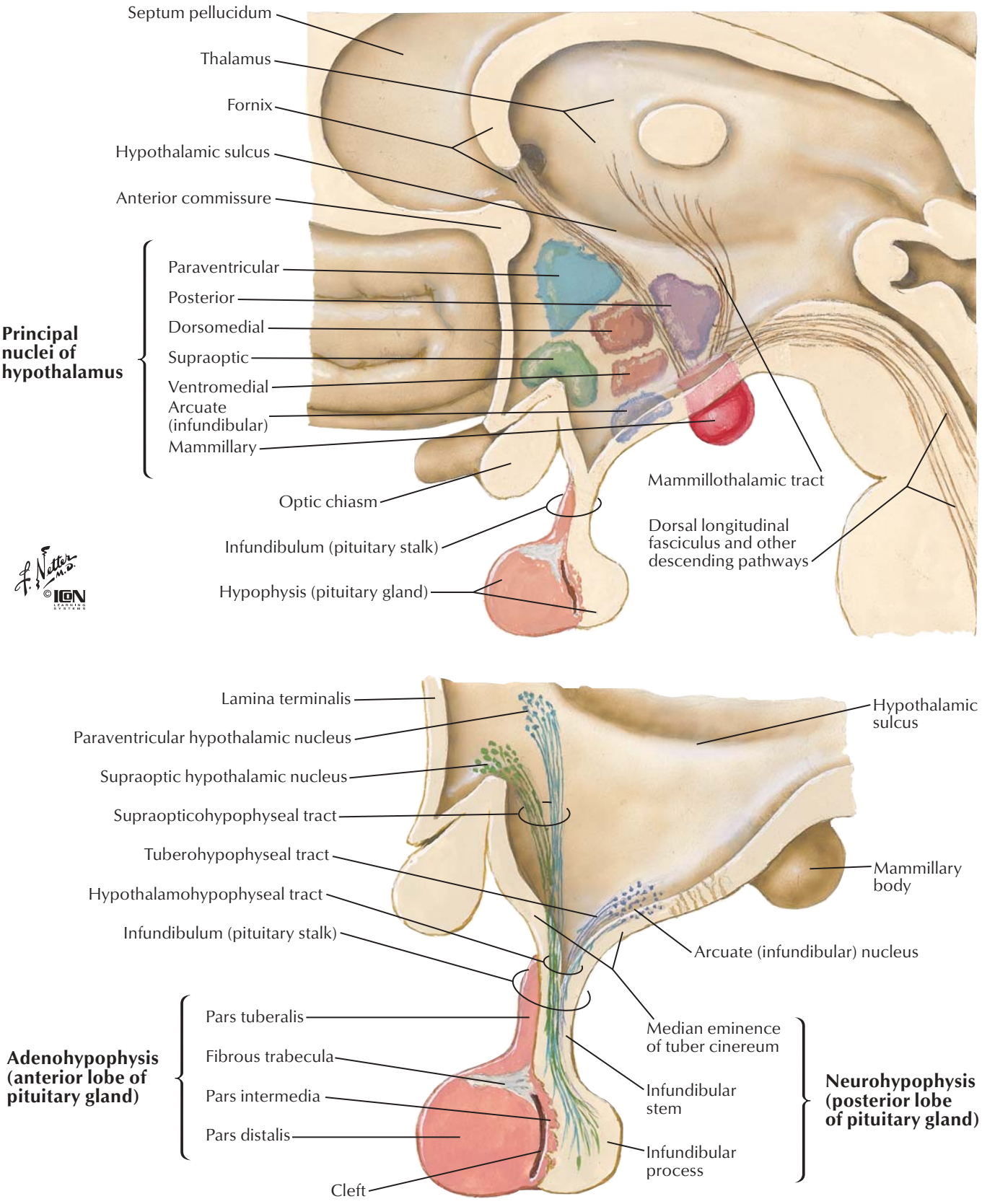
Dissection: superior view

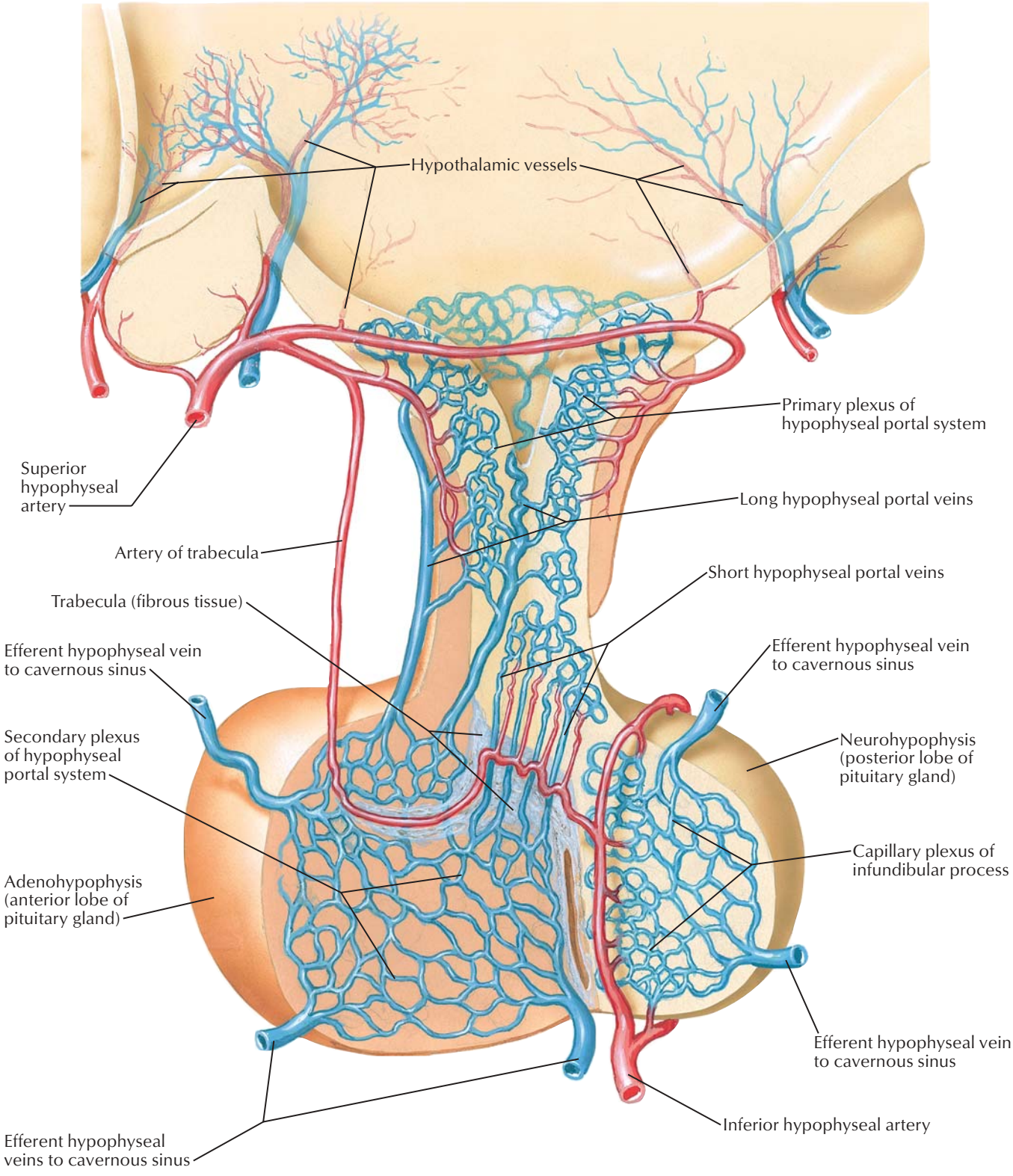


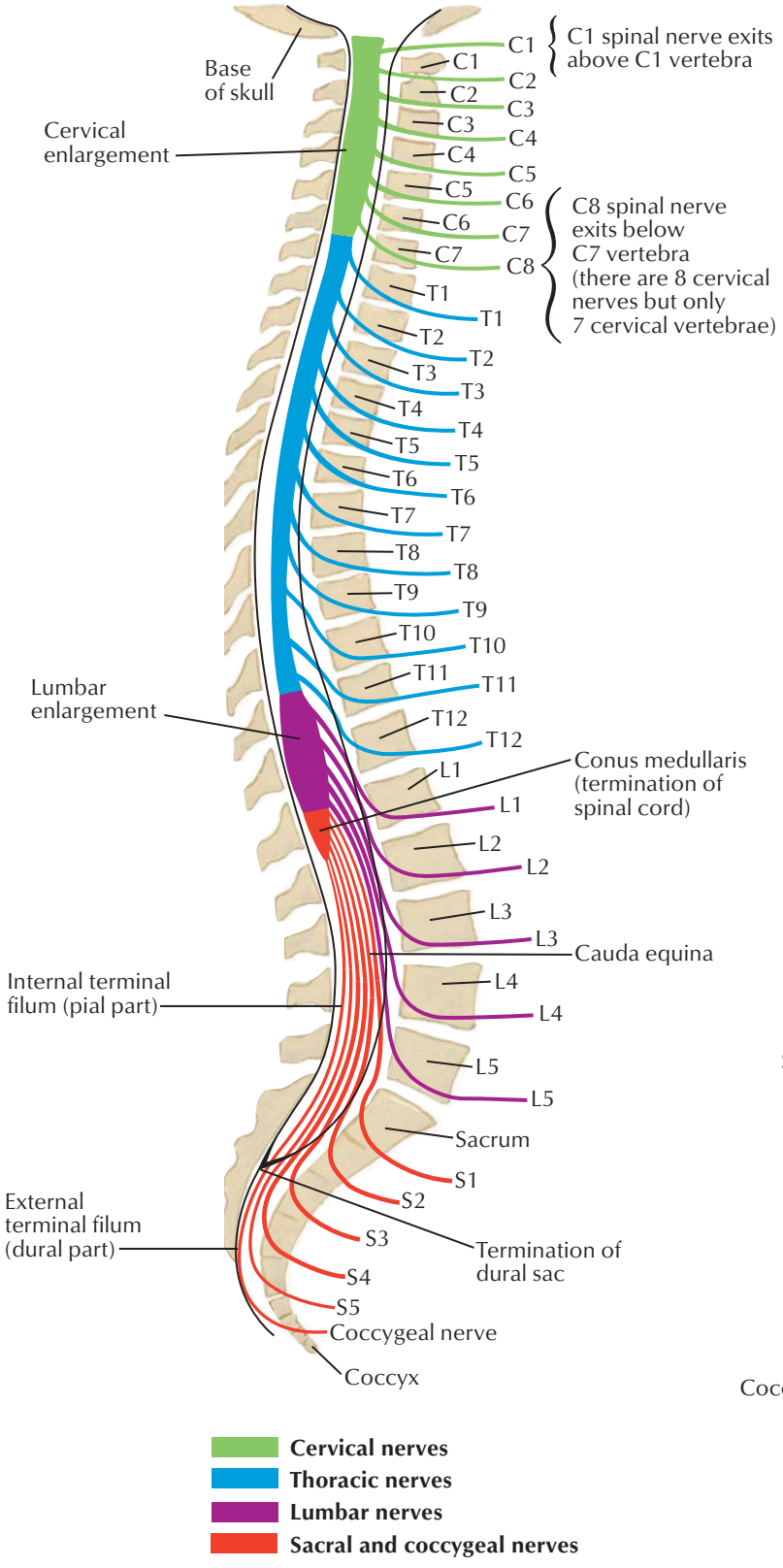
Dissection: inferior view

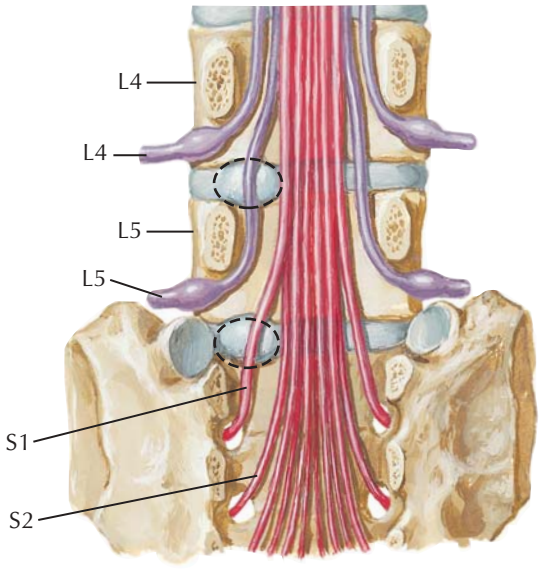


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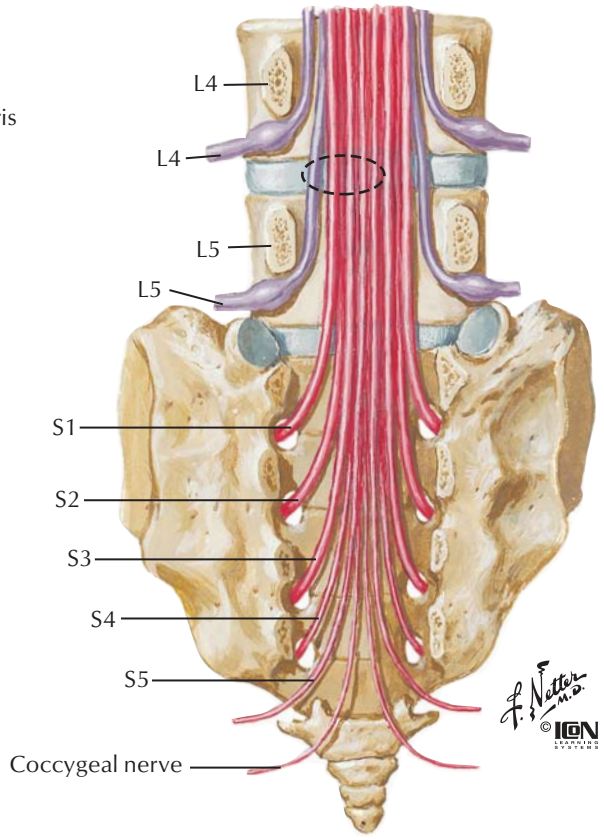

Septum pellucidum
Thalamus
Fornix
Hypothalamic sulcus
Anterior commissure
Principal nuclei of hypothalamus
Paraventricular
Posterior
Dorsomedial
Supraoptic
Ventromedial
Arcuate (infundibular)
Mammillary
Optic chiasm
Infundibulum (pituitary stalk)
Hypophysis (pituitary gland)
Mammillothalamic tract
Dorsal longitudinal fasciculus and other descending pathways
Lamina terminalis
Paraventricular hypothalamic nucleus
Supraoptic hypothalamic nucleus
Supraopticohypophyseal tract
Tuberohypophyseal tract
Hypothalamohypophyseal tract
Infundibulum (pituitary stalk)
Hypothalamic sulcus
Mammillary body
Arcuate (infundibular) nucleus
Median eminence of tuber cinereum
Infundibular stem
Infundibular process
Adenohypophysis (anterior lobe of pituitary gland)
Pars tuberalis
Fibrous trabecula
Pars intermedia
Pars distalis
Cleft
Neurohypophysis (posterior lobe of pituitary gland)


Hypothalamic vessels
Primary plexus of hypophyseal portal system
Superior hypophyseal artery
Long hypophyseal portal veins
Artery of trabecula
Short hypophyseal portal veins
Trabecula (fibrous tissue)
Efferent hypophyseal vein to cavernous sinus
Efferent hypophyseal vein to cavernous sinus
Secondary plexus of hypophyseal portal system
Neurohypophysis (posterior lobe of pituitary gland)
Capillary plexus of infundibular process
Adenohypophysis (anterior lobe of pituitary gland)
Efferent hypophyseal vein to cavernous sinus
Inferior hypophyseal artery
Efferent hypophyseal veins to cavernous sinus

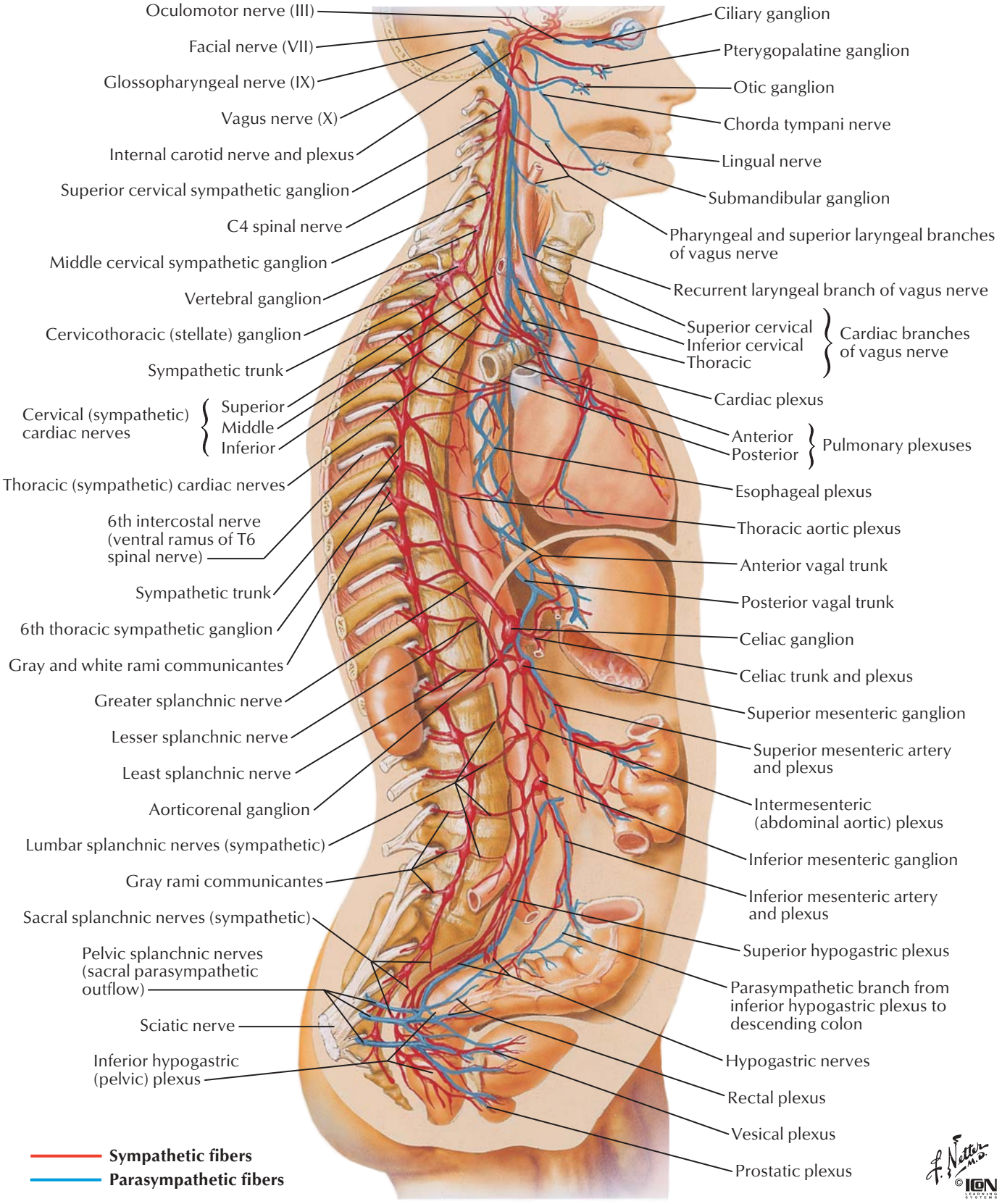




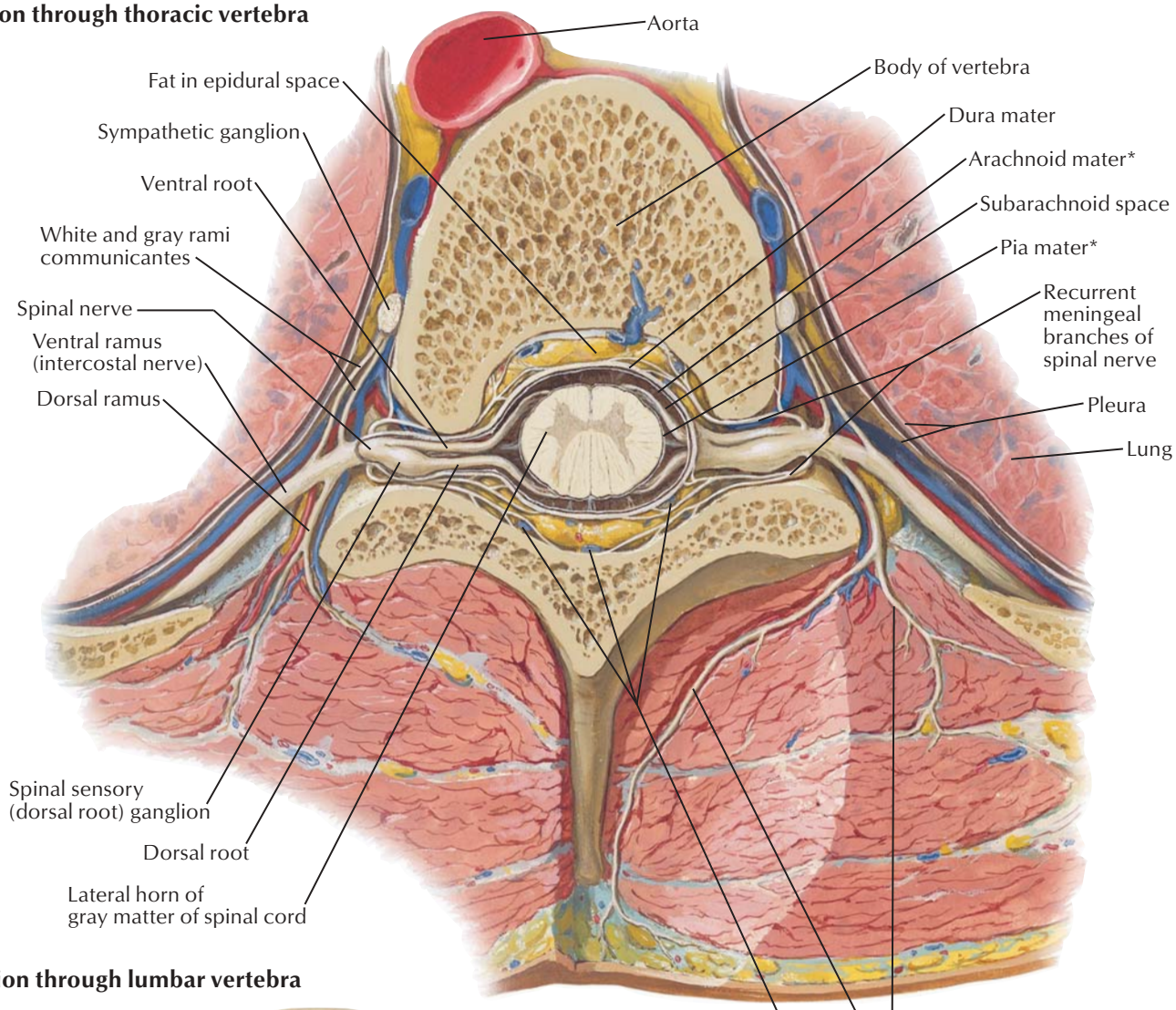
Lumbar disc protrusion does not usually affect nerve exiting above disc. Lateral protrusion at disc level L4–5 affects L5 spinal nerve, not L4 spinal nerve. Protrusion at disc level L5–S1 affects S1 spinal nerve, not L5 spinal nerve



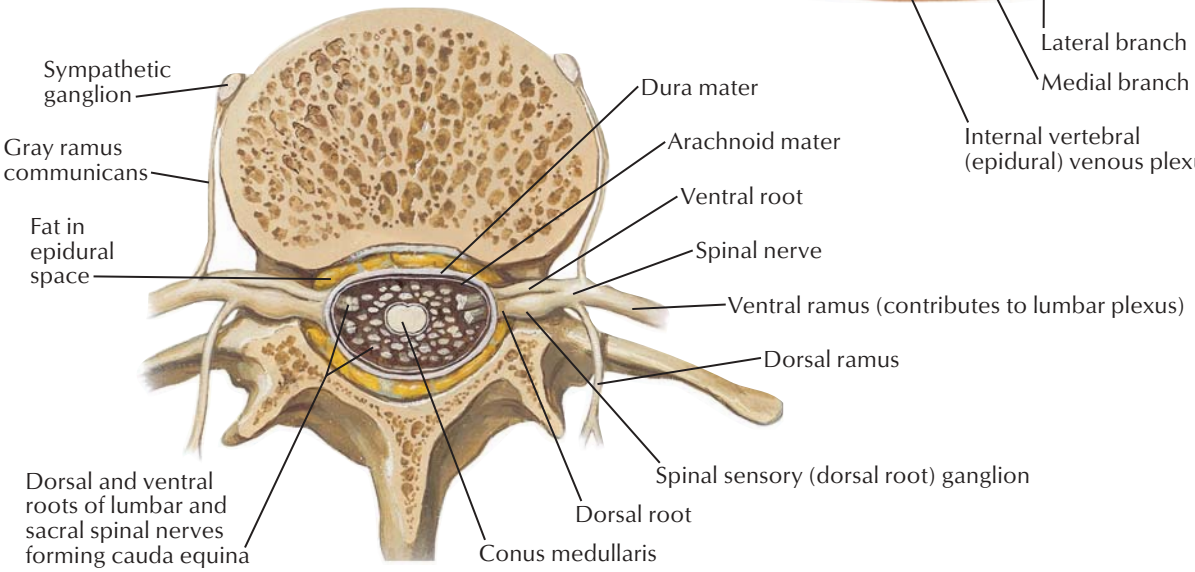
Medial protrusion at disc level L4–5 rarely affects L4 spinal nerve but may affect L5 spinal nerve and sometimes S1–4 spinal nerves


Oculomotor nerve (III)
Facial nerve (VII)
Glossopharyngeal nerve (IX)
Vagus nerve (X)
Internal carotid nerve and plexus
Superior cervical sympathetic ganglion
C4 spinal nerve
Middle cervical sympathetic ganglion
Vertebral ganglion
Cervicothoracic (stellate) ganglion
Sympathetic trunk
Cervical (sympathetic) cardiac nerves
Superior
Middle
Inferior
Thoracic (sympathetic) cardiac nerves
6th intercostal nerve (ventral ramus of T6 spinal nerve)
Sympathetic trunk
6th thoracic sympathetic ganglion
Gray and white rami communicantes
Greater splanchnic nerve
Lesser splanchnic nerve
Least splanchnic nerve
Aorticorenal ganglion
Lumbar splanchnic nerves (sympathetic)
Gray rami communicantes
Sacral splanchnic nerves (sympathetic)
Pelvic splanchnic nerves (sacral parasympathetic outflow)
Sciatic nerve
Inferior hypogastric (pelvic) plexus
Ciliary ganglion
Pterygopalatine ganglion
Otic ganglion
Chorda tympani nerve
Lingual nerve
Submandibular ganglion
Pharyngeal and superior laryngeal branches of vagus nerve
Recurrent laryngeal branch of vagus nerve
Superior cervical
Inferior cervical
Thoracic
Cardiac branches of vagus nerve
Cardiac plexus
Anterior
Posterior
Pulmonary plexuses
Esophageal plexus
Thoracic aortic plexus
Anterior vagal trunk
Posterior vagal trunk
Celiac ganglion
Celiac trunk and plexus
Superior mesenteric ganglion
Superior mesenteric artery and plexus
Intermesenteric (abdominal aortic) plexus
Inferior mesenteric ganglion
Inferior mesenteric artery and plexus
Superior hypogastric plexus
Parasympathetic branch from inferior hypogastric plexus to descending colon
Hypogastric nerves
Rectal plexus
Vesical plexus
Prostatic plexus
Sympathetic fibers
Parasympathetic fibers

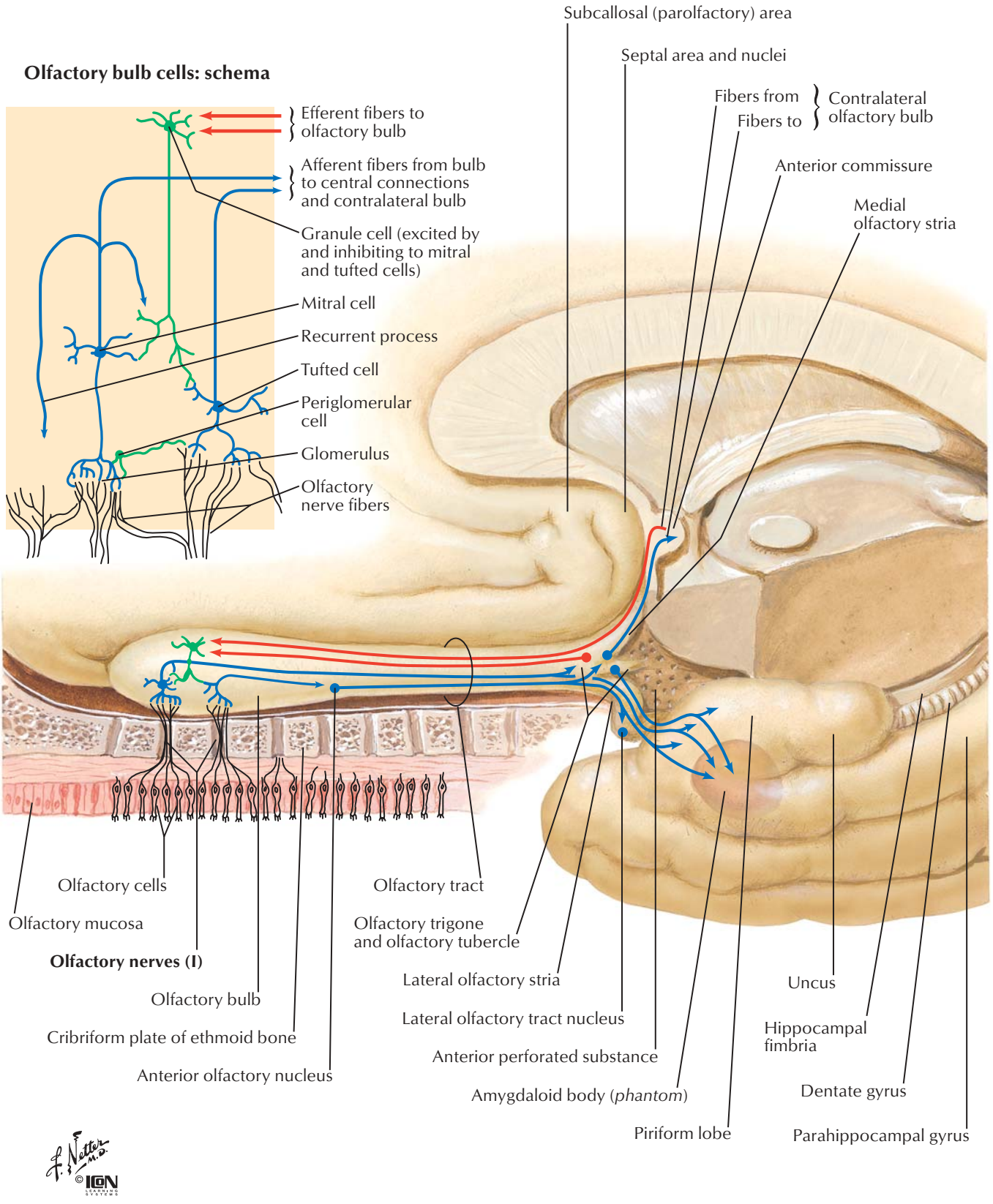
Section through thoracic vertebra



Section through lumbar vertebra



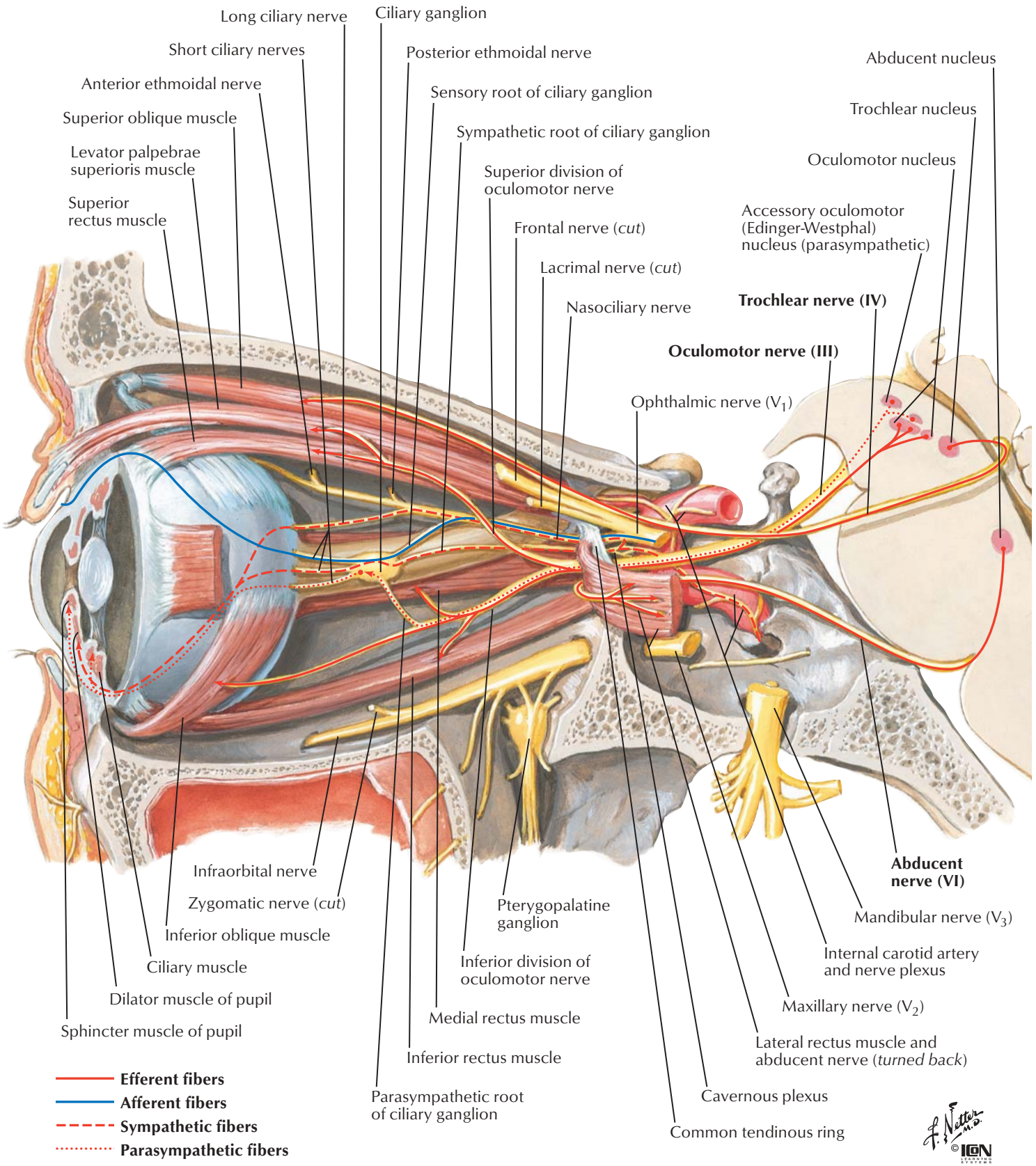
*Leptomeninges

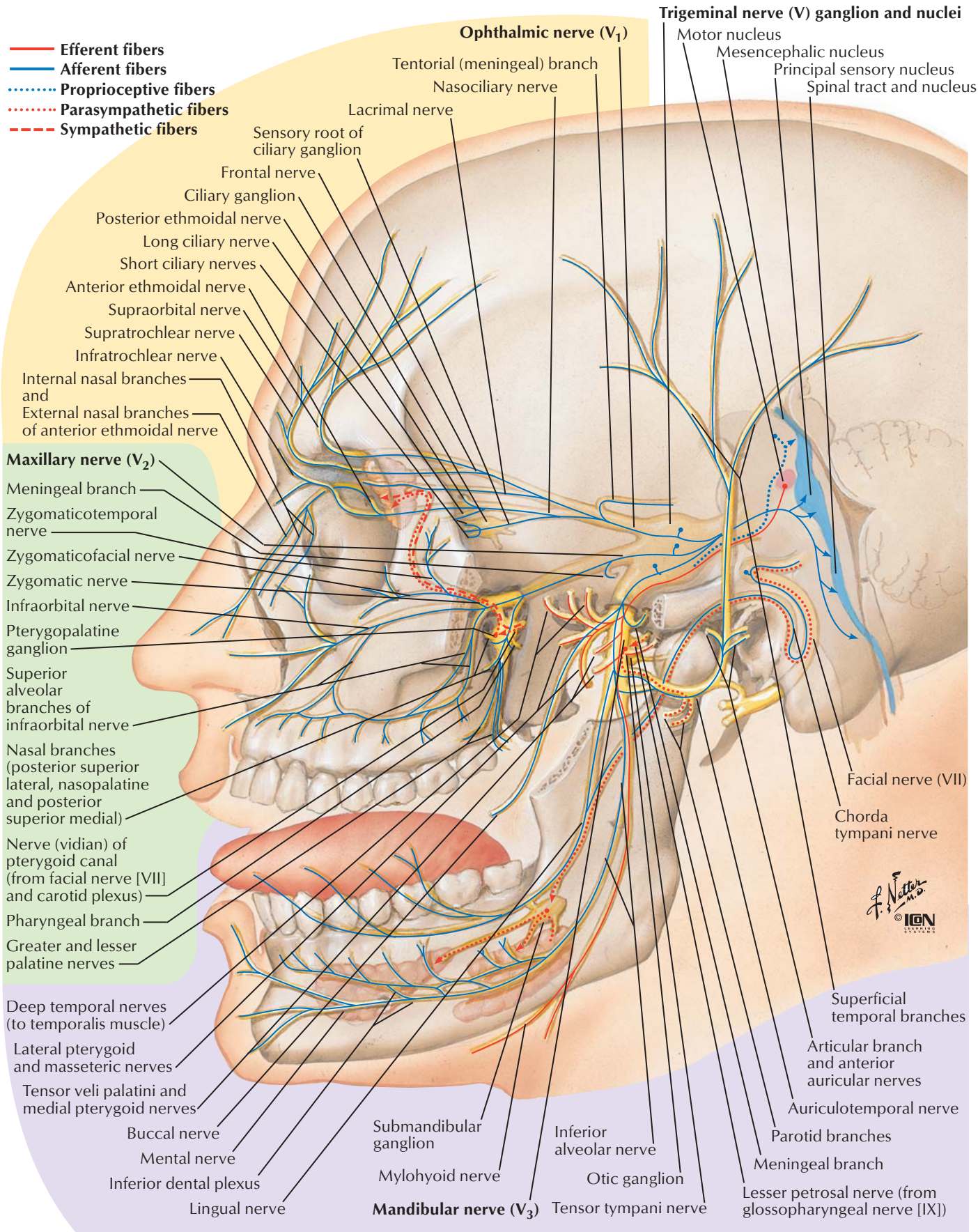

Olfactory bulb cells: schema
Efferent fibers to olfactory bulb
Afferent fibers from bulb to central connections and contralateral bulb
Granule cell (excited by and inhibiting to mitral and tufted cells)
Mitral cell
Recurrent process
Tufted cell
Periglomerular cell
Glomerulus
Olfactory nerve fibers
Subcallosal (parolfactory) area
Septal area and nuclei
Fibers from
Fibers to
Contralateral olfactory bulb
Anterior commissure
Medial olfactory stria
Olfactory cells
Olfactory mucosa
Olfactory nerves (I)
Olfactory bulb
Cribriform plate of ethmoid bone
Anterior olfactory nucleus
Olfactory tract
Olfactory trigone and olfactory tubercle
Lateral olfactory stria
Lateral olfactory tract nucleus
Anterior perforated substance
Amygdaloid body (phantom)
Piriform lobe
Uncus
Hippocampal fimbria
Dentate gyrus
Parahippocampal gyrus

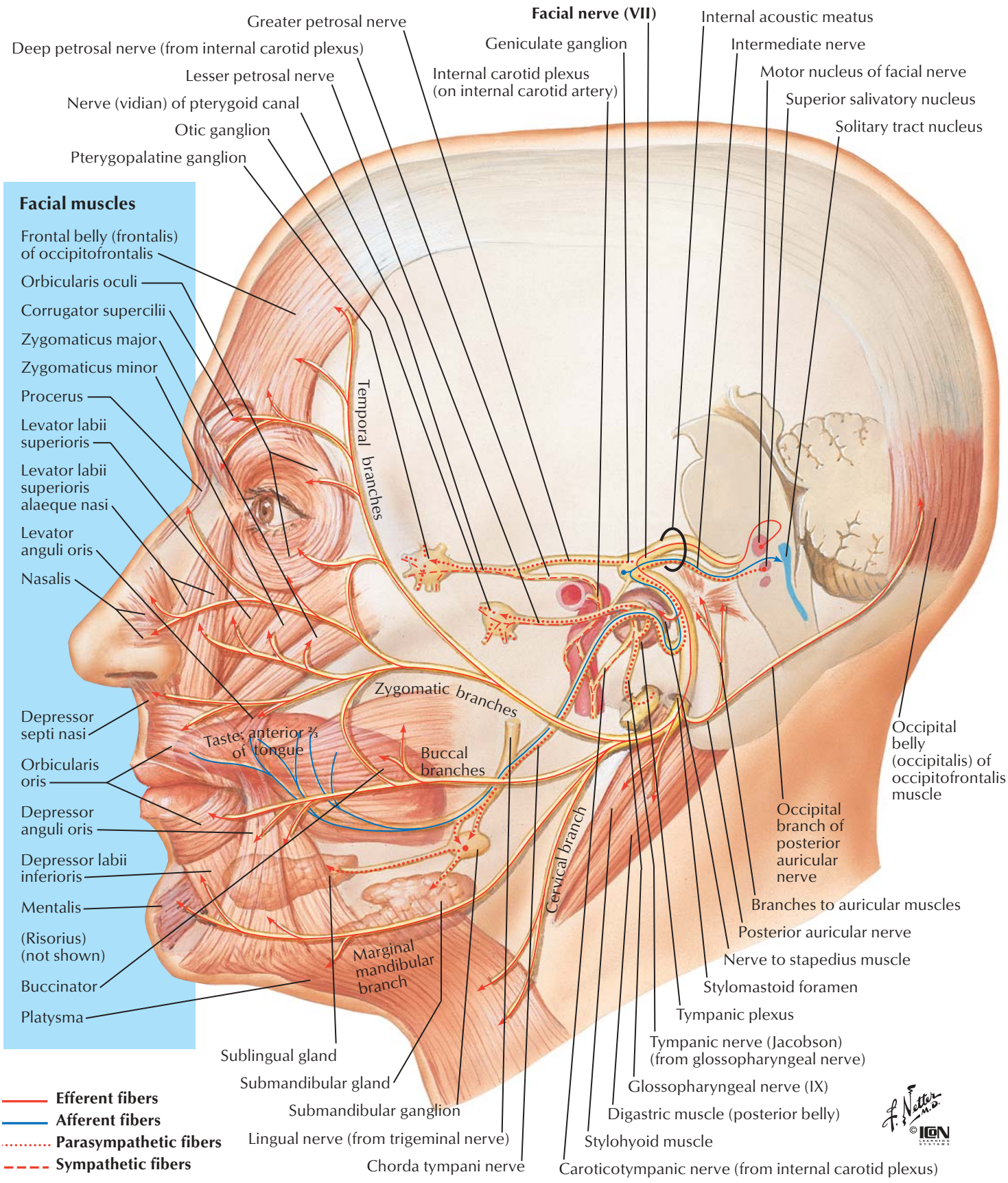


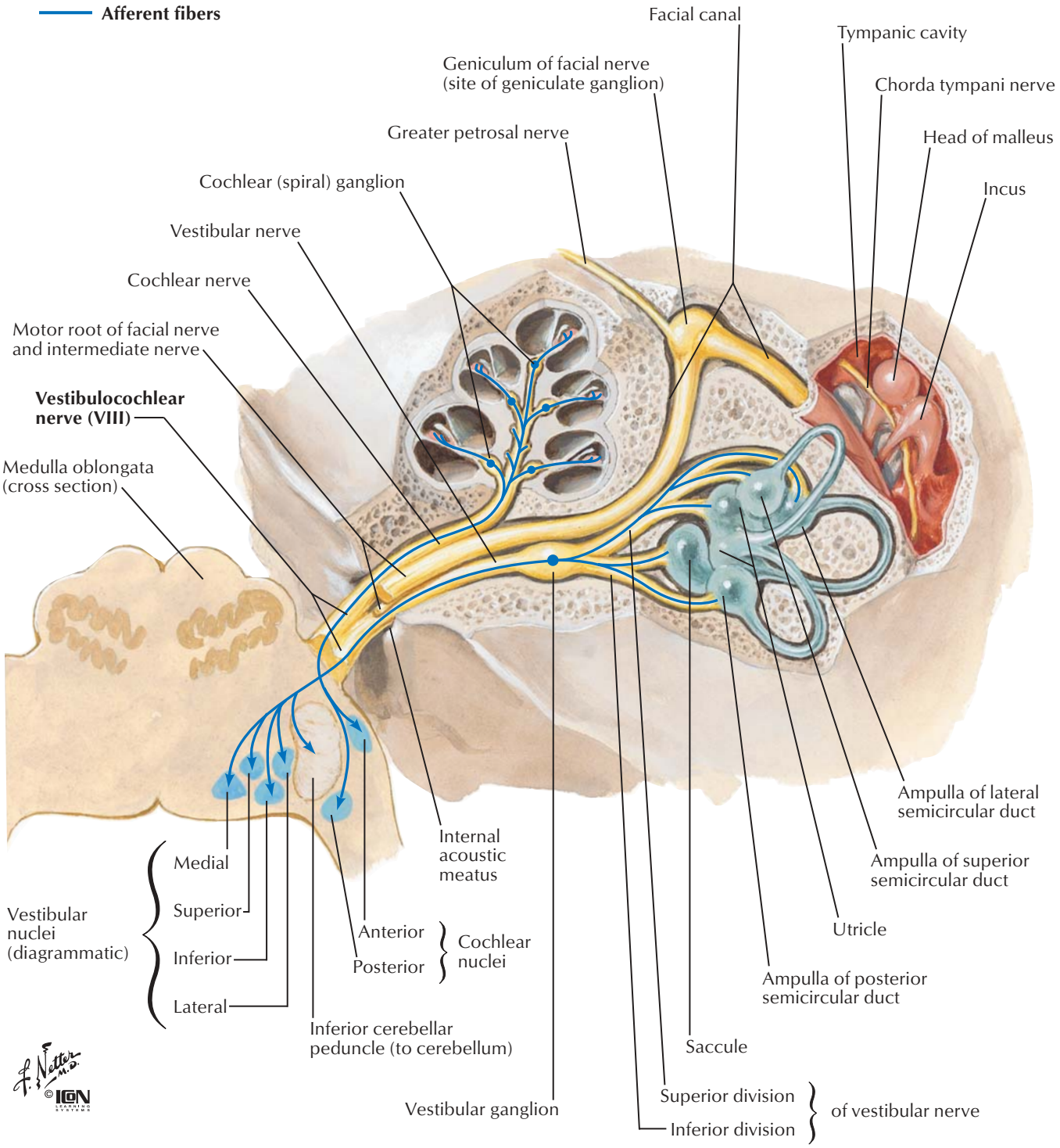
Structure of retina: schema

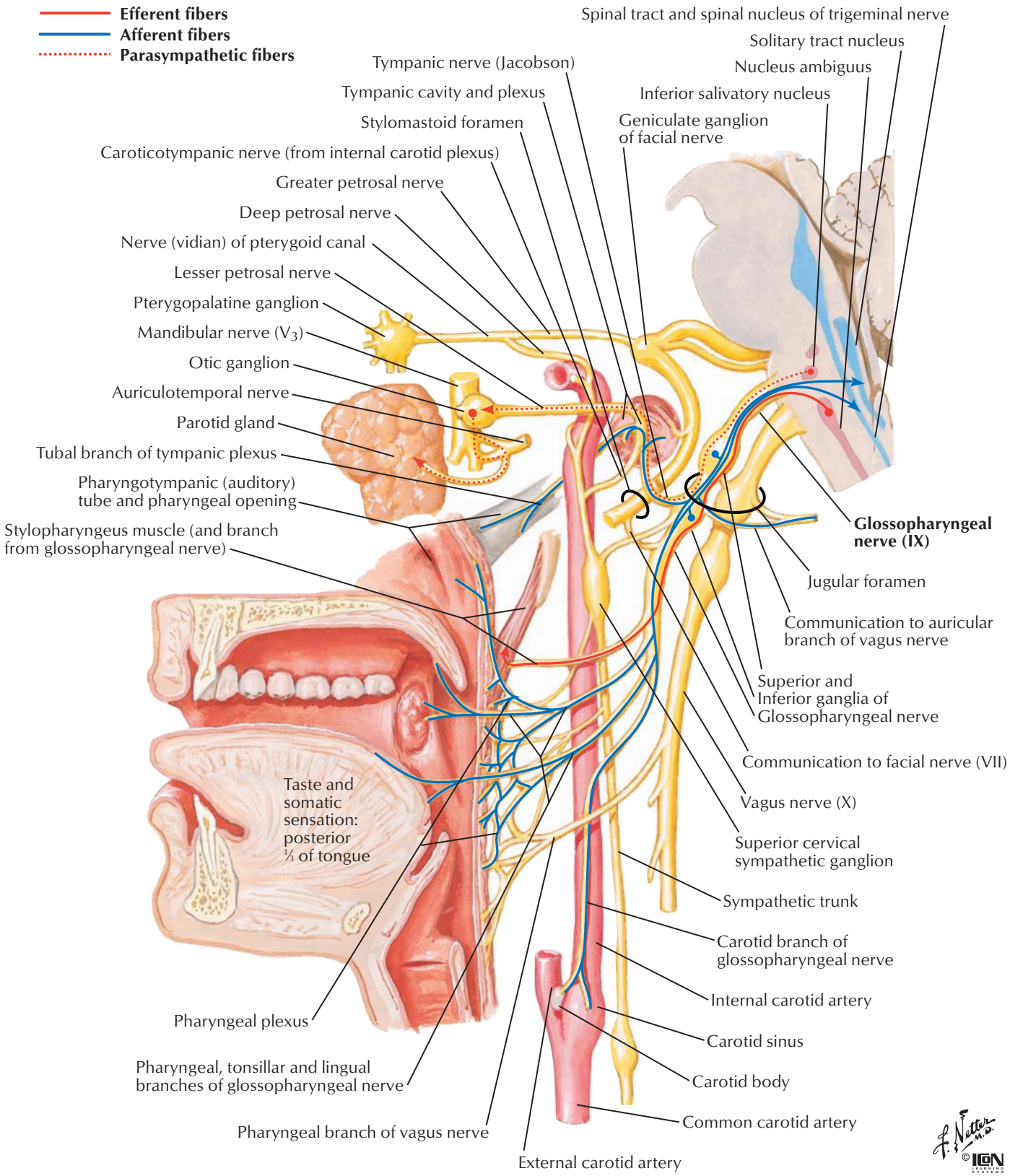
- **A** Amacrine cells
- **B** Bipolar cells
- **C** Cones
- **G** Ganglion cells
- **H** Horizontal cells
- **P** Pigment cells
- **R** Rods


Long ciliary nerve
Ciliary ganglion
Short ciliary nerves
Posterior ethmoidal nerve
Anterior ethmoidal nerve
Sensory root of ciliary ganglion
Superior oblique muscle
Sympathetic root of ciliary ganglion
Levator palpebrae superioris muscle
Superior division of oculomotor nerve
Superior rectus muscle
Frontal nerve (cut)
Lacrimal nerve (cut)
Nasociliary nerve
Abducent nucleus
Trochlear nucleus
Oculomotor nucleus
Accessory oculomotor (Edinger-Westphal) nucleus (parasympathetic)
Trochlear nerve (IV)
Oculomotor nerve (III)
Ophthalmic nerve (V1)
Infraorbital nerve
Zygomatic nerve (cut)
Pterygopalatine ganglion
Abducent nerve (VI)
Mandibular nerve (V3)
Inferior oblique muscle
Internal carotid artery and nerve plexus
Ciliary muscle
Inferior division of oculomotor nerve
Dilator muscle of pupil
Maxillary nerve (V2)
Medial rectus muscle
Sphincter muscle of pupil
Lateral rectus muscle and abducent nerve (turned back)
Inferior rectus muscle
Cavernous plexus
Parasympathetic root of ciliary ganglion
Common tendinous ring
Efferent fibers
Afferent fibers
Sympathetic fibers
Parasympathetic fibers

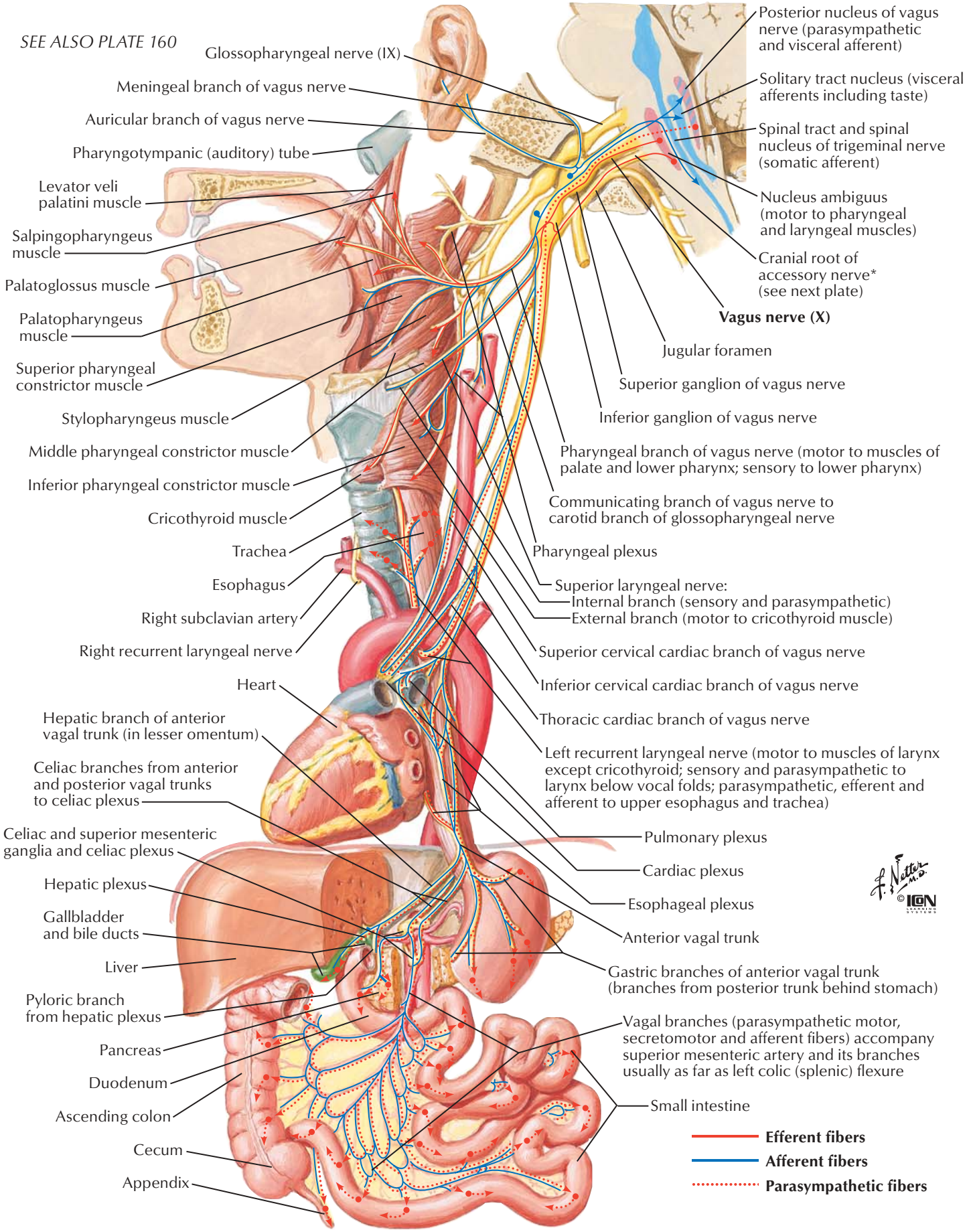

Efferent fibers
Afferent fibers
Proprioceptive fibers
Parasympathetic fibers
Sympathetic fibers
Trigeminal nerve (V) ganglion and nuclei
Motor nucleus
Mesencephalic nucleus
Principal sensory nucleus
Spinal tract and nucleus
Ophthalmic nerve (V1)
Tentorial (meningeal) branch
Nasociliary nerve
Lacrimal nerve
Sensory root of ciliary ganglion
Frontal nerve
Ciliary ganglion
Posterior ethmoidal nerve
Long ciliary nerve
Short ciliary nerves
Anterior ethmoidal nerve
Supraorbital nerve
Supratrochlear nerve
Infratrochlear nerve
Internal nasal branches and External nasal branches of anterior ethmoidal nerve
Maxillary nerve (V2)
Meningeal branch
Zygomaticotemporal nerve
Zygomaticofacial nerve
Zygomatic nerve
Infraorbital nerve
Pterygopalatine ganglion
Superior alveolar branches of infraorbital nerve
Nasal branches (posterior superior lateral, nasopalatine and posterior superior medial)
Nerve (vidian) of pterygoid canal (from facial nerve [VII] and carotid plexus)
Pharyngeal branch
Greater and lesser palatine nerves
Facial nerve (VII)
Chorda tympani nerve
Deep temporal nerves (to temporalis muscle)
Lateral pterygoid and masseteric nerves
Tensor veli palatini and medial pterygoid nerves
Buccal nerve
Mental nerve
Inferior dental plexus
Lingual nerve
Submandibular ganglion
Mylohyoid nerve
Mandibular nerve (V3)
Inferior alveolar nerve
Otic ganglion
Tensor tympani nerve
Superficial temporal branches
Articular branch and anterior auricular nerves
Auriculotemporal nerve
Parotid branches
Meningeal branch
Lesser petrosal nerve (from glossopharyngeal nerve [IX])


Facial nerve (VII)
Greater petrosal nerve
Deep petrosal nerve (from internal carotid plexus)
Lesser petrosal nerve
Nerve (vidian) of pterygoid canal
Otic ganglion
Pterygopalatine ganglion
Geniculate ganglion
Internal carotid plexus (on internal carotid artery)
Internal acoustic meatus
Intermediate nerve
Motor nucleus of facial nerve
Superior salivatory nucleus
Solitary tract nucleus
Facial muscles
Frontal belly (frontalis) of occipitofrontalis
Orbicularis oculi
Corrugator supercilii
Zygomaticus major
Zygomaticus minor
Procerus
Levator labii superioris
Levator labii superioris alaeque nasi
Levator anguli oris
Nasalis
Depressor septi nasi
Orbicularis oris
Depressor anguli oris
Depressor labii inferioris
Mentalis
(Risorius) (not shown)
Buccinator
Platysma
Temporal branches
Zygomatic branches
Buccal branches
Taste: anterior ⅔ of tongue
Marginal mandibular branch
Cervical branch
Occipital belly (occipitalis) of occipitofrontalis muscle
Occipital branch of posterior auricular nerve
Branches to auricular muscles
Posterior auricular nerve
Nerve to stapedius muscle
Stylomastoid foramen
Tympanic plexus
Tympanic nerve (Jacobson) (from glossopharyngeal nerve)
Glossopharyngeal nerve (IX)
Digastric muscle (posterior belly)
Stylohyoid muscle
Caroticotympanic nerve (from internal carotid plexus)
Sublingual gland
Submandibular gland
Submandibular ganglion
Lingual nerve (from trigeminal nerve)
Chorda tympani nerve
Efferent fibers
Afferent fibers
Parasympathetic fibers
Sympathetic fibers

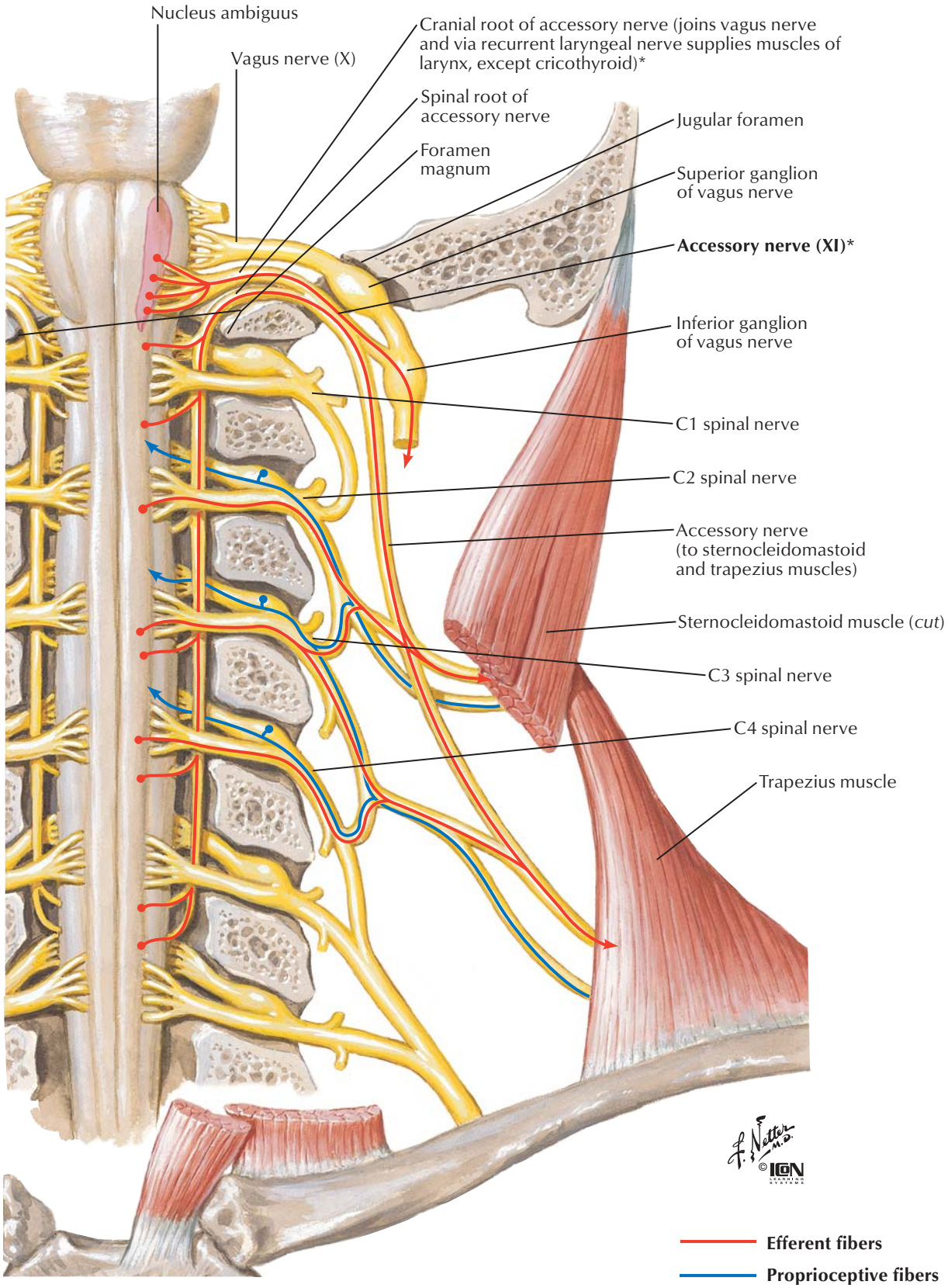

Afferent fibers
Facial canal
Tympanic cavity
Geniculum of facial nerve (site of geniculate ganglion)
Chorda tympani nerve
Greater petrosal nerve
Head of malleus
Cochlear (spiral) ganglion
Incus
Vestibular nerve
Cochlear nerve
Motor root of facial nerve and intermediate nerve
Vestibulocochlear nerve (VIII)
Medulla oblongata (cross section)
Ampulla of lateral semicircular duct
Internal acoustic meatus
Ampulla of superior semicircular duct
Medial
Superior
Vestibular nuclei (diagrammatic)
Inferior
Lateral
Anterior
Posterior
Cochlear nuclei
Utricle
Ampulla of posterior semicircular duct
Inferior cerebellar peduncle (to cerebellum)
Saccule
Vestibular ganglion
Superior division
Inferior division
of vestibular nerve


Efferent fibers
Afferent fibers
Parasympathetic fibers
Spinal tract and spinal nucleus of trigeminal nerve
Solitary tract nucleus
Nucleus ambiguus
Inferior salivatory nucleus
Geniculate ganglion of facial nerve
Tympanic nerve (Jacobson)
Tympanic cavity and plexus
Stylomastoid foramen
Caroticotympanic nerve (from internal carotid plexus)
Greater petrosal nerve
Deep petrosal nerve
Nerve (vidian) of pterygoid canal
Lesser petrosal nerve
Pterygopalatine ganglion
Mandibular nerve (V3)
Otic ganglion
Auriculotemporal nerve
Parotid gland
Tubal branch of tympanic plexus
Pharyngotympanic (auditory) tube and pharyngeal opening
Stylopharyngeus muscle (and branch from glossopharyngeal nerve)
Glossopharyngeal nerve (IX)
Jugular foramen
Communication to auricular branch of vagus nerve
Superior and Inferior ganglia of Glossopharyngeal nerve
Communication to facial nerve (VII)
Vagus nerve (X)
Superior cervical sympathetic ganglion
Sympathetic trunk
Carotid branch of glossopharyngeal nerve
Internal carotid artery
Carotid sinus
Carotid body
Common carotid artery
External carotid artery
Pharyngeal branch of vagus nerve
Pharyngeal, tonsillar and lingual branches of glossopharyngeal nerve
Pharyngeal plexus
Taste and somatic sensation: posterior ⅓ of tongue

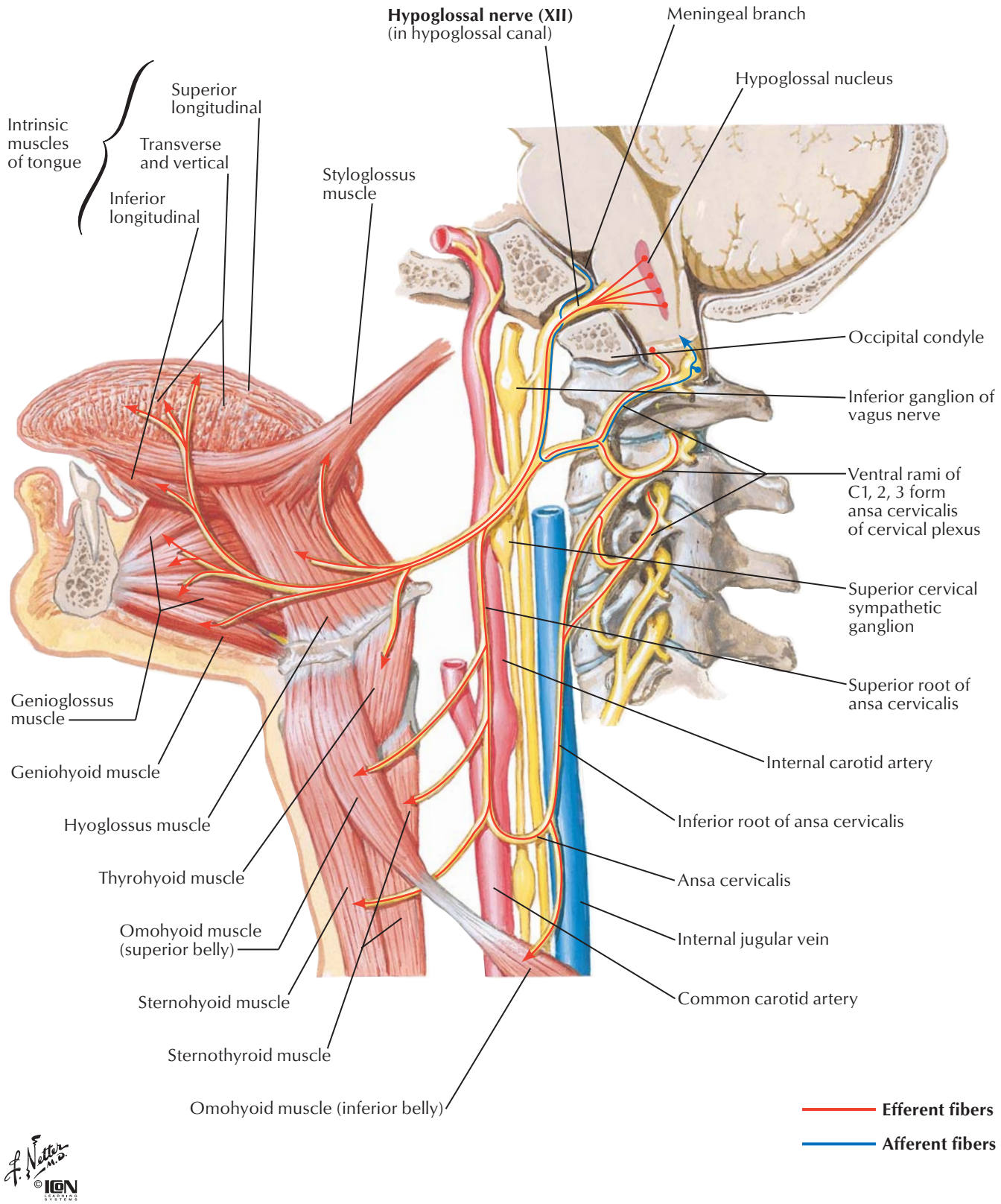
SEE ALSO PLATE 160



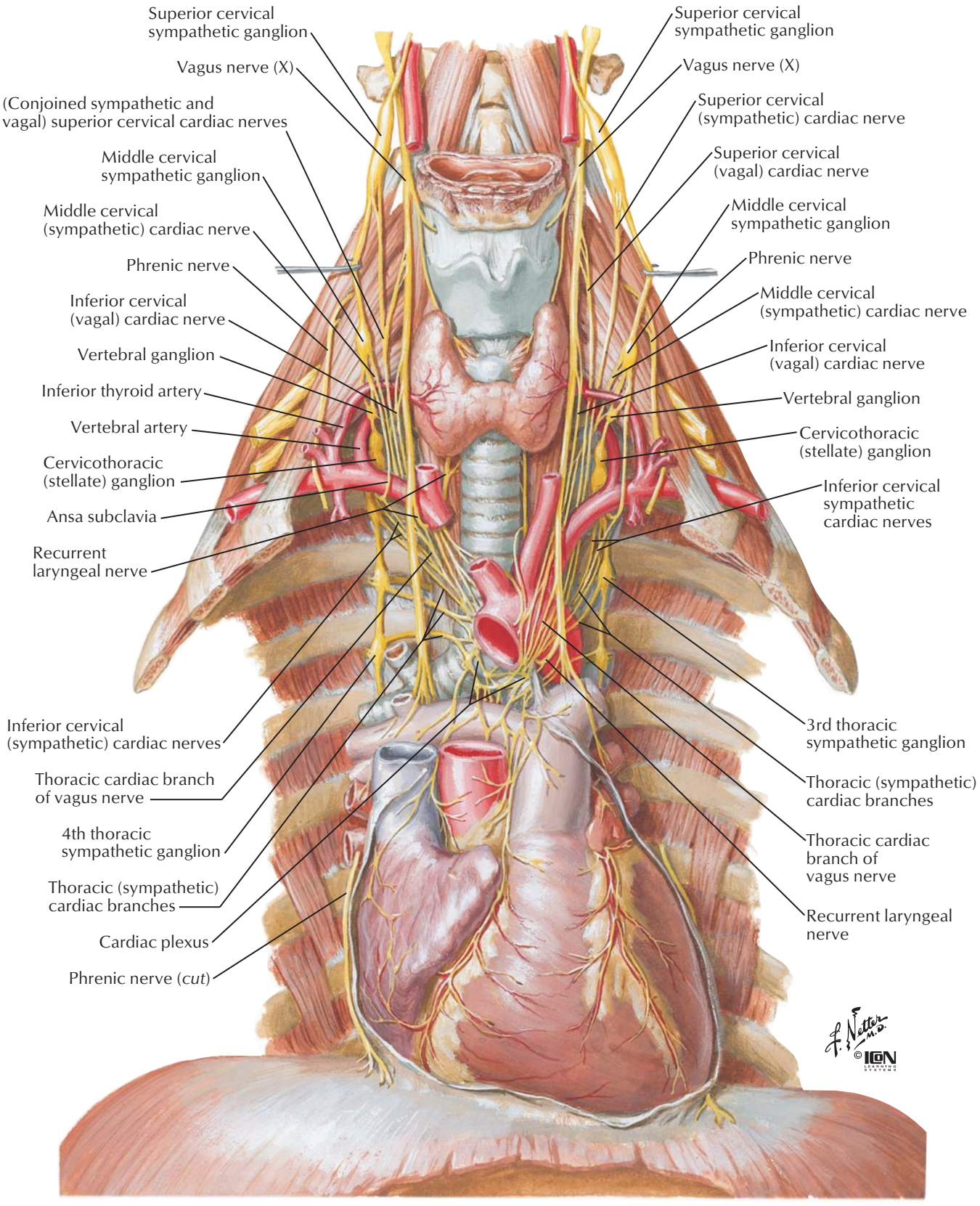
SEE ALSO PLATE 28

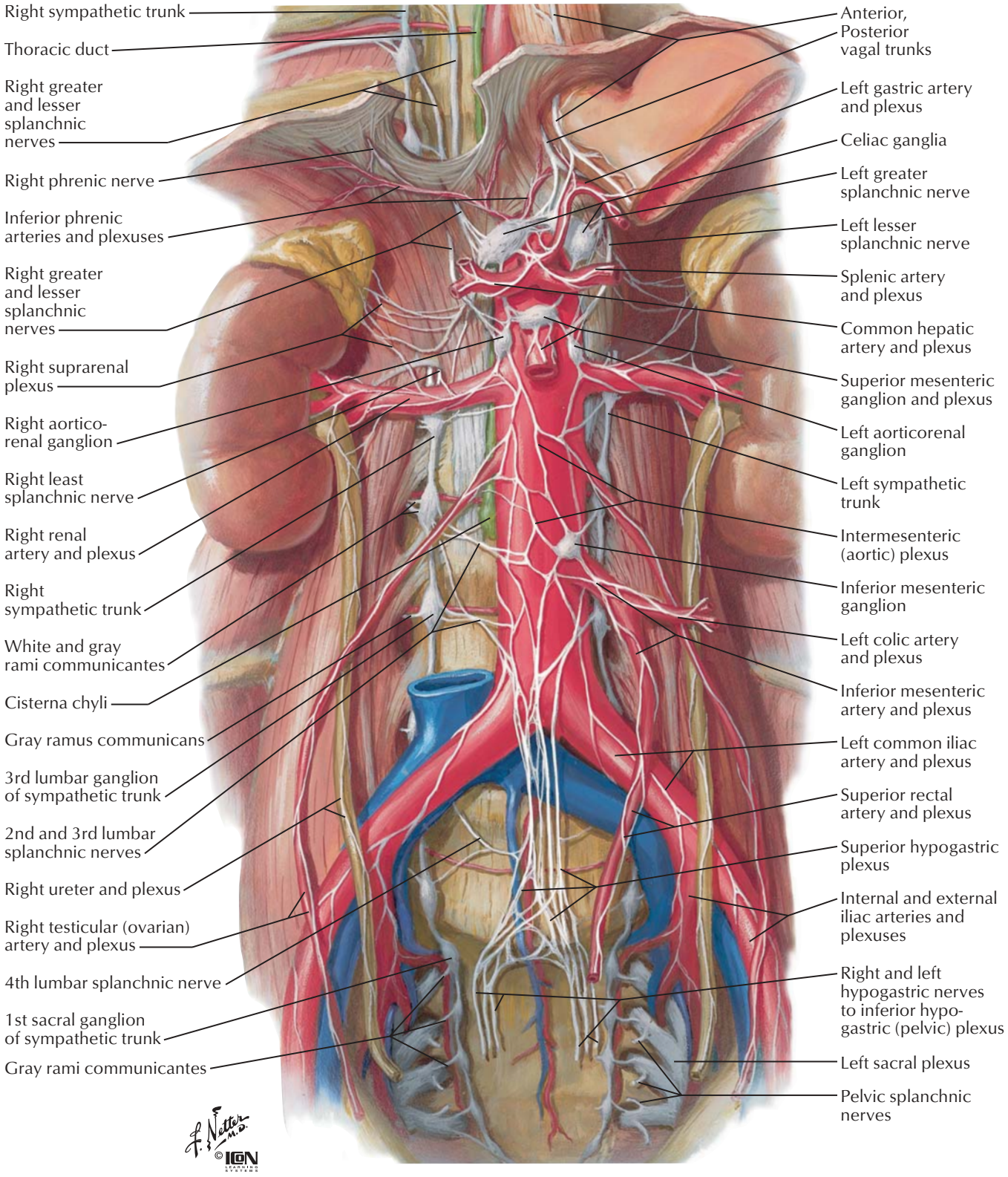


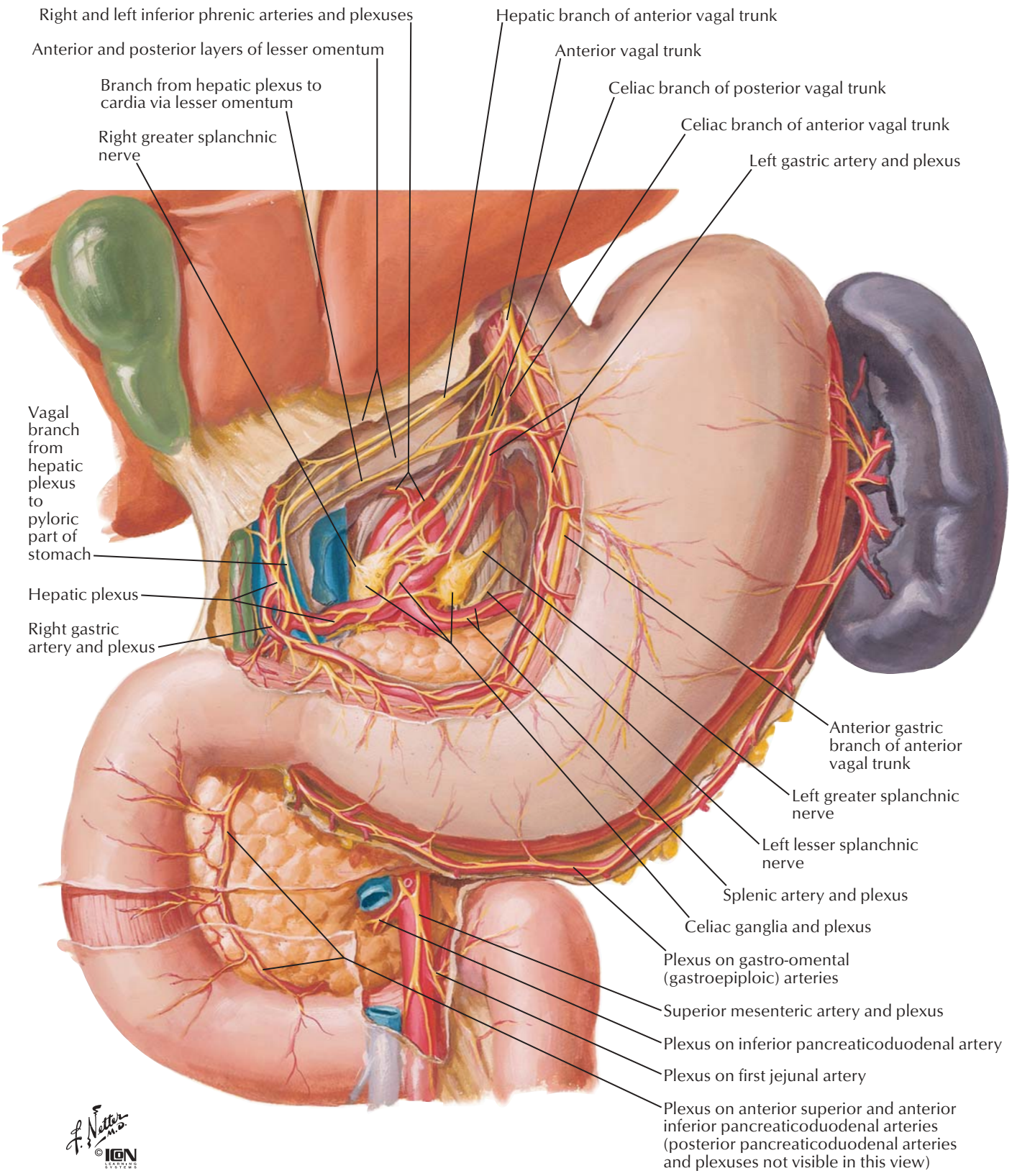
*Recent evidence suggests that the accessory nerve lacks a cranial root and has no connection to the vagus nerve. Verification of this finding awaits further investigation.

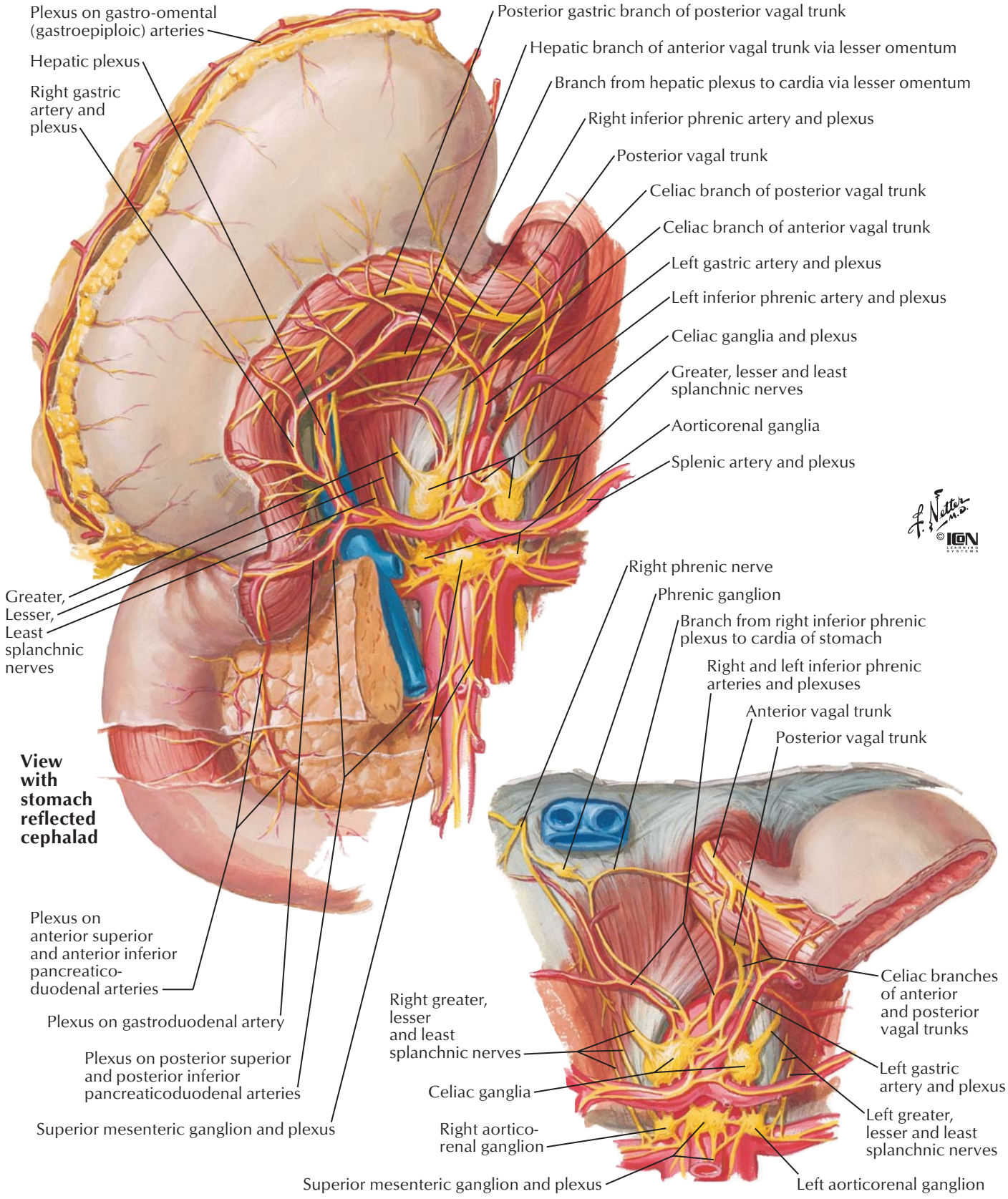


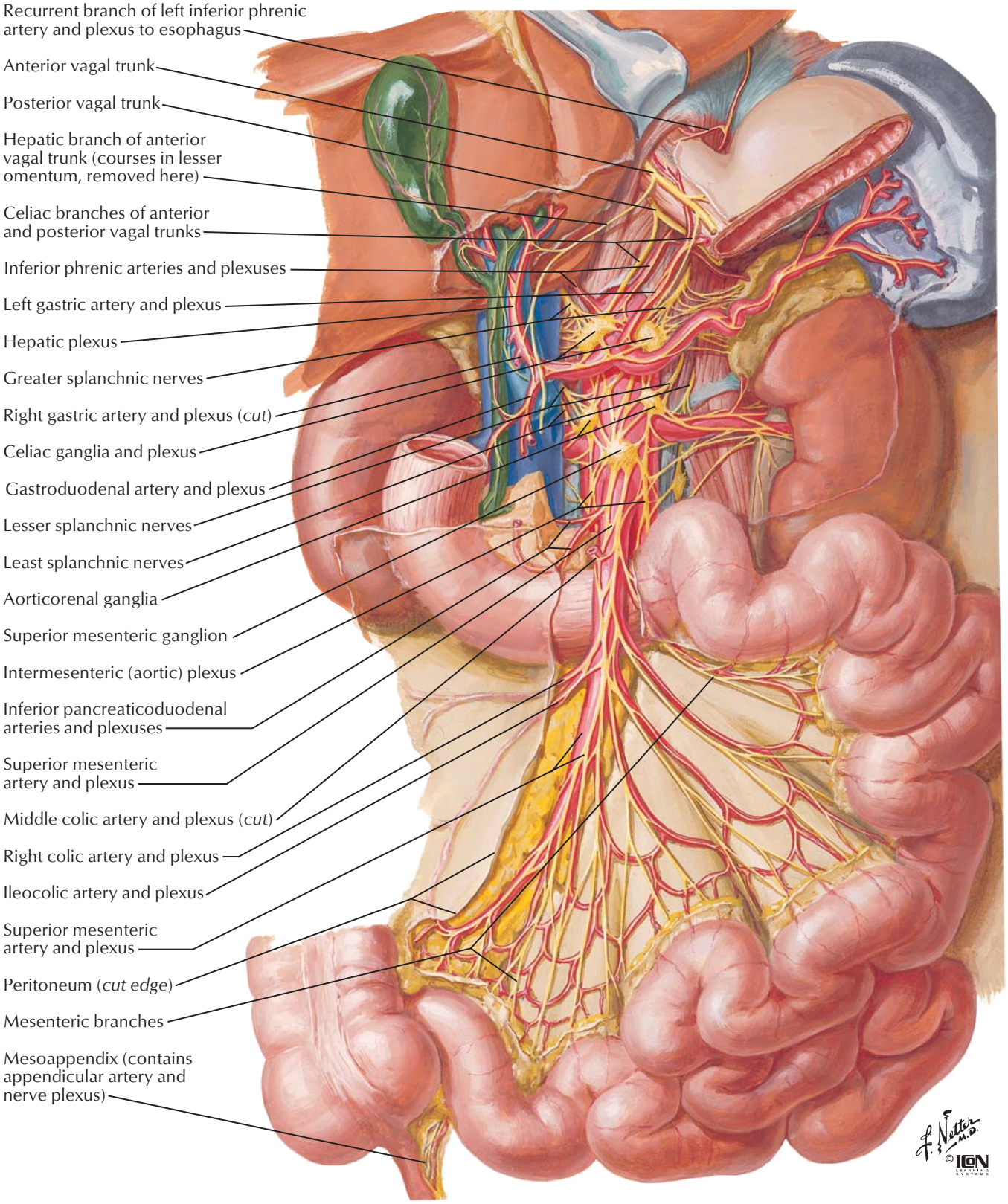
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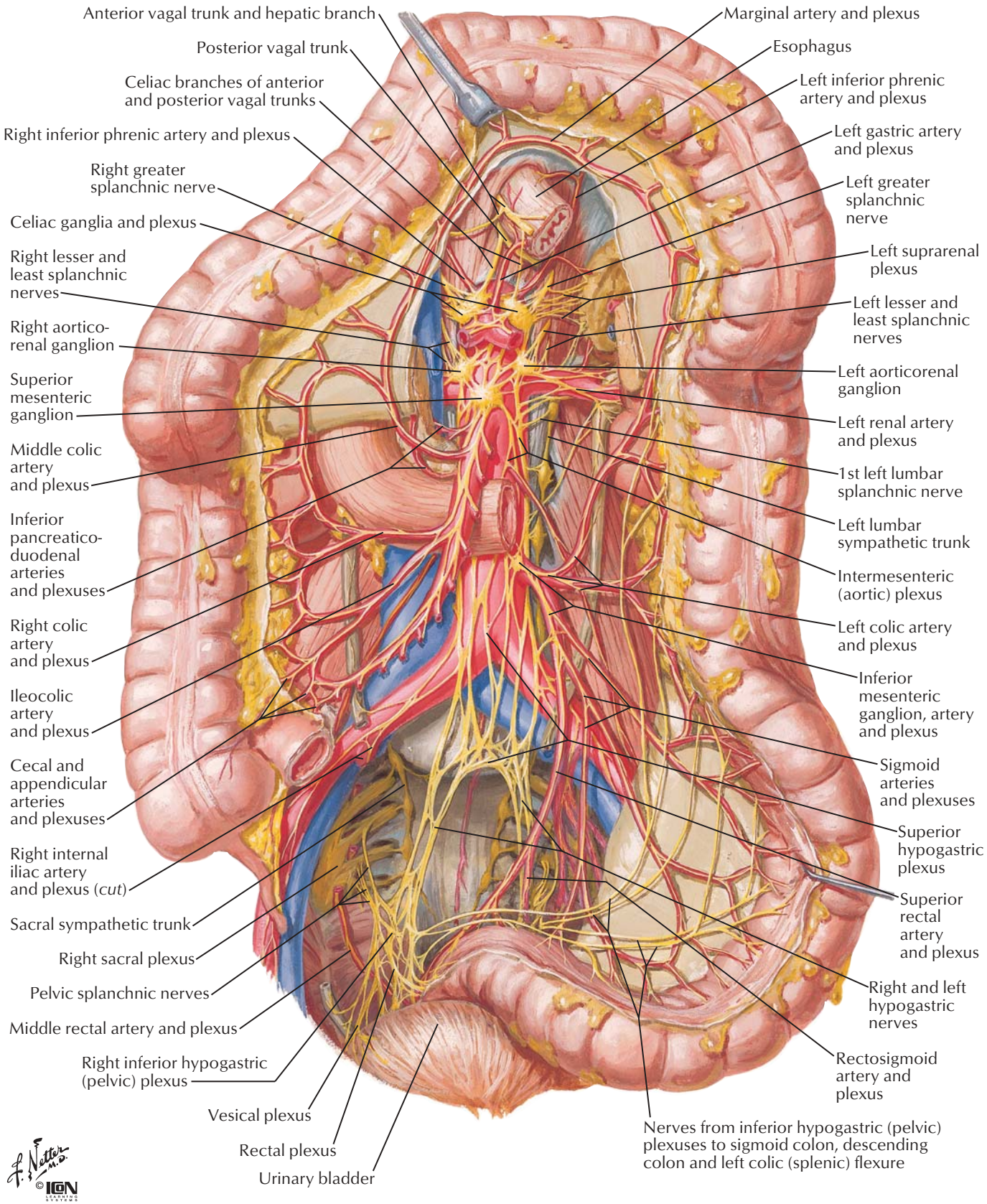

Superior cervical sympathetic ganglion
Vagus nerve (X)
(Conjoined sympathetic and vagal) superior cervical cardiac nerves
Middle cervical sympathetic ganglion
Middle cervical (sympathetic) cardiac nerve
Phrenic nerve
Inferior cervical (vagal) cardiac nerve
Vertebral ganglion
Inferior thyroid artery
Vertebral artery
Cervicothoracic (stellate) ganglion
Ansa subclavia
Recurrent laryngeal nerve
Inferior cervical (sympathetic) cardiac nerves
Thoracic cardiac branch of vagus nerve
4th thoracic sympathetic ganglion
Thoracic (sympathetic) cardiac branches
Cardiac plexus
Phrenic nerve (cut)
Superior cervical sympathetic ganglion
Vagus nerve (X)
Superior cervical (sympathetic) cardiac nerve
Superior cervical (vagal) cardiac nerve
Middle cervical sympathetic ganglion
Phrenic nerve
Middle cervical (sympathetic) cardiac nerve
Inferior cervical (vagal) cardiac nerve
Vertebral ganglion
Cervicothoracic (stellate) ganglion
Inferior cervical sympathetic cardiac nerves
3rd thoracic sympathetic ganglion
Thoracic (sympathetic) cardiac branches
Thoracic cardiac branch of vagus nerve
Recurrent laryngeal nerve
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Right sympathetic trunk
Thoracic duct
Right greater and lesser splanchnic nerves
Right phrenic nerve
Inferior phrenic arteries and plexuses
Right greater and lesser splanchnic nerves
Right suprarenal plexus
Right aortico-renal ganglion
Right least splanchnic nerve
Right renal artery and plexus
Right sympathetic trunk
White and gray rami communicantes
Cisterna chyli
Gray ramus communicans
3rd lumbar ganglion of sympathetic trunk
2nd and 3rd lumbar splanchnic nerves
Right ureter and plexus
Right testicular (ovarian) artery and plexus
4th lumbar splanchnic nerve
1st sacral ganglion of sympathetic trunk
Gray rami communicantes
Anterior, Posterior vagal trunks
Left gastric artery and plexus
Celiac ganglia
Left greater splanchnic nerve
Left lesser splanchnic nerve
Splenic artery and plexus
Common hepatic artery and plexus
Superior mesenteric ganglion and plexus
Left aorticorenal ganglion
Left sympathetic trunk
Intermesenteric (aortic) plexus
Inferior mesenteric ganglion
Left colic artery and plexus
Inferior mesenteric artery and plexus
Left common iliac artery and plexus
Superior rectal artery and plexus
Superior hypogastric plexus
Internal and external iliac arteries and plexuses
Right and left hypogastric nerves to inferior hypogastric (pelvic) plexus
Left sacral plexus
Pelvic splanchnic nerves
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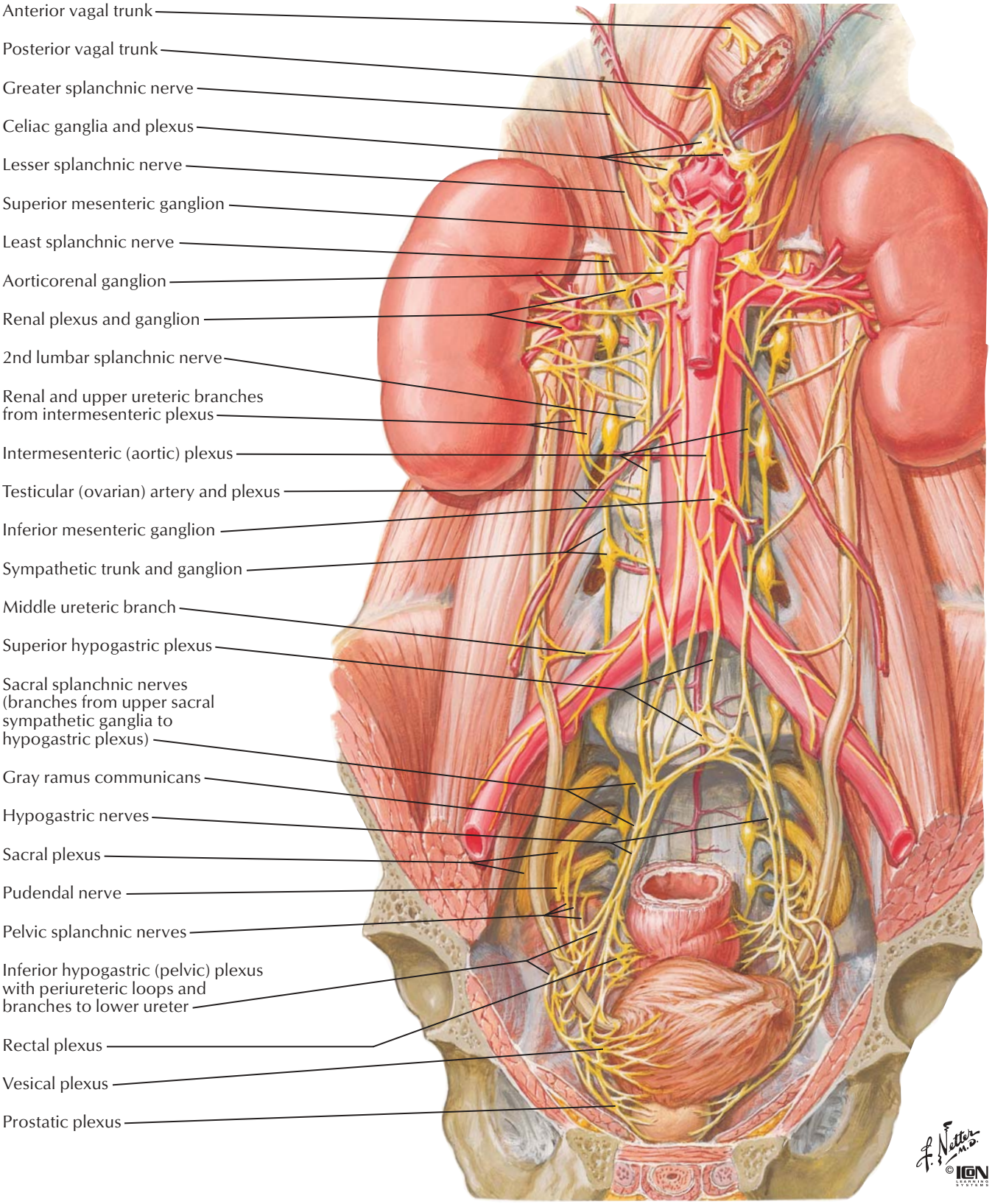

Right and left inferior phrenic arteries and plexuses
Anterior and posterior layers of lesser omentum
Branch from hepatic plexus to cardia via lesser omentum
Right greater splanchnic nerve
Hepatic branch of anterior vagal trunk
Anterior vagal trunk
Celiac branch of posterior vagal trunk
Celiac branch of anterior vagal trunk
Left gastric artery and plexus
Vagal branch from hepatic plexus to pyloric part of stomach
Hepatic plexus
Right gastric artery and plexus
Anterior gastric branch of anterior vagal trunk
Left greater splanchnic nerve
Left lesser splanchnic nerve
Splenic artery and plexus
Celiac ganglia and plexus
Plexus on gastro-omental (gastroepiploic) arteries
Superior mesenteric artery and plexus
Plexus on inferior pancreaticoduodenal artery
Plexus on first jejunal artery
Plexus on anterior superior and anterior inferior pancreaticoduodenal arteries (posterior pancreaticoduodenal arteries and plexuses not visible in this view)

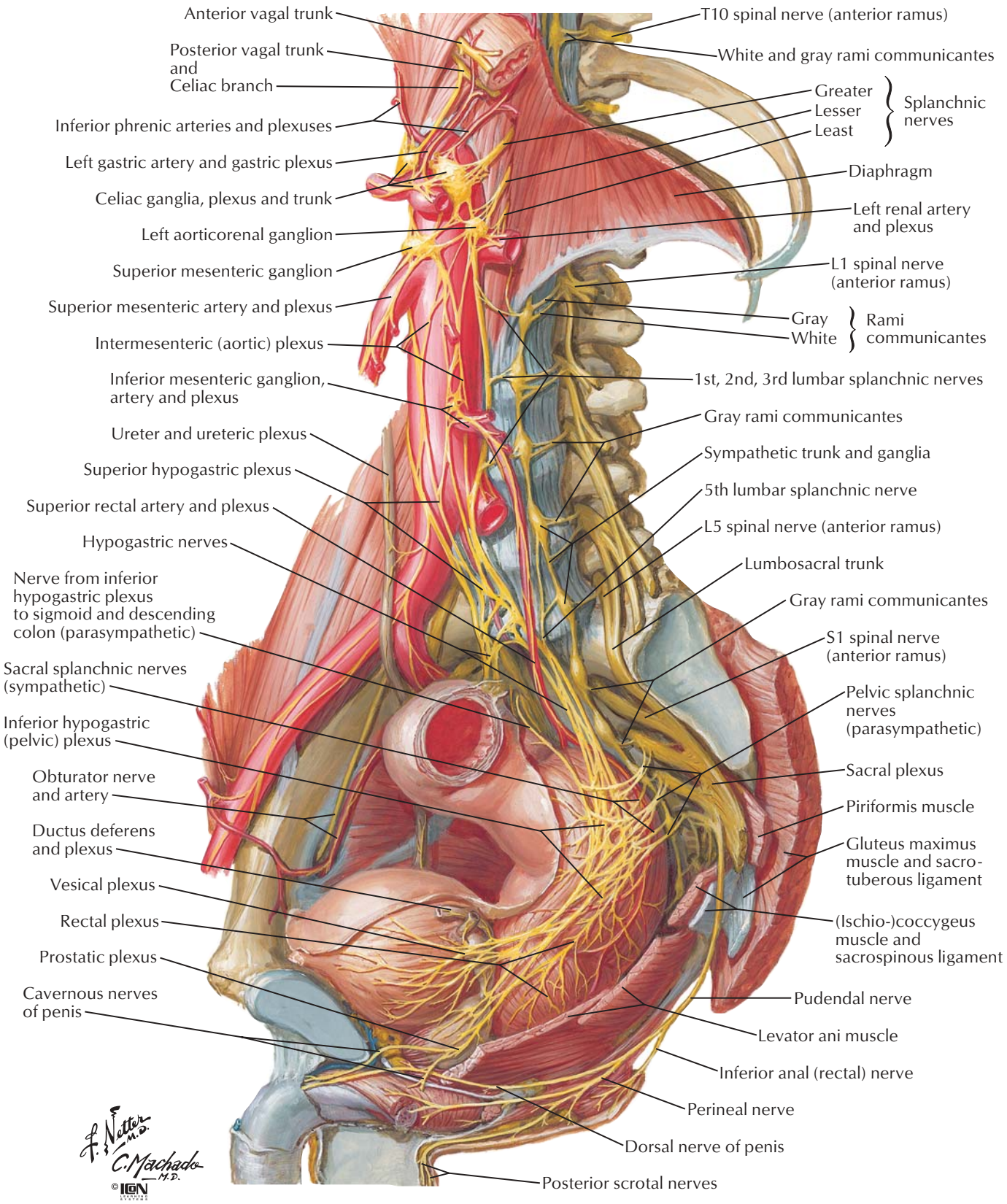

Plexus on gastro-omental (gastroepiploic) arteries
Hepatic plexus
Right gastric artery and plexus
Posterior gastric branch of posterior vagal trunk
Hepatic branch of anterior vagal trunk via lesser omentum
Branch from hepatic plexus to cardia via lesser omentum
Right inferior phrenic artery and plexus
Posterior vagal trunk
Celiac branch of posterior vagal trunk
Celiac branch of anterior vagal trunk
Left gastric artery and plexus
Left inferior phrenic artery and plexus
Celiac ganglia and plexus
Greater, lesser and least splanchnic nerves
Aorticorenal ganglia
Splenic artery and plexus
Greater, Lesser, Least splanchnic nerves
Right phrenic nerve
Phrenic ganglion
Branch from right inferior phrenic plexus to cardia of stomach
Right and left inferior phrenic arteries and plexuses
Anterior vagal trunk
Posterior vagal trunk
View with stomach reflected cephalad
Plexus on anterior superior and anterior inferior pancreatico-duodenal arteries
Plexus on gastroduodenal artery
Plexus on posterior superior and posterior inferior pancreaticoduodenal arteries
Superior mesenteric ganglion and plexus
Right greater, lesser and least splanchnic nerves
Celiac ganglia
Right aortico-renal ganglion
Superior mesenteric ganglion and plexus
Celiac branches of anterior and posterior vagal trunks
Left gastric artery and plexus
Left greater, lesser and least splanchnic nerves
Left aorticorenal ganglion

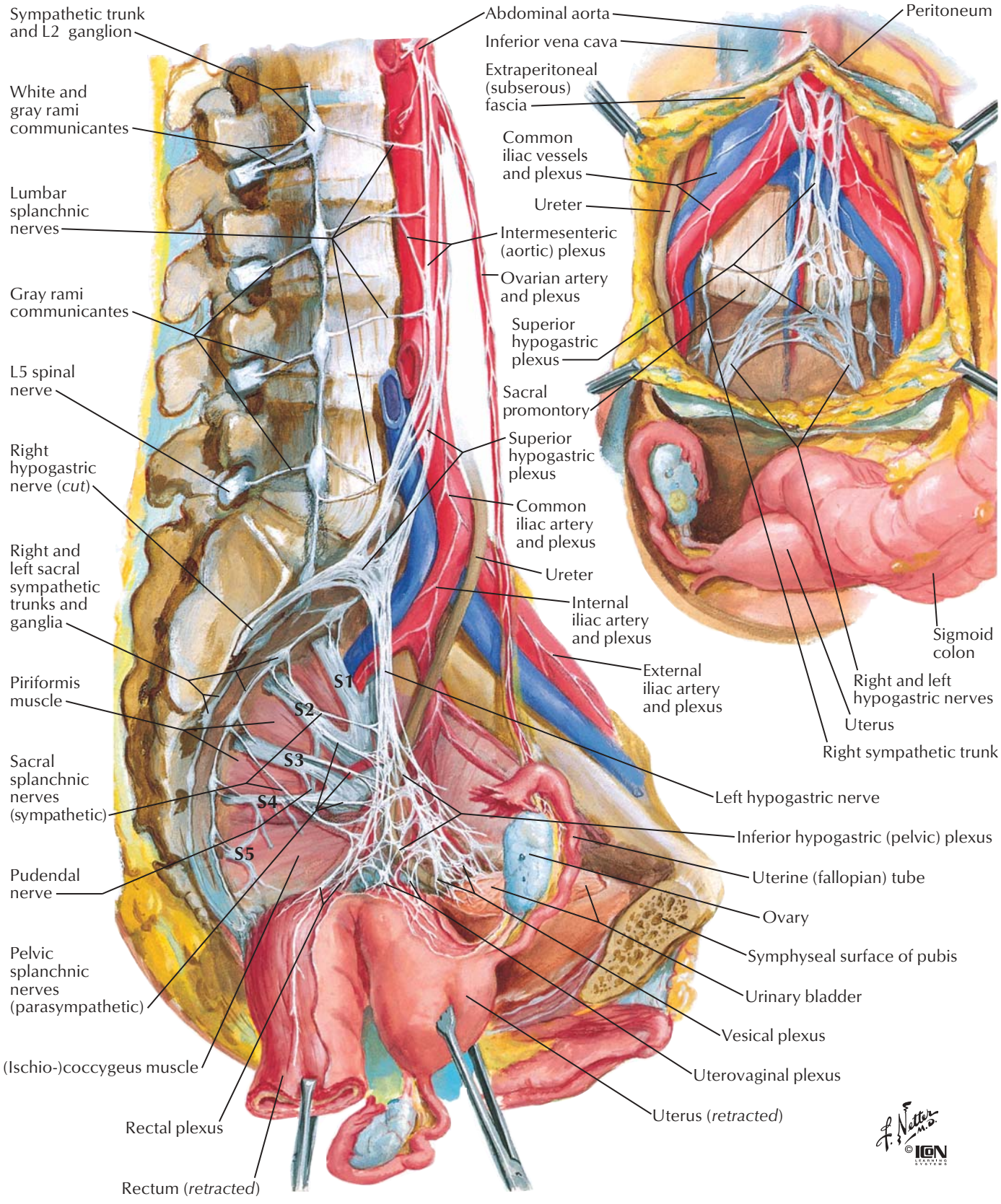

Recurrent branch of left inferior phrenic artery and plexus to esophagus
Anterior vagal trunk
Posterior vagal trunk
Hepatic branch of anterior vagal trunk (courses in lesser omentum, removed here)
Celiac branches of anterior and posterior vagal trunks
Inferior phrenic arteries and plexuses
Left gastric artery and plexus
Hepatic plexus
Greater splanchnic nerves
Right gastric artery and plexus (*cut*)
Celiac ganglia and plexus
Gastroduodenal artery and plexus
Lesser splanchnic nerves
Least splanchnic nerves
Aorticorenal ganglia
Superior mesenteric ganglion
Intermesenteric (aortic) plexus
Inferior pancreaticoduodenal arteries and plexuses
Superior mesenteric artery and plexus
Middle colic artery and plexus (*cut*)
Right colic artery and plexus
Ileocolic artery and plexus
Superior mesenteric artery and plexus
Peritoneum (*cut edge*)
Mesenteric branches
Mesoappendix (contains appendicular artery and nerve plexus)
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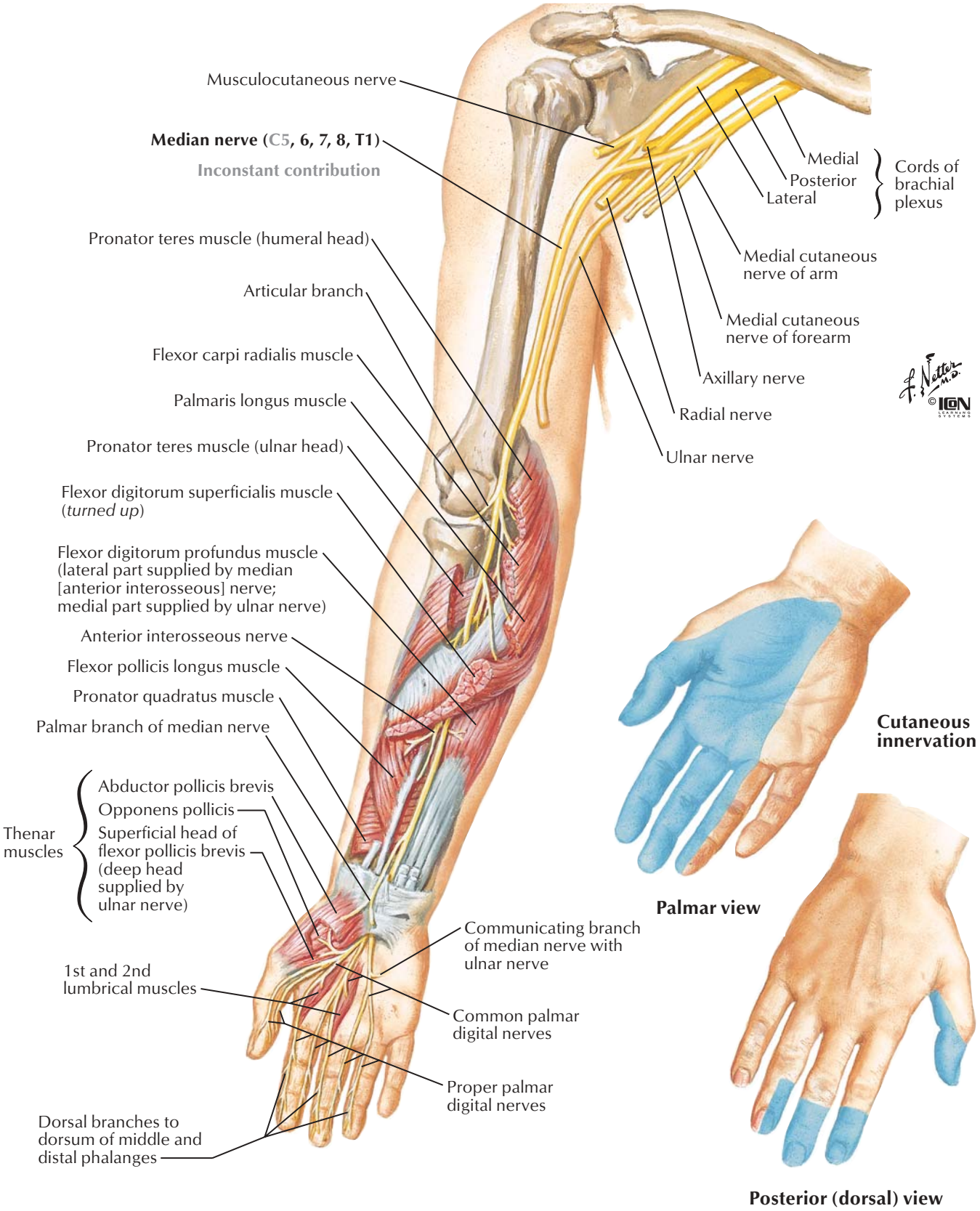

Anterior vagal trunk
Posterior vagal trunk
Greater splanchnic nerve
Celiac ganglia and plexus
Lesser splanchnic nerve
Superior mesenteric ganglion
Least splanchnic nerve
Aorticorenal ganglion
Renal plexus and ganglion
2nd lumbar splanchnic nerve
Renal and upper ureteric branches from intermesenteric plexus
Intermesenteric (aortic) plexus
Testicular (ovarian) artery and plexus
Inferior mesenteric ganglion
Sympathetic trunk and ganglion
Middle ureteric branch
Superior hypogastric plexus
Sacral splanchnic nerves (branches from upper sacral sympathetic ganglia to hypogastric plexus)
Gray ramus communicans
Hypogastric nerves
Sacral plexus
Pudendal nerve
Pelvic splanchnic nerves
Inferior hypogastric (pelvic) plexus with periureteric loops and branches to lower ureter
Rectal plexus
Vesical plexus
Prostatic plexus
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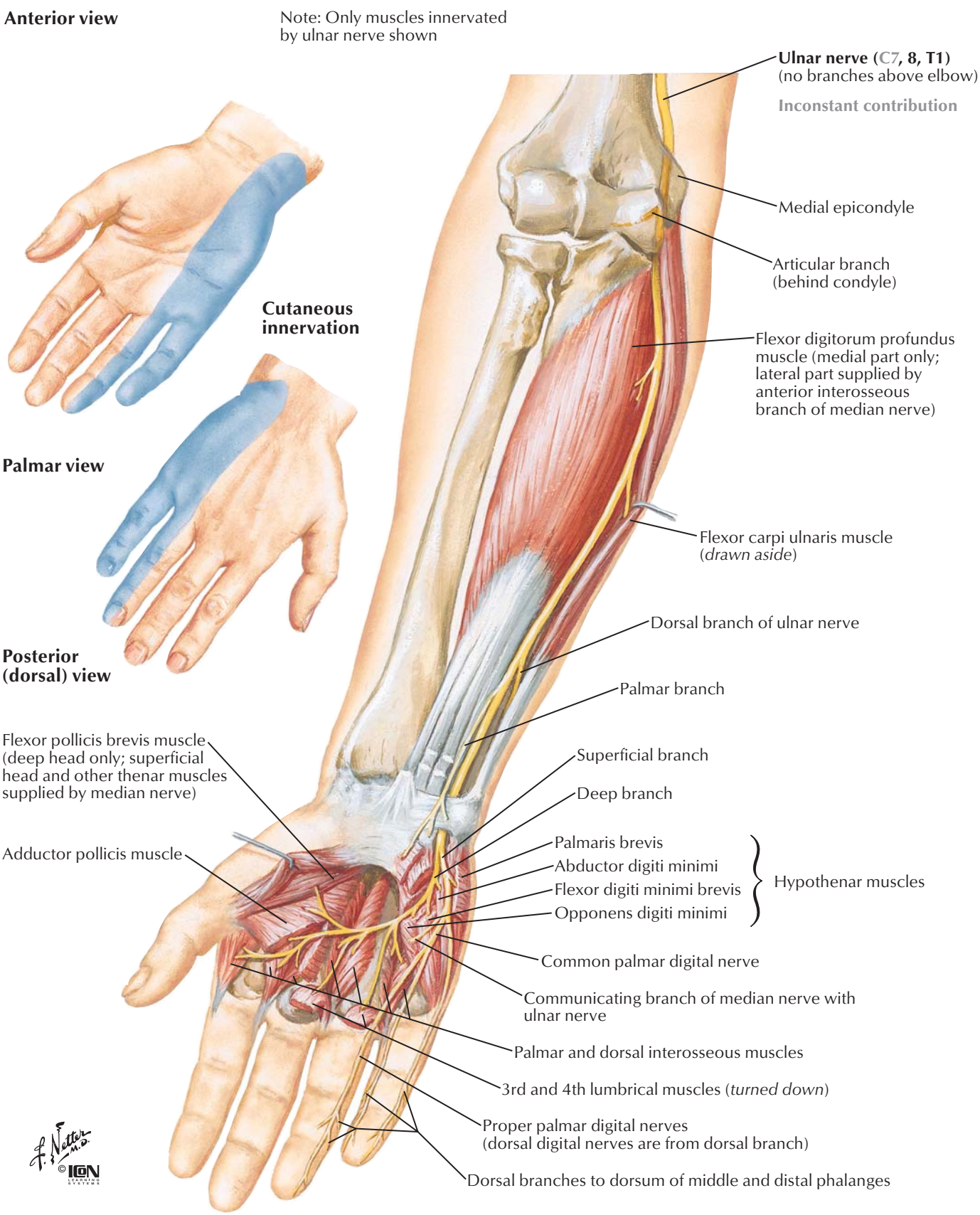

Anterior vagal trunk
Posterior vagal trunk and Celiac branch
Inferior phrenic arteries and plexuses
Left gastric artery and gastric plexus
Celiac ganglia, plexus and trunk
Left aorticorenal ganglion
Superior mesenteric ganglion
Superior mesenteric artery and plexus
Intermesenteric (aortic) plexus
Inferior mesenteric ganglion, artery and plexus
Ureter and ureteric plexus
Superior hypogastric plexus
Superior rectal artery and plexus
Hypogastric nerves
Nerve from inferior hypogastric plexus to sigmoid and descending colon (parasympathetic)
Sacral splanchnic nerves (sympathetic)
Inferior hypogastric (pelvic) plexus
Obturator nerve and artery
Ductus deferens and plexus
Vesical plexus
Rectal plexus
Prostatic plexus
Cavernous nerves of penis
T10 spinal nerve (anterior ramus)
White and gray rami communicantes
Greater
Lesser
Least
Splanchnic nerves
Diaphragm
Left renal artery and plexus
L1 spinal nerve (anterior ramus)
Gray
White
Rami communicantes
1st, 2nd, 3rd lumbar splanchnic nerves
Gray rami communicantes
Sympathetic trunk and ganglia
5th lumbar splanchnic nerve
L5 spinal nerve (anterior ramus)
Lumbosacral trunk
Gray rami communicantes
S1 spinal nerve (anterior ramus)
Pelvic splanchnic nerves (parasympathetic)
Sacral plexus
Piriformis muscle
Gluteus maximus muscle and sacro-tuberous ligament
(Ischio-)coccygeus muscle and sacrospinous ligament
Pudendal nerve
Levator ani muscle
Inferior anal (rectal) nerve
Perineal nerve
Dorsal nerve of penis
Posterior scrotal nerves
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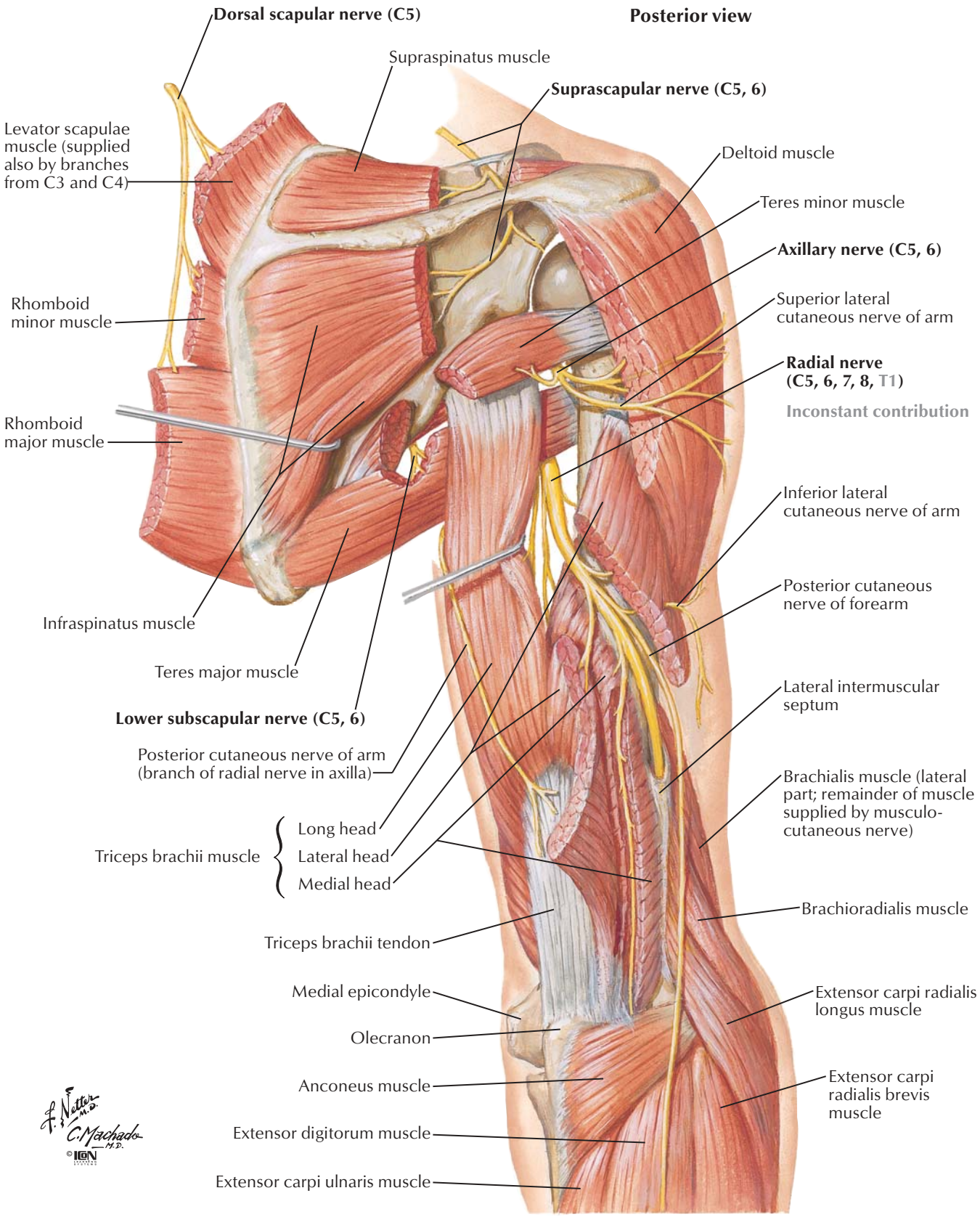

Sympathetic trunk and L2 ganglion
White and gray rami communicantes
Lumbar splanchnic nerves
Gray rami communicantes
L5 spinal nerve
Right hypogastric nerve (*cut*)
Right and left sacral sympathetic trunks and ganglia
Piriformis muscle
Sacral splanchnic nerves (sympathetic)
Pudendal nerve
Pelvic splanchnic nerves (parasympathetic)
(Ischio-)coccygeus muscle
Rectal plexus
Rectum (*retracted*)
S1
S2
S3
S4
S5
Abdominal aorta
Inferior vena cava
Extraperitoneal (subserous) fascia
Common iliac vessels and plexus
Ureter
Intermesenteric (aortic) plexus
Ovarian artery and plexus
Superior hypogastric plexus
Sacral promontory
Superior hypogastric plexus
Common iliac artery and plexus
Ureter
Internal iliac artery and plexus
External iliac artery and plexus
Left hypogastric nerve
Inferior hypogastric (pelvic) plexus
Uterine (fallopian) tube
Ovary
Symphyseal surface of pubis
Urinary bladder
Vesical plexus
Uterovaginal plexus
Uterus (*retracted*)
Peritoneum
Sigmoid colon
Right and left hypogastric nerves
Uterus
Right sympathetic trunk

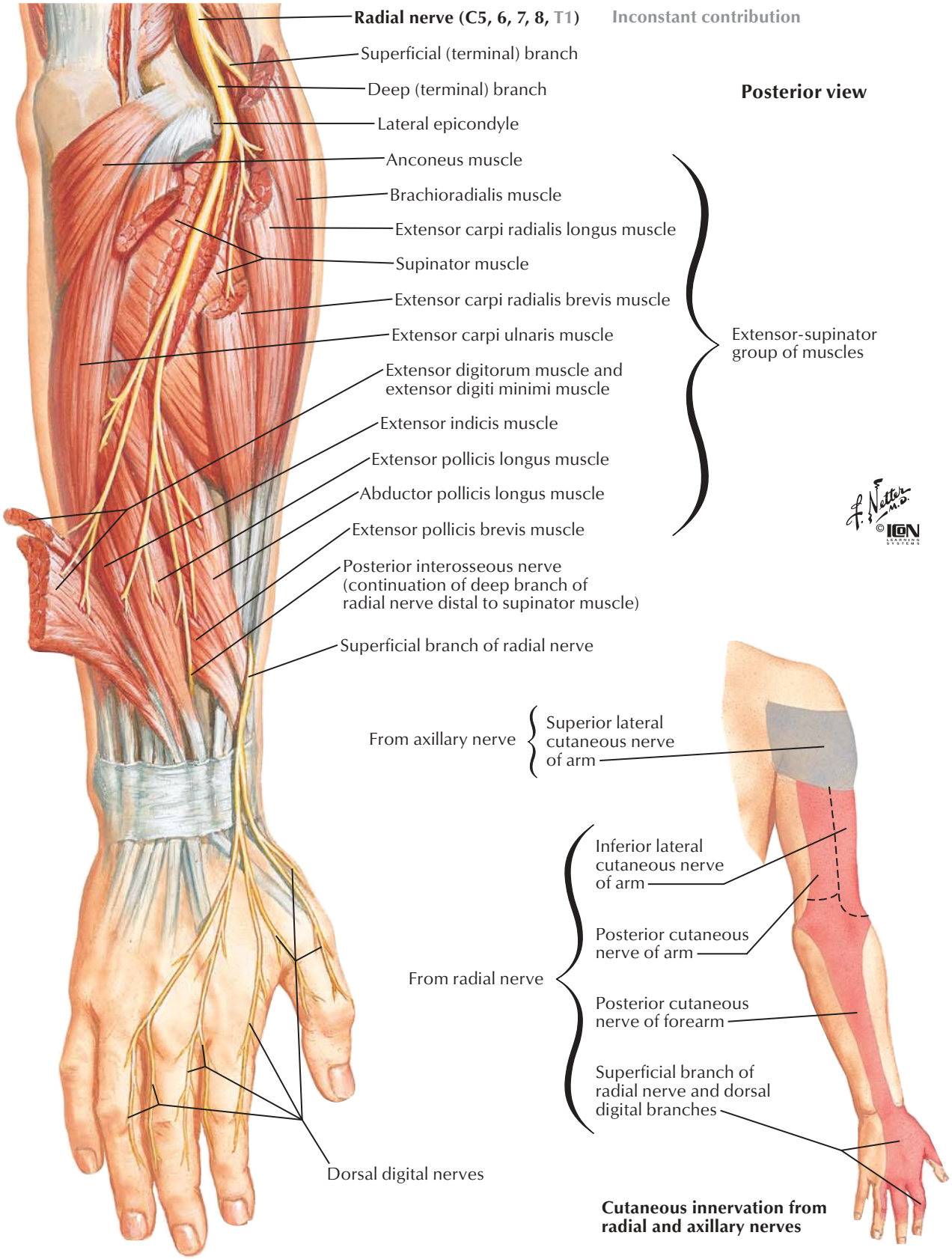
Anterior view

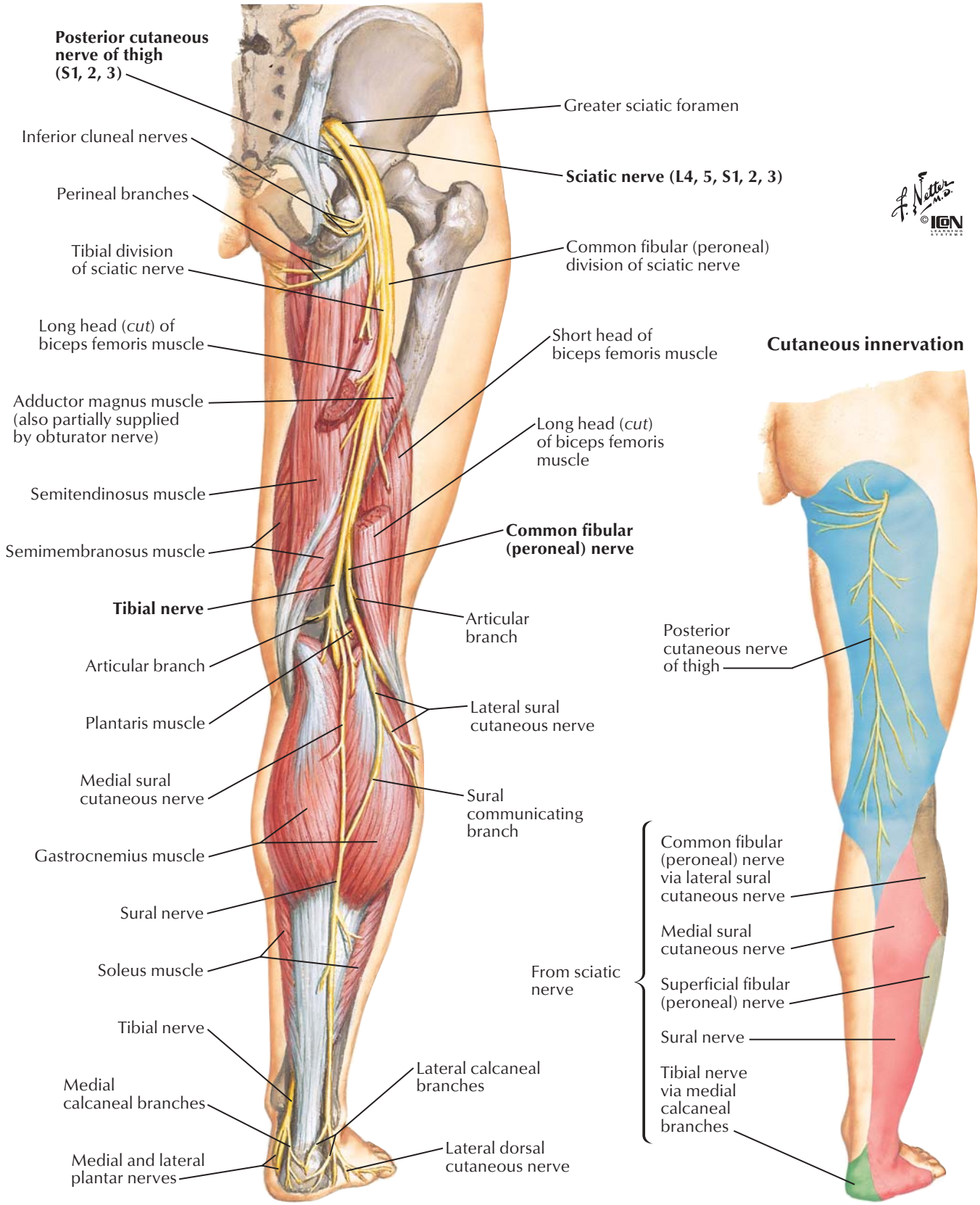
Note: Only muscles innervated by median nerve shown

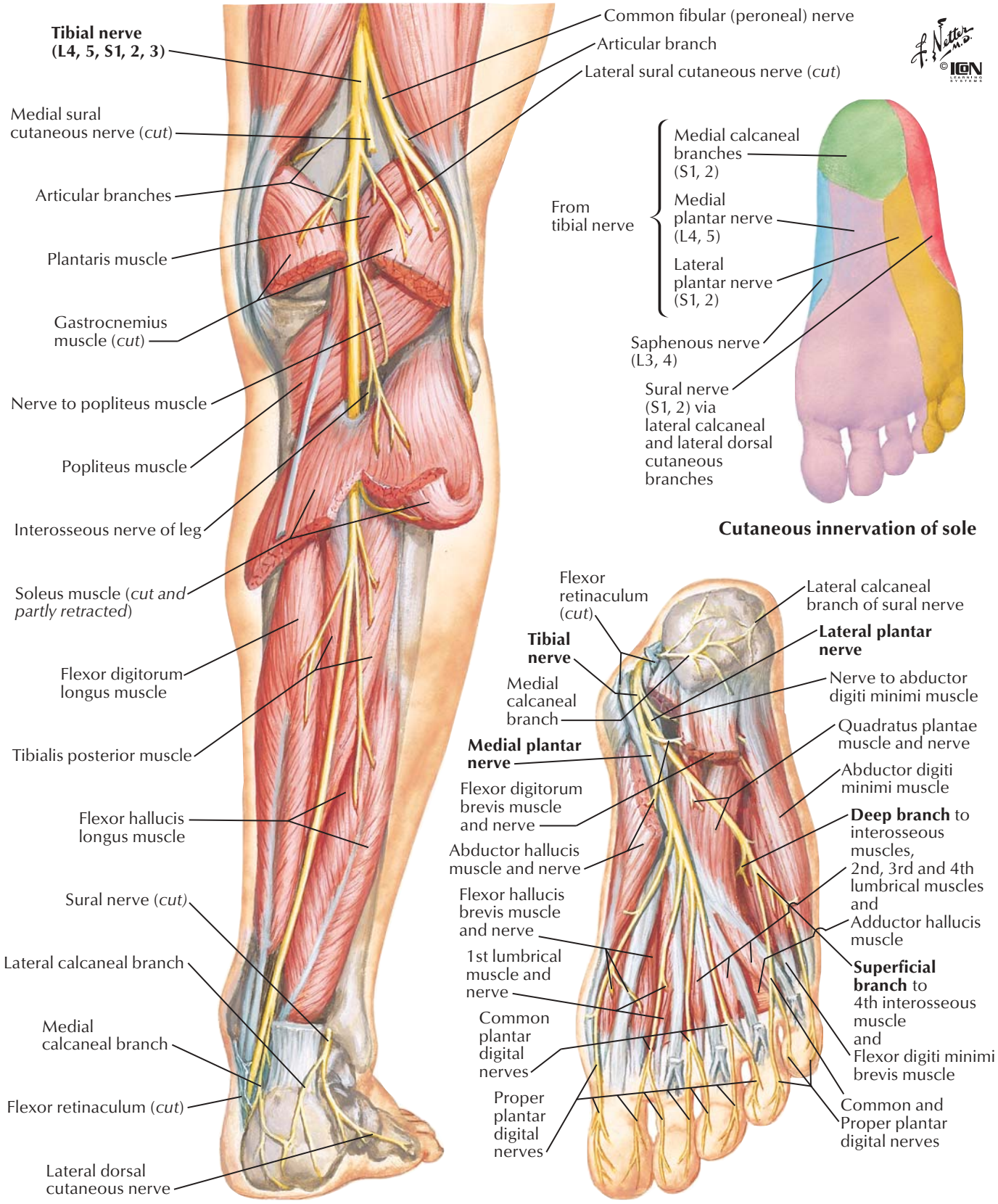



Anterior view
Note: Only muscles innervated by ulnar nerve shown
Ulnar nerve (C7, 8, T1)
(no branches above elbow)
Inconstant contribution
Medial epicondyle
Articular branch (behind condyle)
Cutaneous innervation
Flexor digitorum profundus muscle (medial part only; lateral part supplied by anterior interosseous branch of median nerve)
Palmar view
Flexor carpi ulnaris muscle (drawn aside)
Dorsal branch of ulnar nerve
Posterior (dorsal) view
Palmar branch
Flexor pollicis brevis muscle (deep head only; superficial head and other thenar muscles supplied by median nerve)
Superficial branch
Deep branch
Adductor pollicis muscle
Palmaris brevis
Abductor digiti minimi
Flexor digiti minimi brevis
Opponens digiti minimi
Hypothenar muscles
Common palmar digital nerve
Communicating branch of median nerve with ulnar nerve
Palmar and dorsal interosseous muscles
3rd and 4th lumbrical muscles (turned down)
Proper palmar digital nerves (dorsal digital nerves are from dorsal branch)
Dorsal branches to dorsum of middle and distal phalanges
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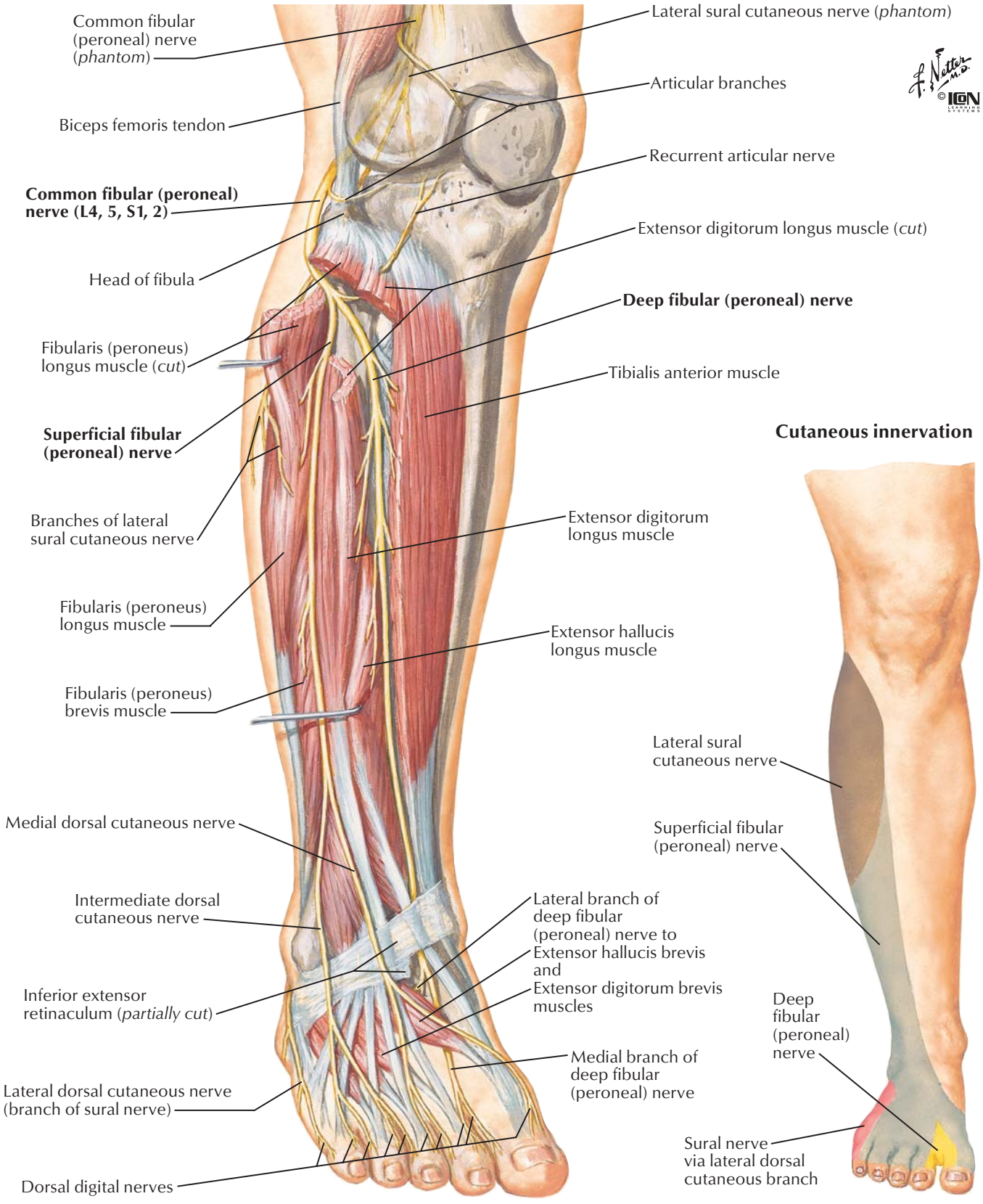

Posterior view
Dorsal scapular nerve (C5)
Supraspinatus muscle
Suprascapular nerve (C5, 6)
Levator scapulae muscle (supplied also by branches from C3 and C4)
Deltoid muscle
Teres minor muscle
Axillary nerve (C5, 6)
Rhomboid minor muscle
Superior lateral cutaneous nerve of arm
Radial nerve (C5, 6, 7, 8, T1)
Inconstant contribution
Rhomboid major muscle
Inferior lateral cutaneous nerve of arm
Posterior cutaneous nerve of forearm
Infraspinatus muscle
Teres major muscle
Lateral intermuscular septum
Lower subscapular nerve (C5, 6)
Posterior cutaneous nerve of arm (branch of radial nerve in axilla)
Brachialis muscle (lateral part; remainder of muscle supplied by musculo-cutaneous nerve)
Triceps brachii muscle
Long head
Lateral head
Medial head
Brachioradialis muscle
Triceps brachii tendon
Medial epicondyle
Extensor carpi radialis longus muscle
Olecranon
Anconeus muscle
Extensor carpi radialis brevis muscle
Extensor digitorum muscle
Extensor carpi ulnaris muscle
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Radial nerve (C5, 6, 7, 8, T1)
Inconstant contribution
Superficial (terminal) branch
Deep (terminal) branch
Posterior view
Lateral epicondyle
Anconeus muscle
Brachioradialis muscle
Extensor carpi radialis longus muscle
Supinator muscle
Extensor carpi radialis brevis muscle
Extensor carpi ulnaris muscle
Extensor digitorum muscle and extensor digiti minimi muscle
Extensor indicis muscle
Extensor pollicis longus muscle
Abductor pollicis longus muscle
Extensor pollicis brevis muscle
Posterior interosseous nerve (continuation of deep branch of radial nerve distal to supinator muscle)
Superficial branch of radial nerve
Extensor-supinator group of muscles
From axillary nerve
Superior lateral cutaneous nerve of arm
Inferior lateral cutaneous nerve of arm
Posterior cutaneous nerve of arm
From radial nerve
Posterior cutaneous nerve of forearm
Superficial branch of radial nerve and dorsal digital branches
Dorsal digital nerves
Cutaneous innervation from radial and axillary nerves


Posterior cutaneous nerve of thigh (S1, 2, 3)
Inferior cluneal nerves
Perineal branches
Tibial division of sciatic nerve
Long head (cut) of biceps femoris muscle
Adductor magnus muscle (also partially supplied by obturator nerve)
Semitendinosus muscle
Semimembranosus muscle
Tibial nerve
Articular branch
Plantaris muscle
Medial sural cutaneous nerve
Gastrocnemius muscle
Sural nerve
Soleus muscle
Tibial nerve
Medial calcaneal branches
Medial and lateral plantar nerves
Greater sciatic foramen
Sciatic nerve (L4, 5, S1, 2, 3)
Common fibular (peroneal) division of sciatic nerve
Short head of biceps femoris muscle
Long head (cut) of biceps femoris muscle
Common fibular (peroneal) nerve
Articular branch
Lateral sural cutaneous nerve
Sural communicating branch
Lateral calcaneal branches
Lateral dorsal cutaneous nerve
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Cutaneous innervation
Posterior cutaneous nerve of thigh
From sciatic nerve
Common fibular (peroneal) nerve via lateral sural cutaneous nerve
Medial sural cutaneous nerve
Superficial fibular (peroneal) nerve
Sural nerve
Tibial nerve via medial calcaneal branches



Note: Articular branches not shown


Common fibular (peroneal) nerve (*phantom*)
Lateral sural cutaneous nerve (*phantom*)
Articular branches
Biceps femoris tendon
Recurrent articular nerve
Common fibular (peroneal) nerve (L4, 5, S1, 2)
Extensor digitorum longus muscle (*cut*)
Head of fibula
Deep fibular (peroneal) nerve
Fibularis (peroneus) longus muscle (*cut*)
Tibialis anterior muscle
Superficial fibular (peroneal) nerve
Branches of lateral sural cutaneous nerve
Extensor digitorum longus muscle
Fibularis (peroneus) longus muscle
Extensor hallucis longus muscle
Fibularis (peroneus) brevis muscle
Medial dorsal cutaneous nerve
Intermediate dorsal cutaneous nerve
Lateral branch of deep fibular (peroneal) nerve to Extensor hallucis brevis and Extensor digitorum brevis muscles
Inferior extensor retinaculum (*partially cut*)
Medial branch of deep fibular (peroneal) nerve
Lateral dorsal cutaneous nerve (branch of sural nerve)
Dorsal digital nerves
Cutaneous innervation
Lateral sural cutaneous nerve
Superficial fibular (peroneal) nerve
Deep fibular (peroneal) nerve
Sural nerve via lateral dorsal cutaneous branch

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Part 2 Neurophysiology

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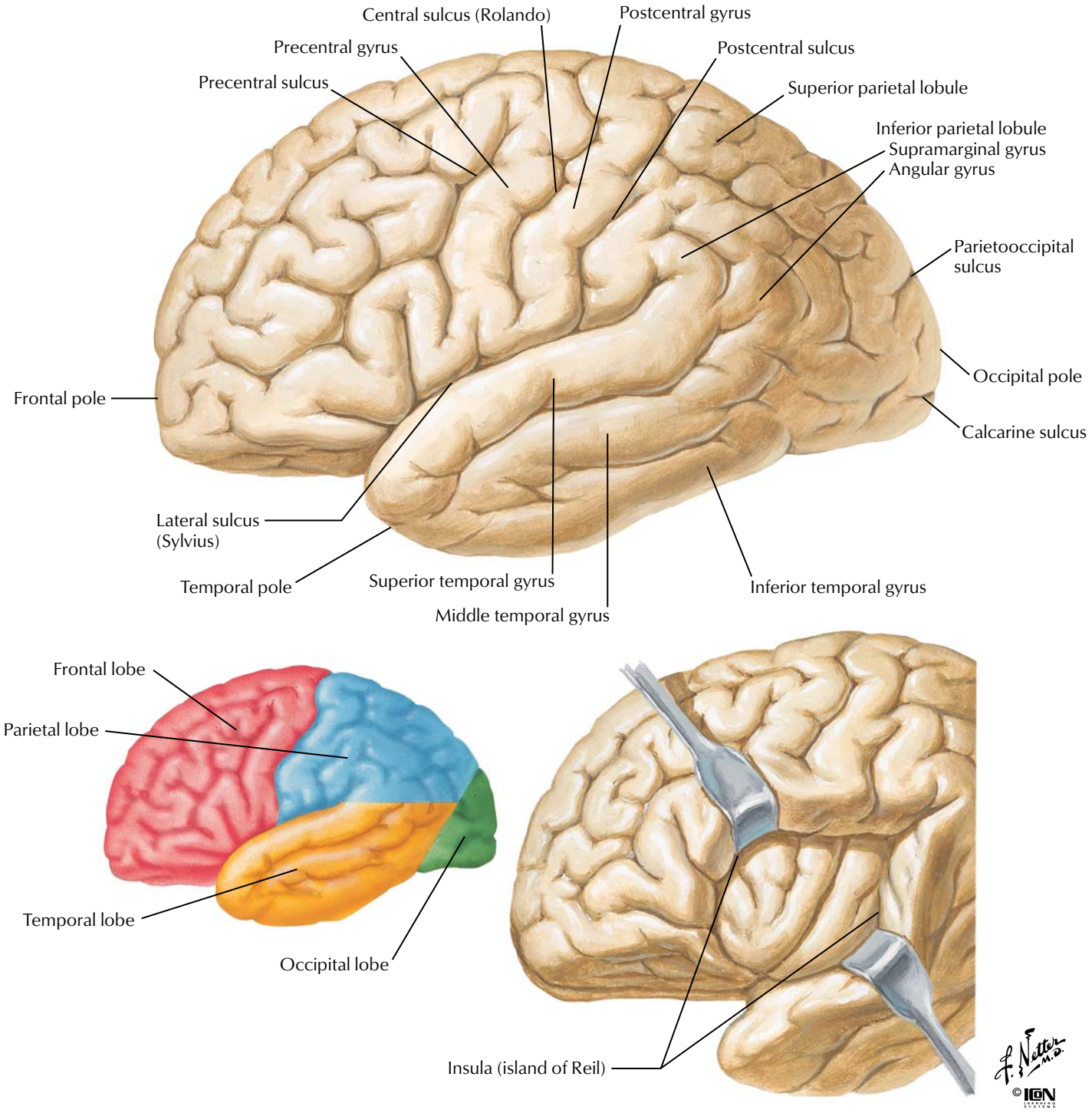


Figure 2.1 Organization of the Brain: Cerebrum

The cerebral cortex represents the highest center for sensory and motor processing. In general, the frontal lobe processes motor, visual, speech, and personality modalities. The parietal lobe processes sensory information; the temporal lobe, auditory and memory modalities; and the occipital lobe, vision. The cerebellum coordinates smooth motor activities and processes muscle position. The brainstem (medulla, pons, midbrain) conveys motor and sensory information and mediates important autonomic functions. The spinal cord receives sensory input from the body and conveys somatic and autonomic motor information to peripheral targets (muscles, viscera).

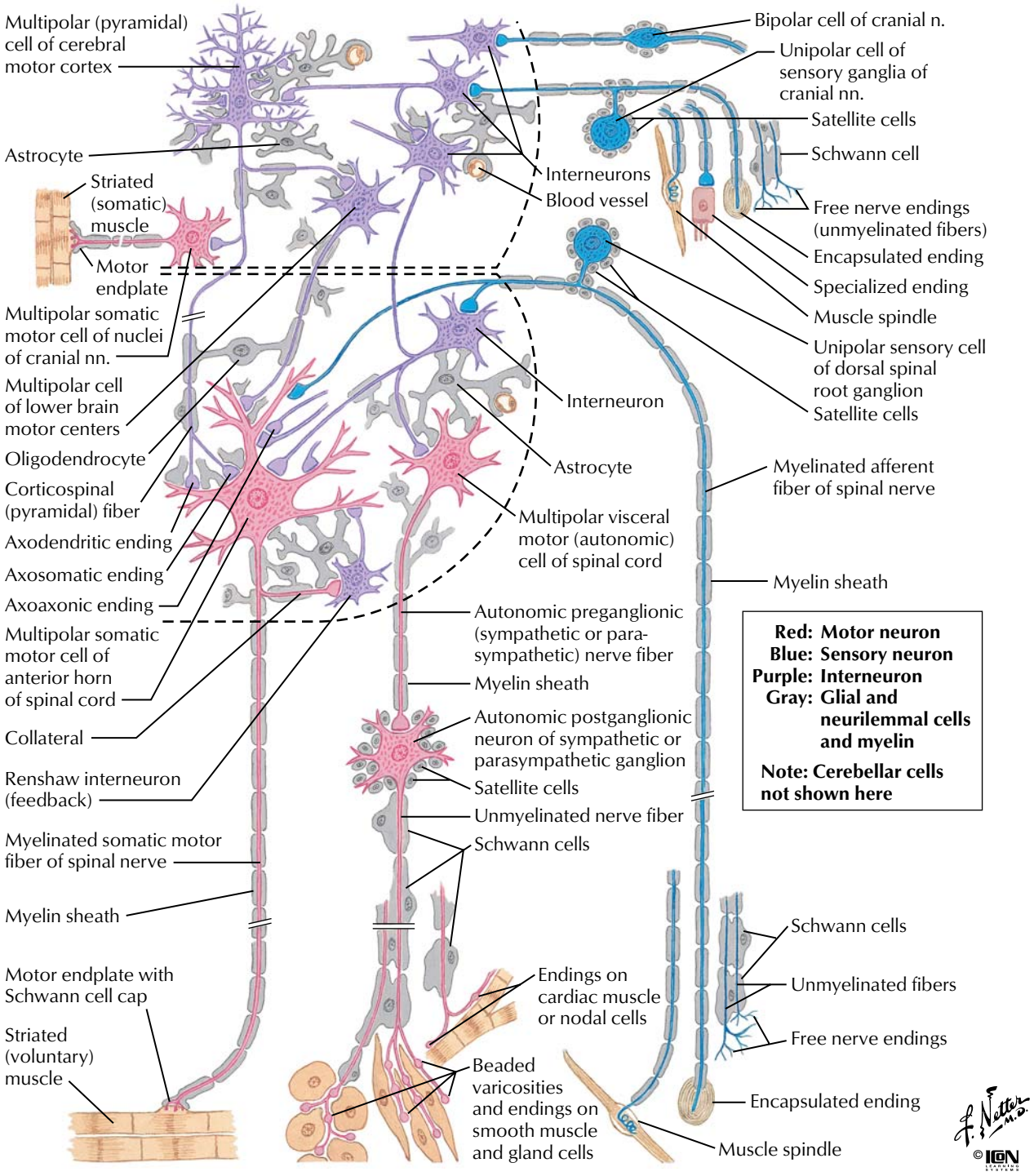


FIGURE 2.2 ORGANIZATION OF THE BRAIN: CELL TYPES

Neurons form the functional cellular units responsible for communication, and throughout the nervous system, they are characterized by their distinctive size and shapes (e.g., bipolar, unipolar, multipolar). Supporting cells include the neuroglia (e.g., astrocytes, oligodendrocytes), satellite cells, and other specialized cells that optimize neuronal function, provide maintenance functions, or protect the nervous system.

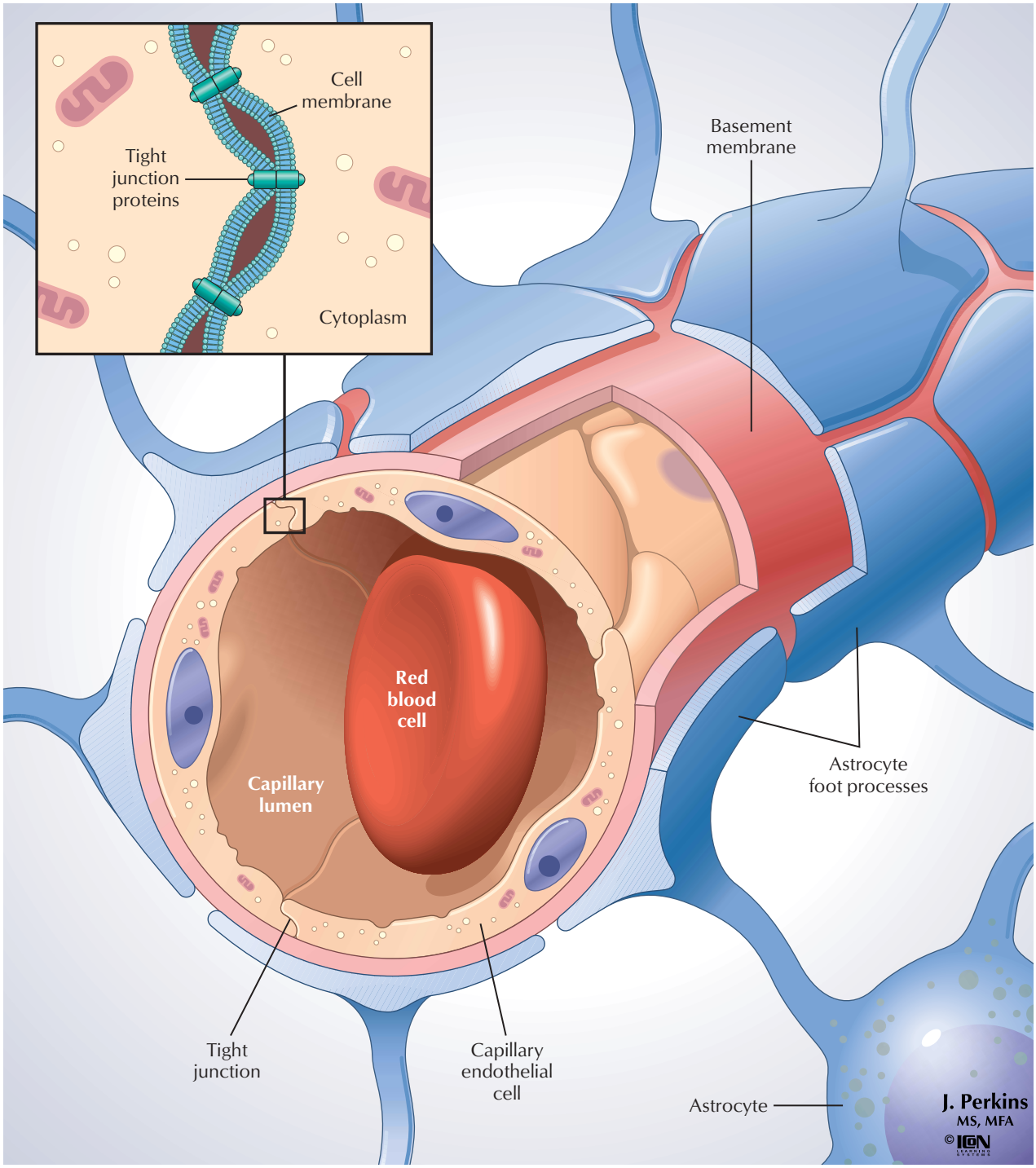


FIGURE 2.3 BLOOD-BRAIN BARRIER

The blood-brain barrier (BBB) is the cellular interface between the blood and the central nervous system (CNS; brain and spinal cord). It serves to maintain the interstitial fluid environment to ensure optimal functionality of the neurons. This barrier consists of the capillary endothelial cells with an elaborate network of tight junctions and astrocytic foot processes that abut the endothelium and its basement membrane. The movement of large molecules and other substances (including many drugs) from the blood to the interstitial space of the CNS is restricted by the BBB. CNS endothelial cells also exhibit a low level of pinocytotic activity across the cell, so specific carrier systems for the transport of essential substrates of energy and amino acid metabolism are characteristic of these cells. The astrocytes help transfer important metabolites from the blood to the neurons and also remove excess K^+ and neurotransmitters from the interstitial fluid.

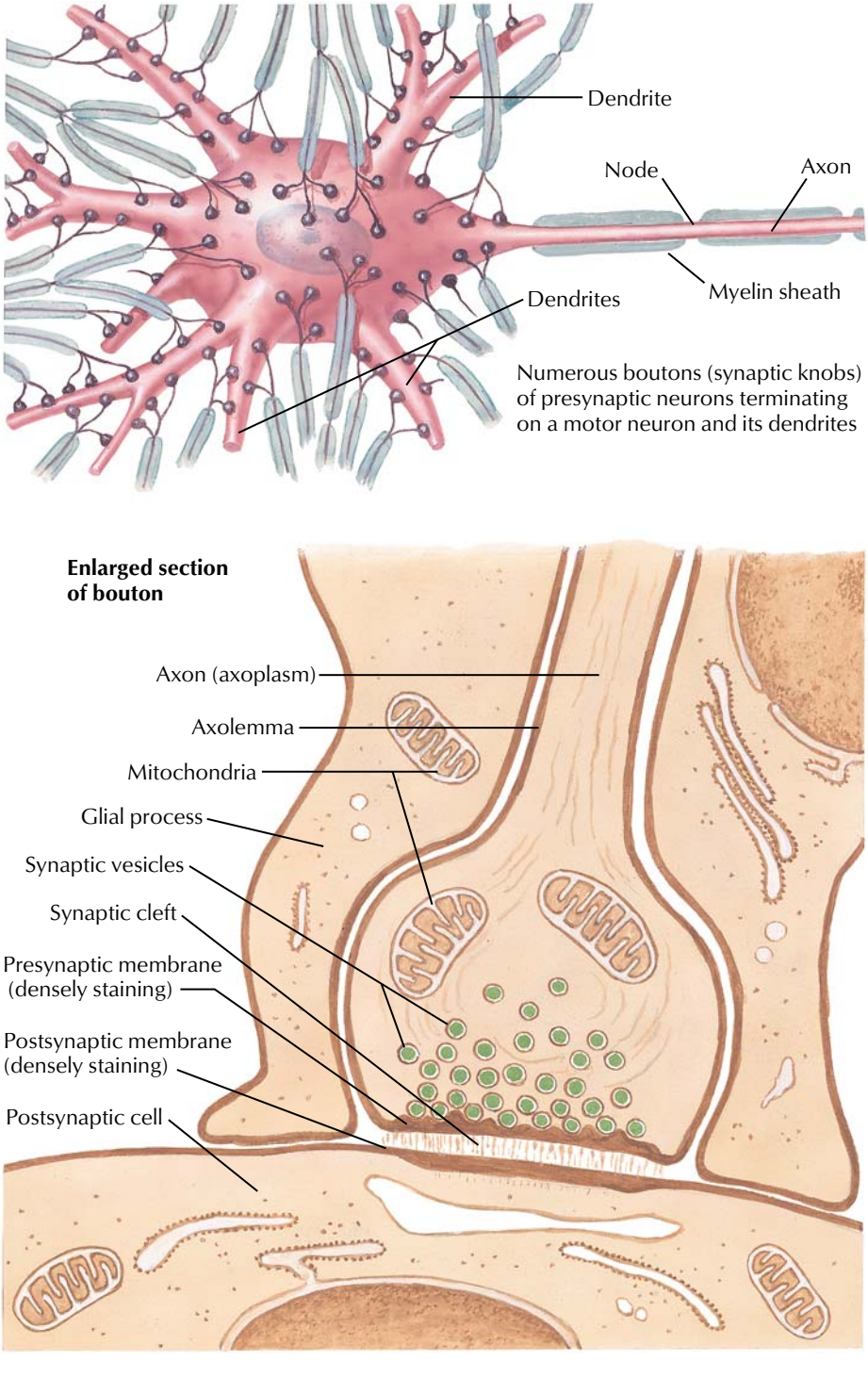


FIGURE 2.4 MORPHOLOGY OF SYNAPSES

Neurons communicate with each other and with effector targets at specialized regions called synapses. The top figure shows a typical motor neuron that receives numerous synaptic contacts on its cell body and associated dendrites. Incoming axons lose their myelin sheaths, exhibit extensive branching, and terminate as synaptic boutons (synaptic terminals or knobs) on the motor neuron. The lower figure shows an enlargement of one such synaptic bouton. Chemical neurotransmitters are contained in synaptic vesicles, which can fuse with the presynaptic membrane, release the transmitters into the synaptic cleft, and then bind to receptors situated in the postsynaptic membrane. This synaptic transmission results in excitatory, inhibitory, or modulatory effects on the target cell.

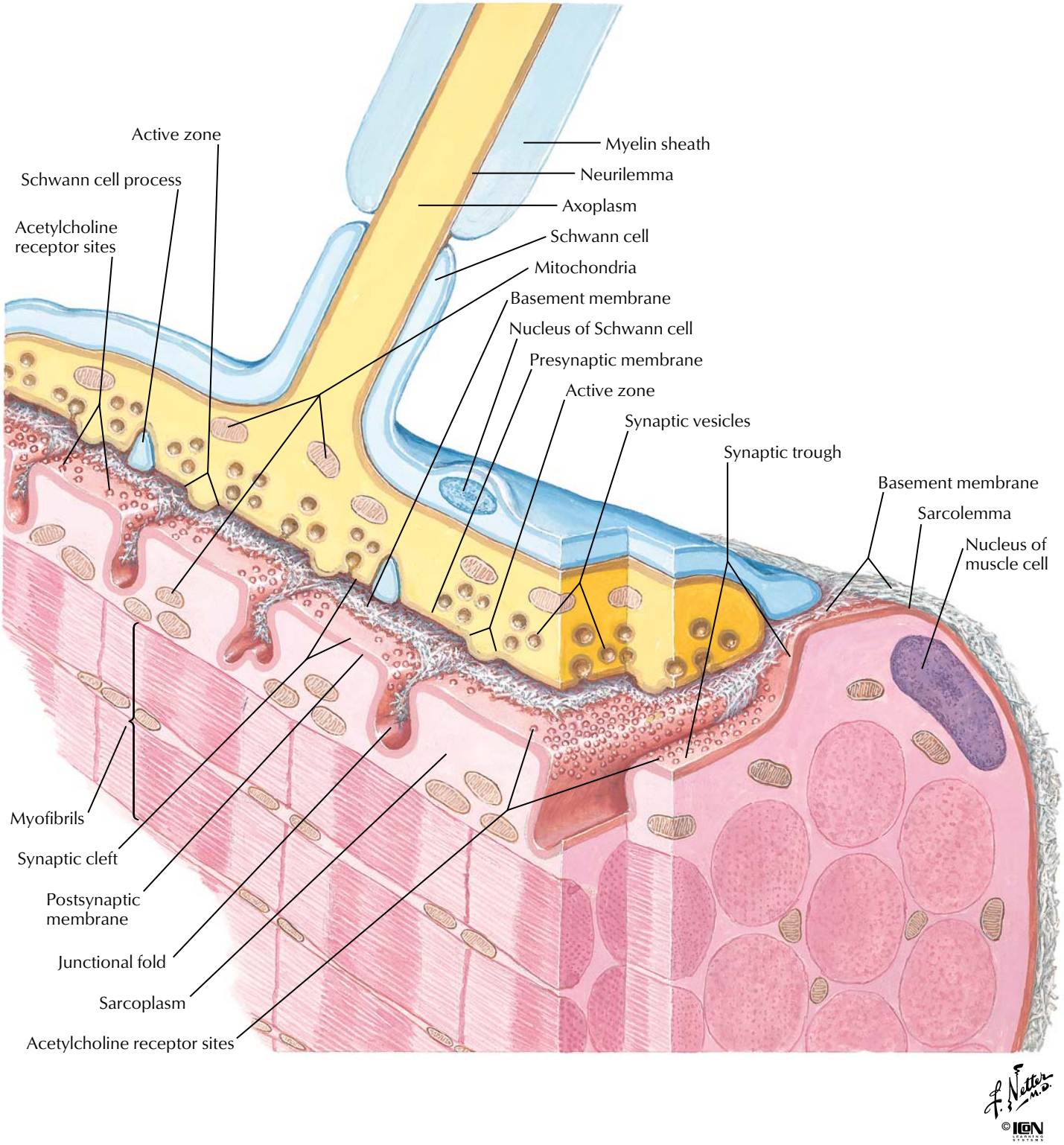


FIGURE 2.5 STRUCTURE OF THE NEUROMUSCULAR JUNCTION

Motor axons that synapse on skeletal muscle form expanded terminals called neuromuscular junctions (motor endplates). The motor axon loses its myelin sheath and expands into a Schwann cell–invested synaptic terminal that resides within a trough in the muscle fiber. Acetylcholine-containing synaptic vesicles accumulate adjacent to the presynaptic membrane and, when appropriately stimulated, release their neurotransmitter into the synaptic cleft. The transmitter then binds to receptors that mediate depolarization of the muscle sarcolemma and initiate a muscle action potential. A single muscle fiber has only one neuromuscular junction, but a motor axon can innervate multiple muscle fibers.

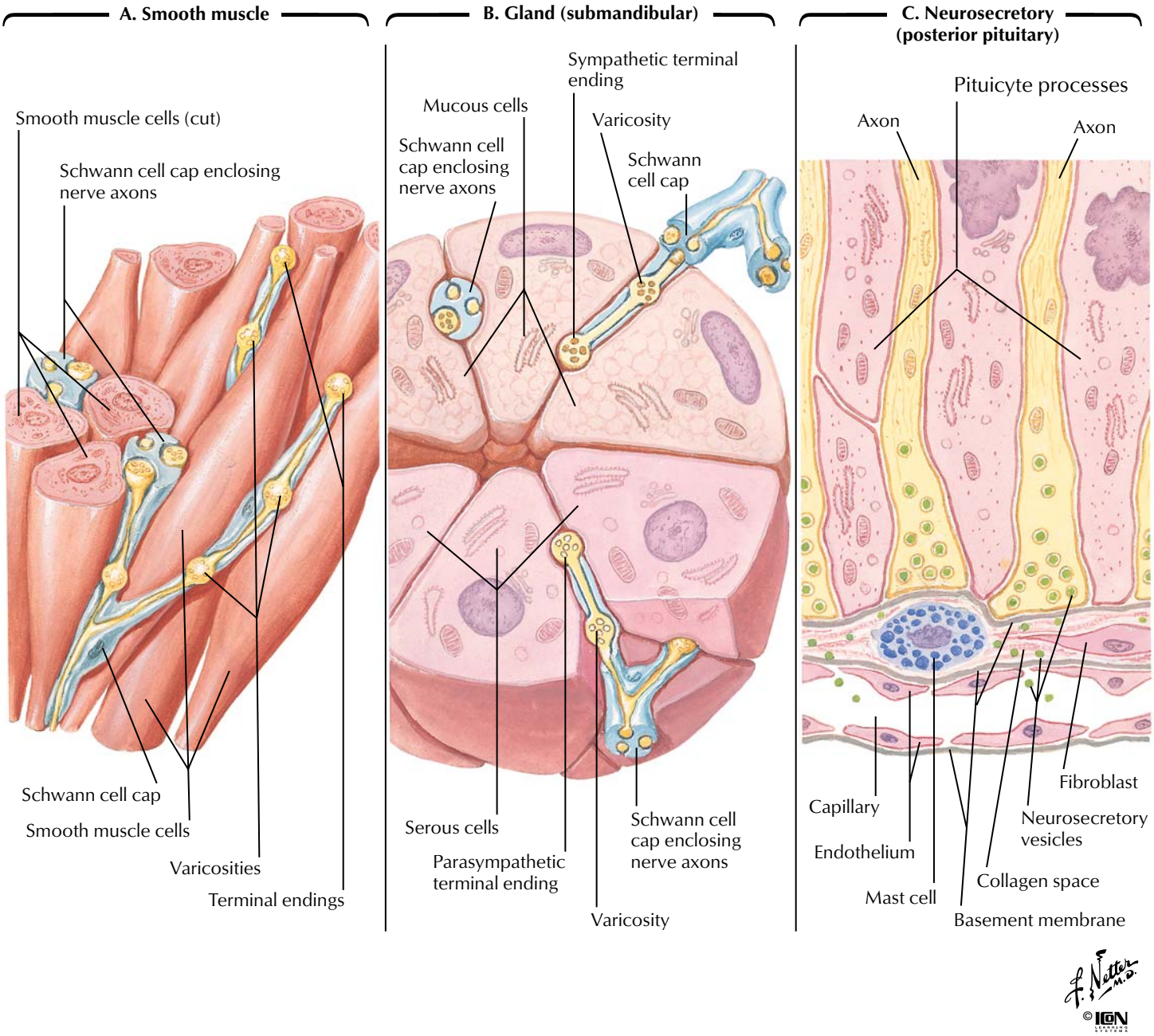


FIGURE 2.6 VISCERAL EFFERENT ENDINGS

Neuronal efferent endings on smooth muscle (A) and glands (B and C) exhibit unique endings unlike the presynaptic and postsynaptic terminals observed in neuronal and neuromuscular junction synapses. Rather, neurotransmitter substances are released into interstitial spaces (A and B) or into the bloodstream (C, neurosecretion) from expanded nerve terminal endings. This arrangement allows for the stimulation of numerous target cells over a wide area. Not all smooth muscle cells are innervated. They are connected to adjacent cells by gap junctions and can therefore contract together with the innervated cells.

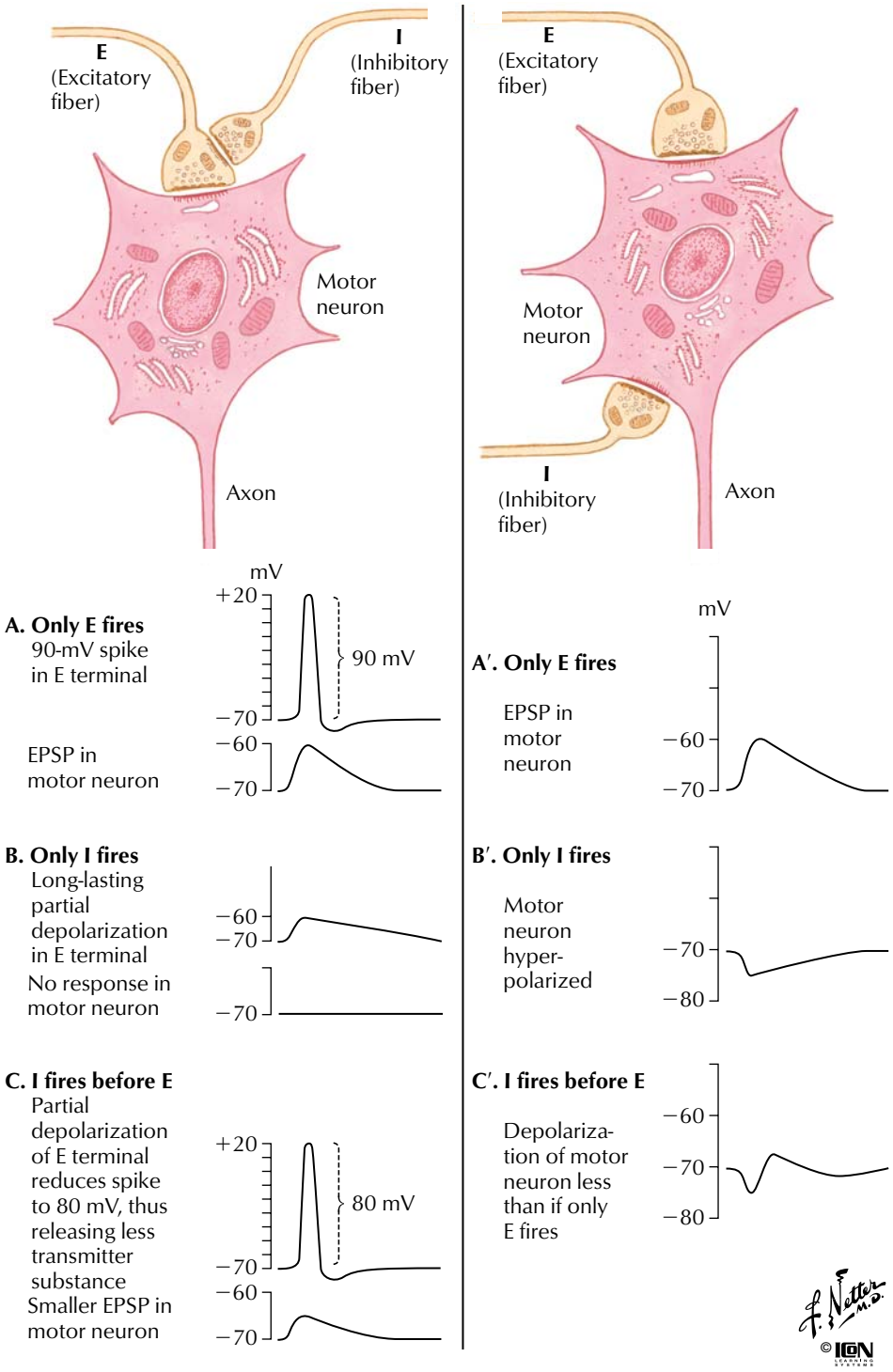


FIGURE 2.7 SYNAPTIC INHIBITORY MECHANISMS

Inhibitory synapses modulate neuronal activity. Illustrated here is presynaptic inhibition (left panel) and postsynaptic inhibition (right panel) at a motor neuron.

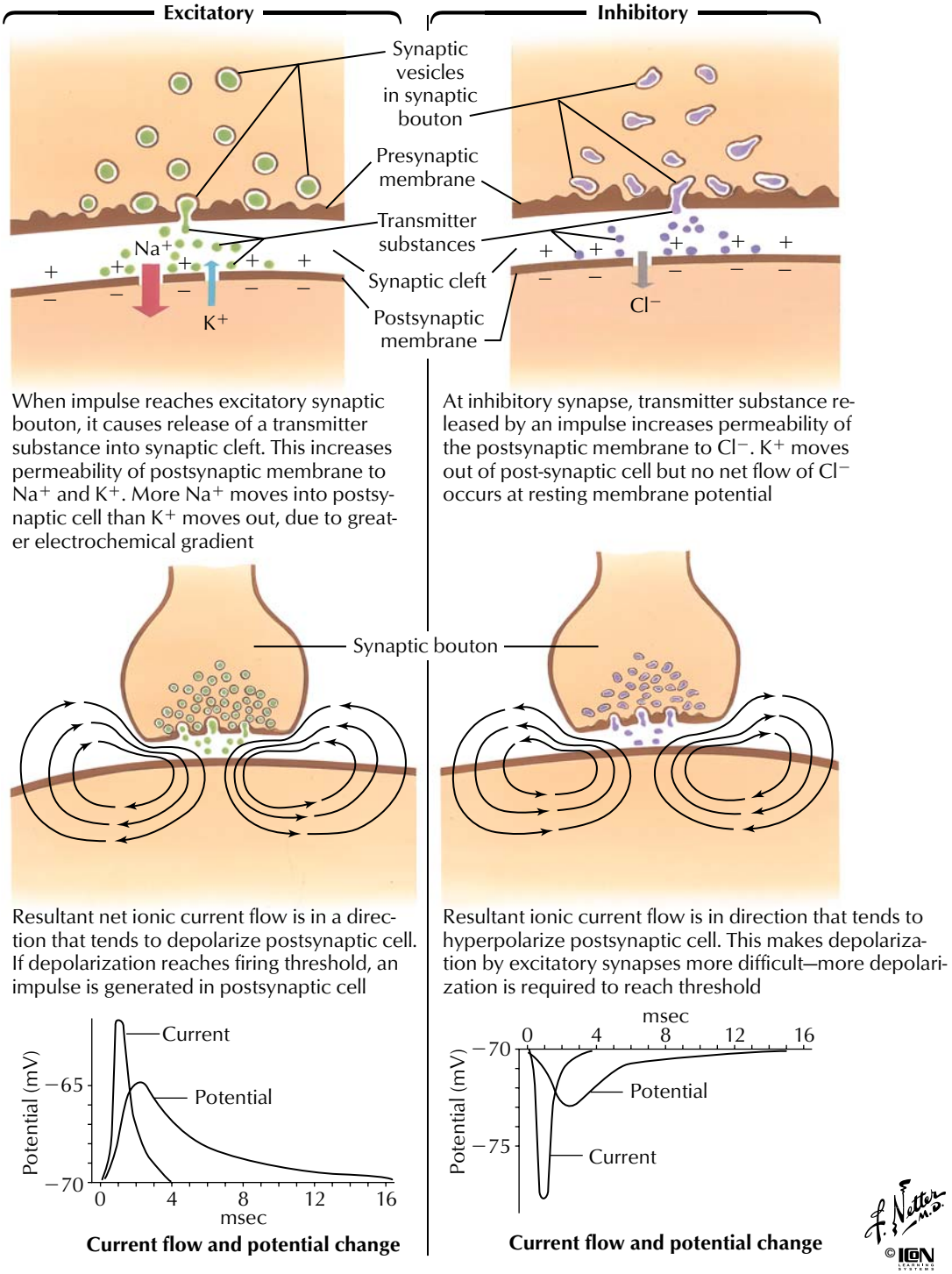
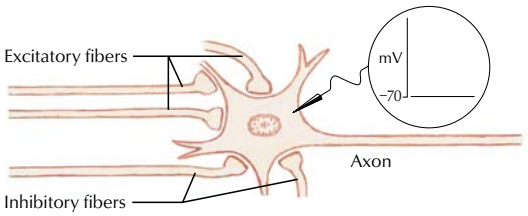
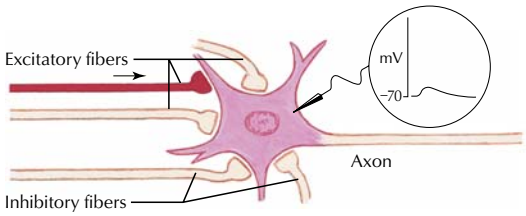


FIGURE 2.8 CHEMICAL SYNAPTIC TRANSMISSION

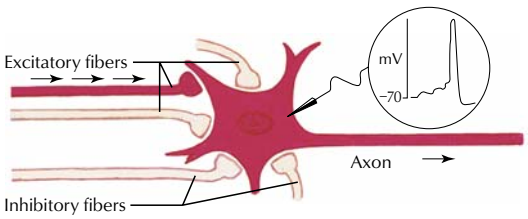
Chemical synaptic transmission between neurons may be excitatory or inhibitory. During excitation (left column), a net increase in the inward flow of Na^+ compared with the outward flow of K^+ results in a depolarizing potential change (excitatory postsynaptic potential [EPSP]) that drives the postsynaptic cell closer to its threshold for an action potential. During inhibition (right column), the opening of K^+ and Cl^- channels drives the membrane potential away from threshold (hyperpolarization) and decreases the probability that the neuron will reach threshold (inhibitory postsynaptic potential [IPSP]) for an action potential.



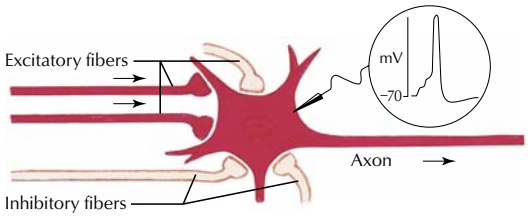
A. Resting state: motor nerve cell shown with synaptic boutons of excitatory and inhibitory nerve fibers ending close to it



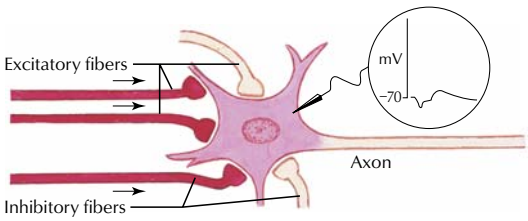
B. Partial depolarization: impulse from one excitatory fiber has caused partial (below firing threshold) depolarization of motor neuron



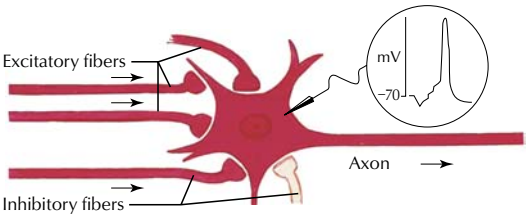
C. Temporal excitatory summation: a series of impulses in one excitatory fiber together produce a suprathreshold depolarization that triggers an action potential



D. Spatial excitatory summation: impulses in two excitatory fibers cause two synaptic depolarizations that together reach firing threshold triggering an action potential



E. Spatial excitatory summation with inhibition: impulses from two excitatory fibers reach motor neuron but impulses from inhibitory fiber prevent depolarization from reaching threshold



E. (continued): motor neuron now receives additional excitatory impulses and reaches firing threshold despite a simultaneous inhibitory impulse; additional inhibitory impulses might still prevent firing

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CHART 2.1 SUMMARY OF SOME NEUROTRANSMITTERS AND WHERE WITHIN THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM THEY ARE FOUND

Transmitter	Location	Transmitter	Location
Acetylcholine	Neuromuscular junction, autonomic endings and ganglia, CNS	Gas Nitric oxide	 CNS, GI tract
Biogenic amines Norepinephrine Dopamine Serotonin	 Sympathetic endings, CNS CNS CNS, GI tract	Peptides β-Endorphins Enkephalins Antidiuretic hormone Pituitary-releasing hormones Somatostatin Neuropeptide Y Vasoactive intestinal peptide	 CNS, GI tract CNS CNS (hypothalamus/posterior pituitary) CNS (hypothalamus/anterior pituitary) CNS, GI tract CNS CNS, GI tract
Amino acids γ-Aminobutyric acid (GABA) Glutamate	 CNS CNS		
Purines Adenosine Adenosine triphosphate (ATP)	 CNS CNS		

CNS, Central nervous system; *GI,* gastrointestinal.

FIGURE 2.9 TEMPORAL AND SPATIAL SUMMATION

Neurons receive multiple excitatory and inhibitory inputs. Temporal summation occurs when a series of subthreshold impulses in one excitatory fiber produces an action potential in the postsynaptic cell (panel C). Spatial summation occurs when subthreshold impulses from two or more different fibers trigger an action potential (panel D). Both temporal and spatial summation can be modulated by simultaneous inhibitory input (panel E). Inhibitory and excitatory neurons use a wide variety of neurotransmitters, some of which are summarized here.

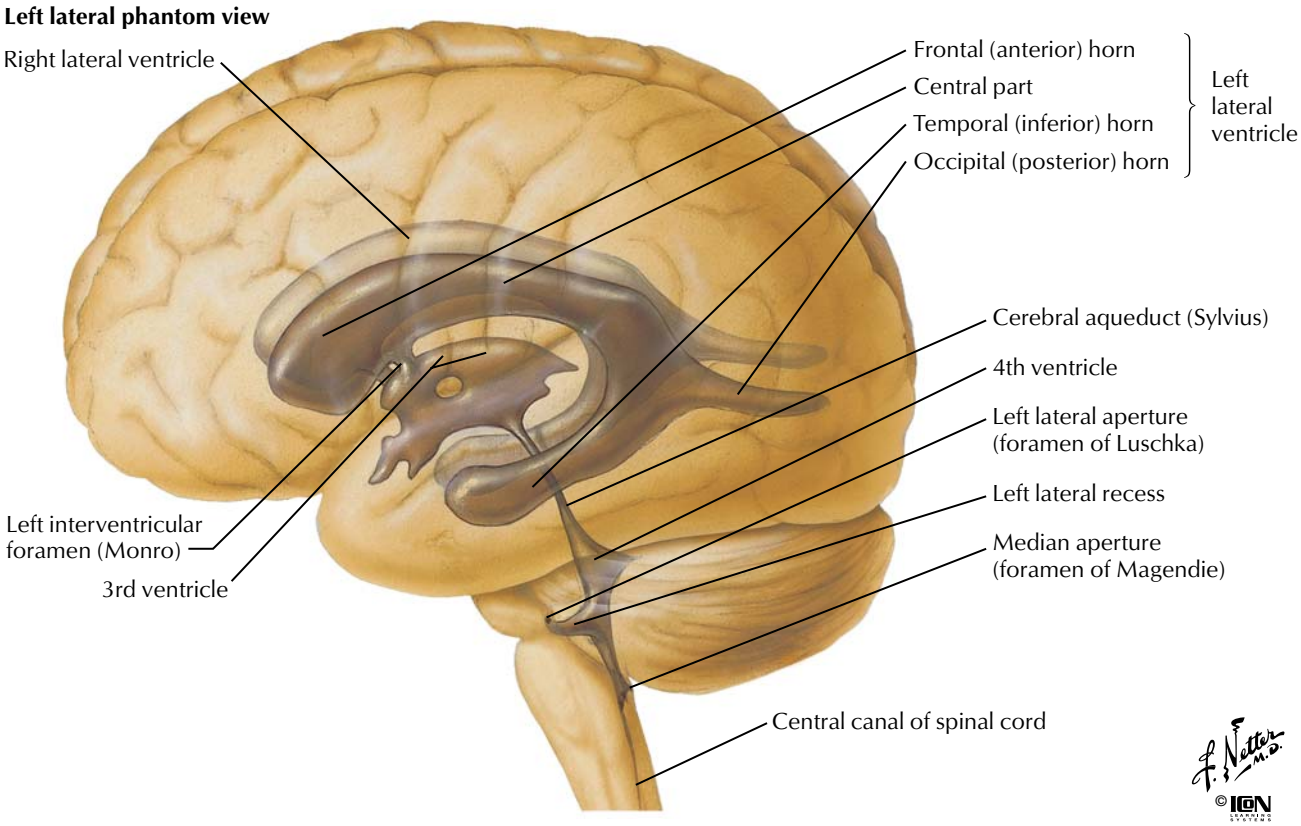


CHART 2.2 CSF COMPOSITION

	CSF	Blood Plasma
Na^+ (mEq/L)	140–145	135–147
K^+ (mEq/L)	3	3.5–5.0
Cl^- (mEq/L)	115–120	95–105
HCO_3^- (mEq/L)	20	22–28
Glucose (mg/dL)	50–75	70–110
Protein (g/dL)	0.05–0.07	6.0–7.8
pH	7.3	7.35–7.45

FIGURE 2.10 BRAIN VENTRICLES AND CSF COMPOSITION

CSF circulates through the four brain ventricles (two lateral ventricles and a third and fourth ventricle) and in the subarachnoid space surrounding the brain and spinal cord. The electrolyte composition of the CSF is regulated by the choroid plexus, which secretes the CSF. Importantly, the CSF has a lower [HCO_3^-] than plasma and therefore a lower pH. This allows small changes in blood P_{CO_2} to cause changes in CSF pH, which in turn regulates the rate of respiration (see Chapter 5).

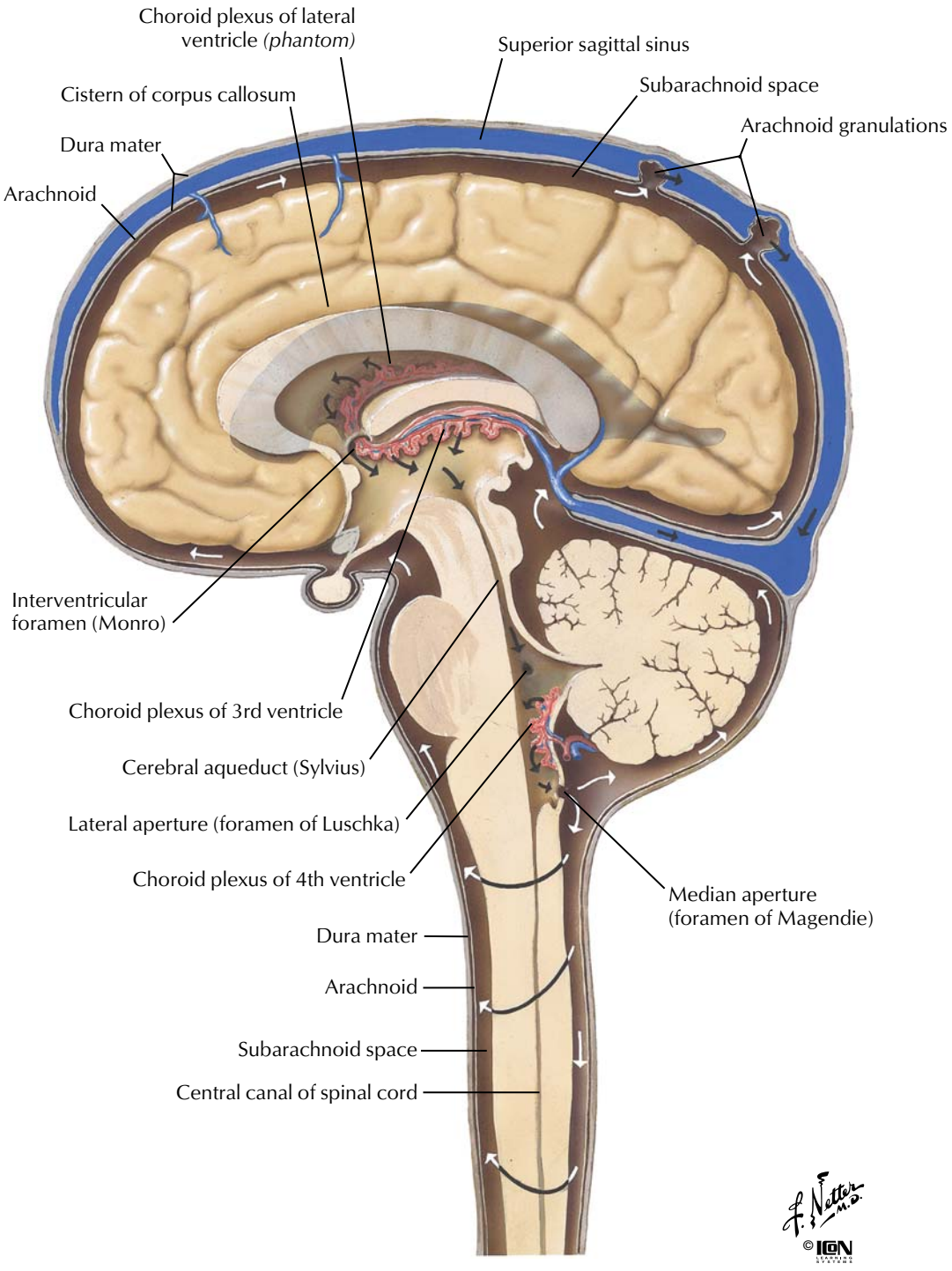


FIGURE 2.11 CIRCULATION OF CEREBROSPINAL FLUID

CSF circulates through the four brain ventricles (two lateral ventricles and a third and fourth ventricle) and in the subarachnoid space surrounding the brain and spinal cord. Most of the CSF is reabsorbed into the venous system through the arachnoid granulations and through the walls of the capillaries of the central nervous system and pia mater.

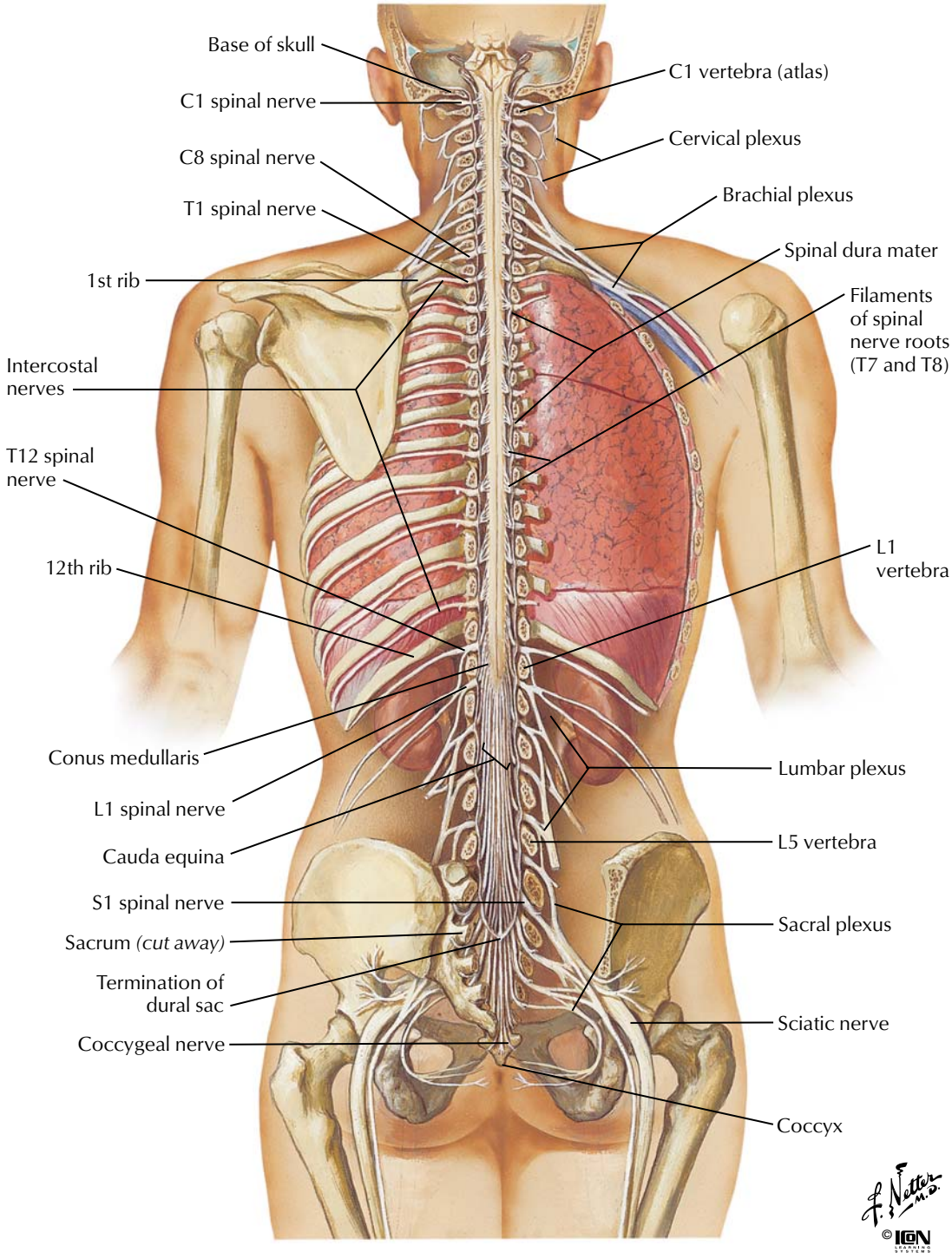


Figure 2.12 Spinal Cord and Ventral Rami In Situ

The spinal cord gives rise to 31 pairs of spinal nerves that distribute segmentally to the body. These nerves are organized into plexuses that distribute to the neck (cervical plexus), upper limb (brachial plexus), and pelvis and lower limb (lumbosacral plexus). Motor fibers of these spinal nerves innervate skeletal muscle, and sensory fibers convey information back to the central nervous system from the skin, skeletal muscles, and joints.

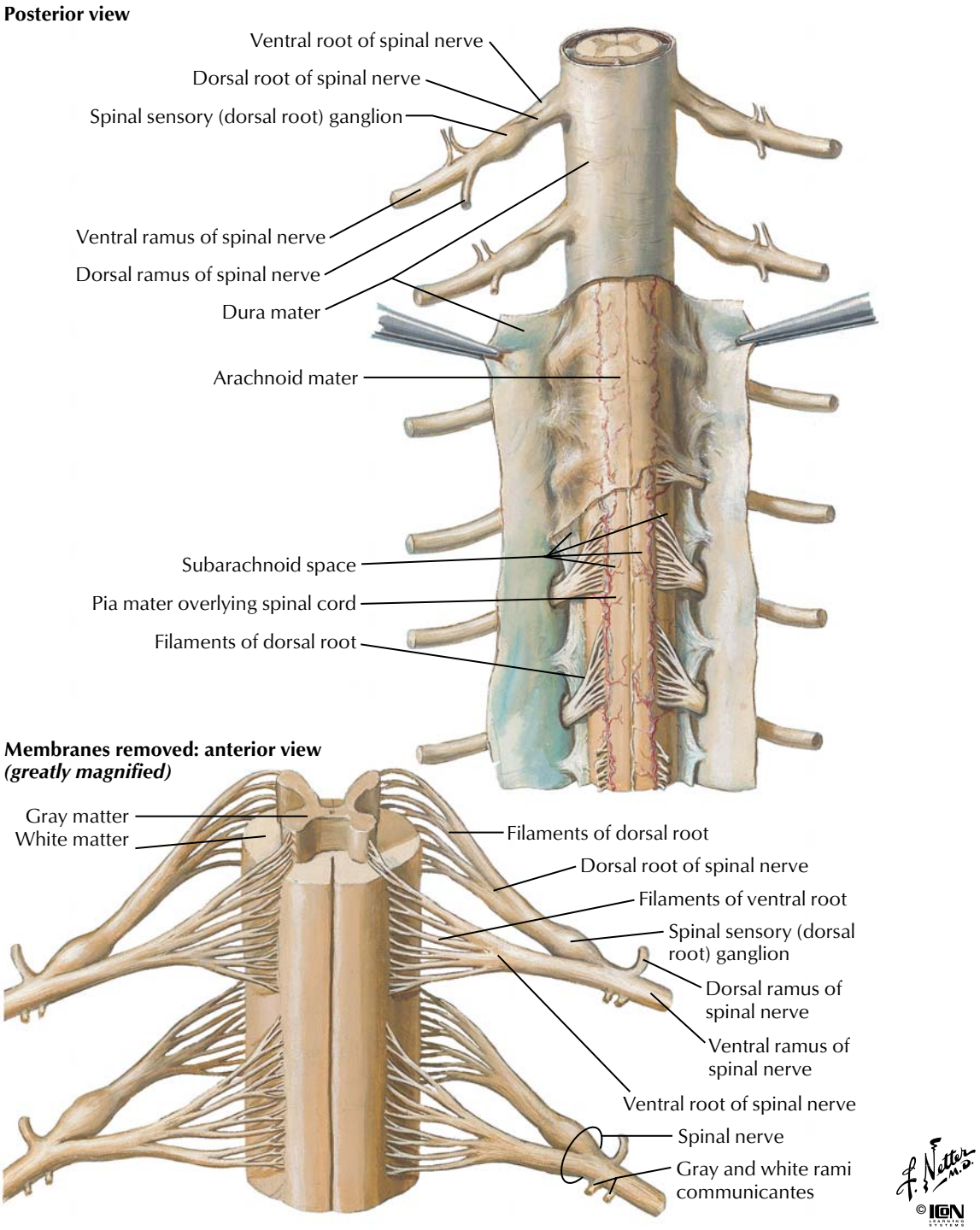


FIGURE 2.13 SPINAL MEMBRANES AND NERVE ROOTS

The spinal cord gives rise to 31 pairs of spinal nerves that distribute segmentally to the body. Motor fibers of these spinal nerves innervate skeletal muscle, and sensory fibers convey information back to the central nervous system from the skin, skeletal muscles, and joints.

The spinal cord is ensheathed in three meningeal coverings: the outer, tough dura mater; the arachnoid mater; and the pia mater, which intimately ensheaths the cord itself. CSF bathes the cord and is found in the subarachnoid space.

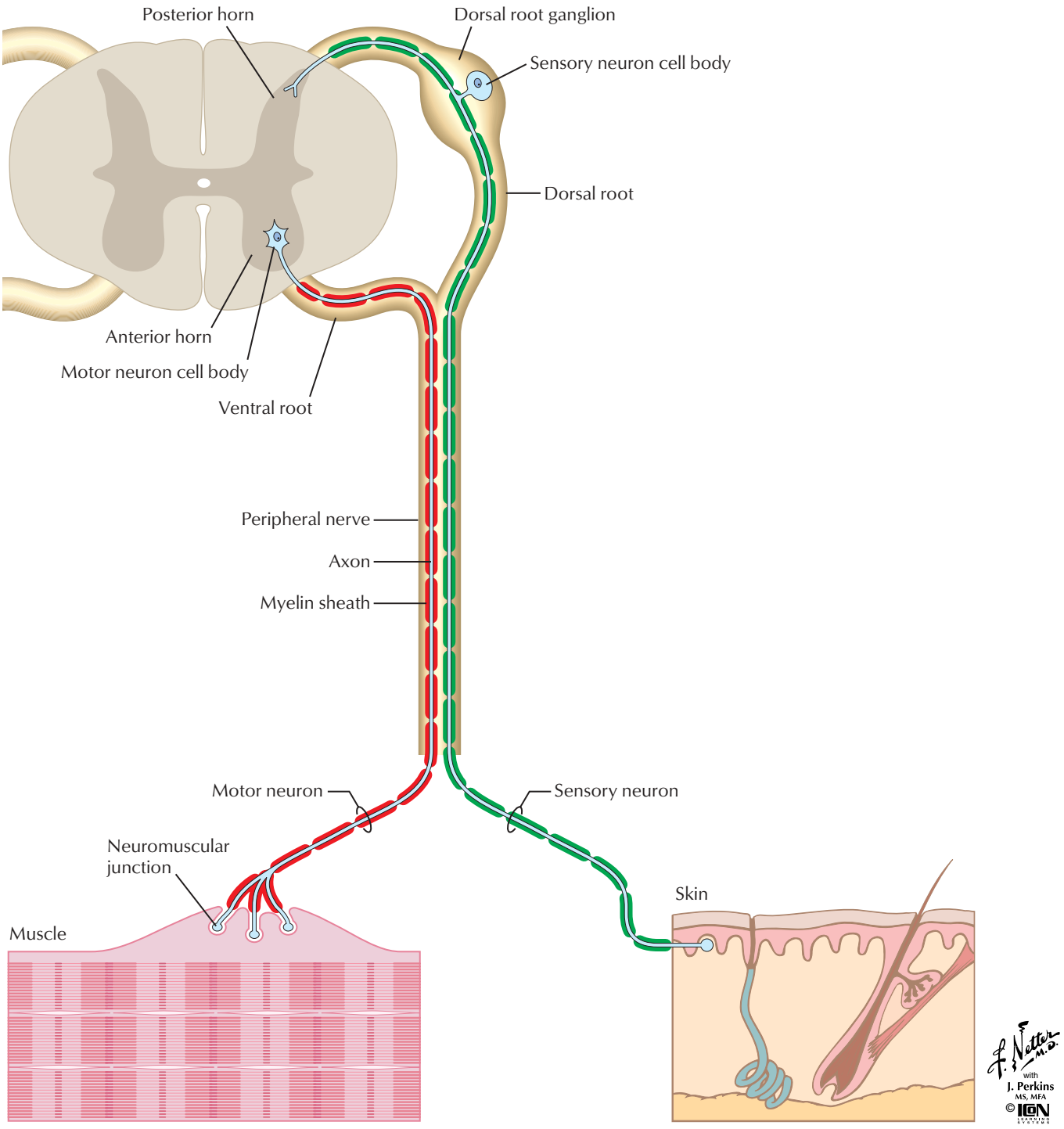


FIGURE 2.14 PERIPHERAL NERVOUS SYSTEM

The peripheral nervous system (PNS) consists of all of the neural elements outside of the CNS (brain and spinal cord) and provides the connections between the CNS and all other body organ systems. The PNS consists of somatic and autonomic components. The somatic component innervates skeletal muscle and skin and is shown here (see Figure 2.15 for the autonomic nervous system). The somatic component of the peripheral nerves contains both motor and sensory axons. Cell bodies of the motor neurons are found in the anterior horn gray matter, whereas the cell bodies of sensory neurons are located in the dorsal root ganglia.

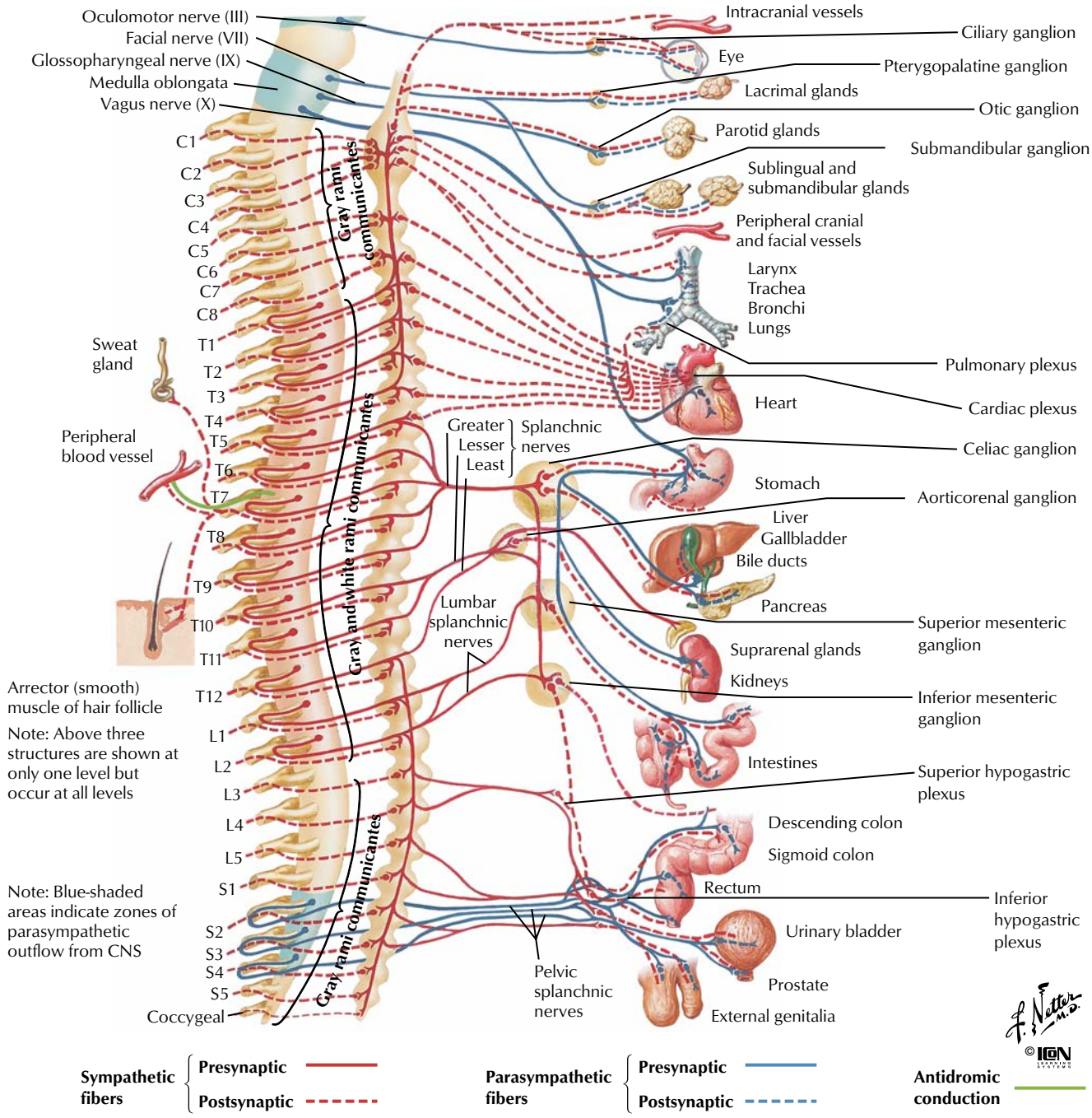


FIGURE 2.15 AUTONOMIC NERVOUS SYSTEM: SCHEMA

The autonomic nervous system is composed of two divisions: the parasympathetic division derived from four of the cranial nerves (CN III, VII, IX, and X) and the S2-S4 sacral spinal cord levels, and the sympathetic division associated with the thoracic and upper lumbar spinal cord levels (T1-L2). The autonomic nervous system is a two-neuron chain, with the preganglionic neuron arising from the central nervous system and synapsing on a postganglionic neuron located in a peripheral autonomic ganglion. Postganglionic axons of the autonomic nervous system innervate smooth muscle, cardiac muscle, and glands. Basically, the sympathetic division mobilizes our body ("fight or flight") while the parasympathetic division regulates digestive and homeostatic functions. Normally, both divisions work in concert to regulate visceral activity (respiration, cardiovascular function, digestion, and associated glandular activity).

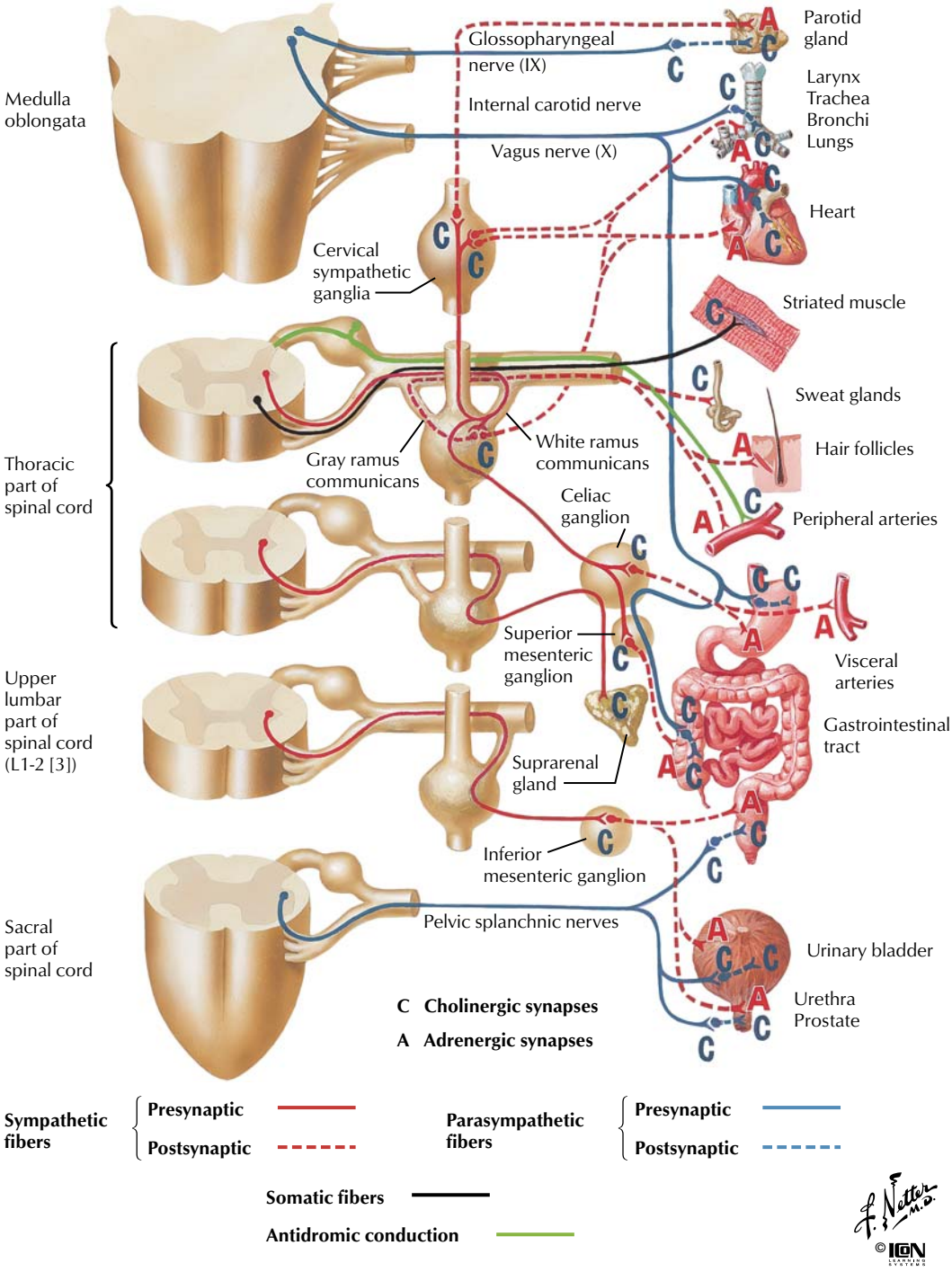


FIGURE 2.16 CHOLINERGIC AND ADRENERGIC SYNAPSES: SCHEMA

The autonomic nervous system (ANS) is a two-neuron chain, with the preganglionic neuron arising from the central nervous system and synapsing on a postganglionic neuron located in a peripheral autonomic ganglion. Acetylcholine is the neurotransmitter in both the sympathetic and parasympathetic ganglia. The parasympathetic division of the ANS releases acetylcholine at its postganglionic synapses and is characterized as having cholinergic (C) effects, whereas the sympathetic division releases predominantly noradrenaline (norepinephrine) at its postganglionic synapses, causing adrenergic (A) effects (except on sweat glands, where acetylcholine is released). Although acetylcholine and noradrenaline are the chief transmitter substances, other neuroactive peptides often are colocalized with them and include such substances as gamma-aminobutyric acid (GABA), substance P, enkephalins, histamine, glutamic acid, neuropeptide Y, and others.

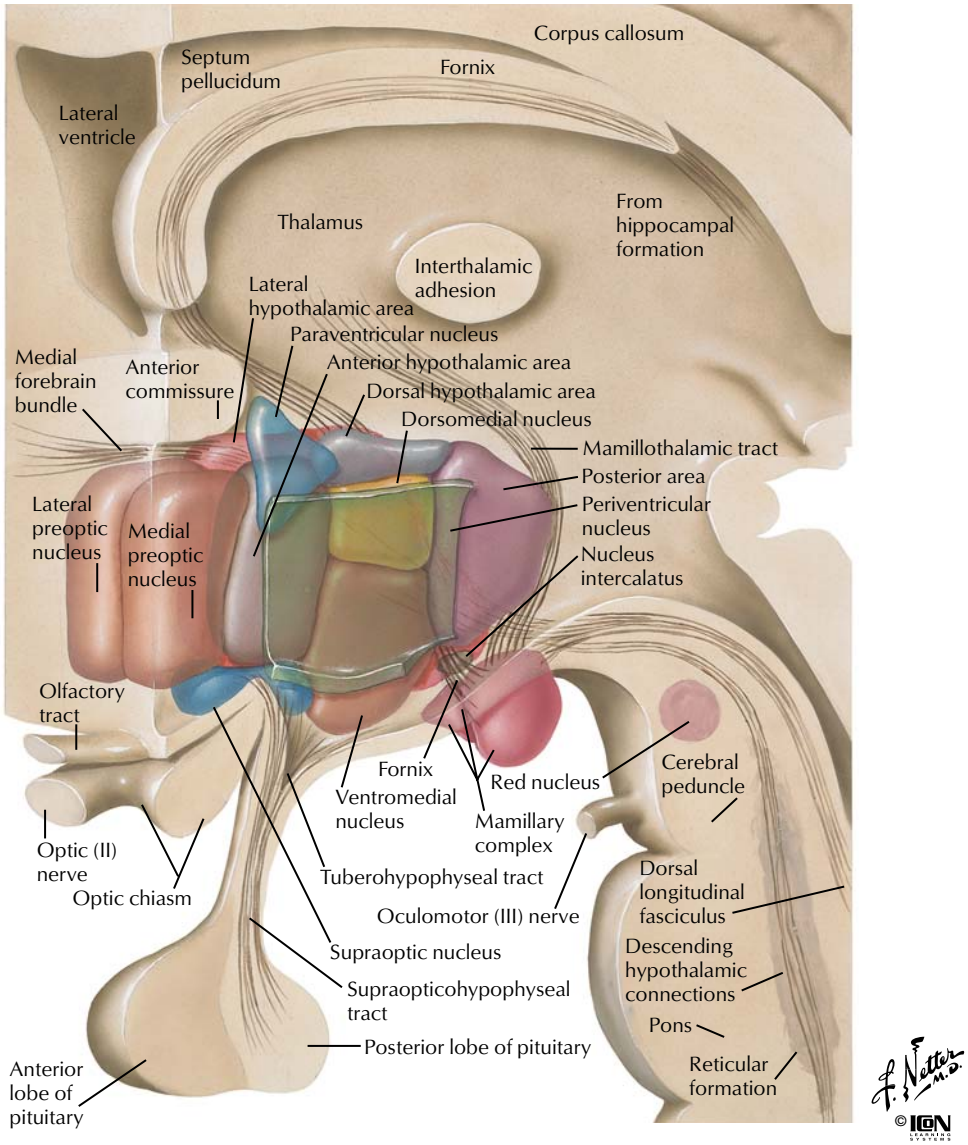


CHART 2.3 MAJOR FUNCTIONS OF THE HYPOTHALAMUS

Hypothalamic Area	Major Functions*
Preoptic and anterior	Heat loss center: cutaneous vasodilation and sweating
Posterior	Heat conservation center: cutaneous vasoconstriction and shivering
Lateral	Feeding center: eating behavior
Ventromedial	Satiety center: inhibits eating behavior
Supraoptic (subfornical organ and organum vasculosum)	ADH and oxytocin secretion (sensation of thirst)
Paraventricular	ADH and oxytocin secretion
Periventricular	Releasing hormones for the anterior pituitary

*Stimulation of the center causes the responses listed.

FIGURE 2.17 SCHEMATIC RECONSTRUCTION OF THE HYPOTHALAMUS

The hypothalamus, part of the diencephalon, controls a number of important homeostatic systems within the body, including temperature regulation, food intake, water intake, many of the endocrine systems (see Chapter 8), motivation, and emotional behavior. It receives inputs from the reticular formation (sleep/wake cycle information), the thalamus (pain), the limbic system (emotion, fear, anger, smell), the medulla oblongata (blood pressure and heart rate), and the optic system, and it integrates these inputs for regulation of the functions listed.

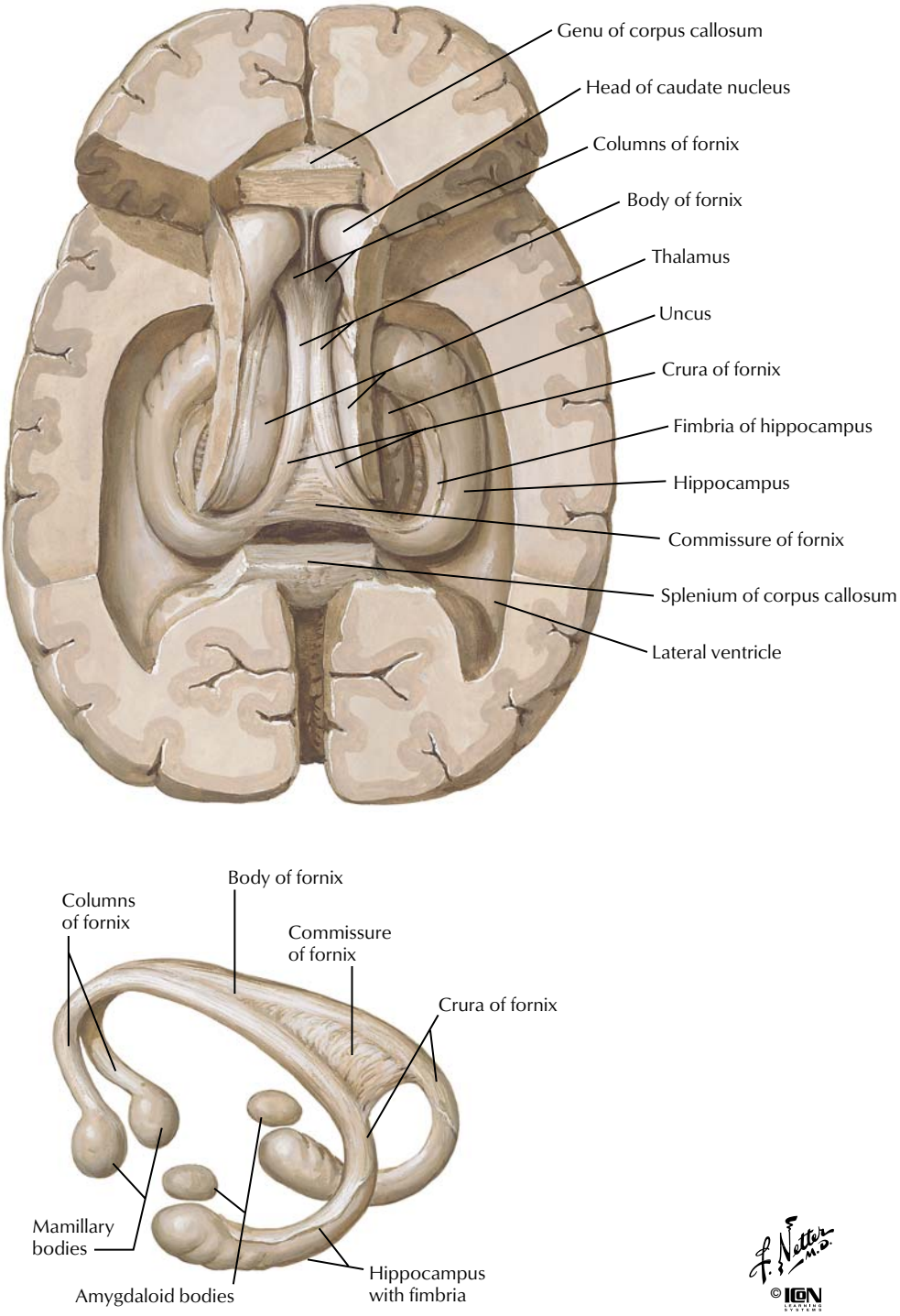


FIGURE 2.18 HIPPOCAMPUS AND FORNIX

The limbic system includes the hypothalamus and a collection of interconnected structures in the telencephalon (cingulate, parahippocampal, and subcallosal gyri), as well as the amygdala and hippocampal formation. The limbic system functions in linking emotion and motivation (amygdala), learning and memory (hippocampal formation), and sexual behavior (hypothalamus).

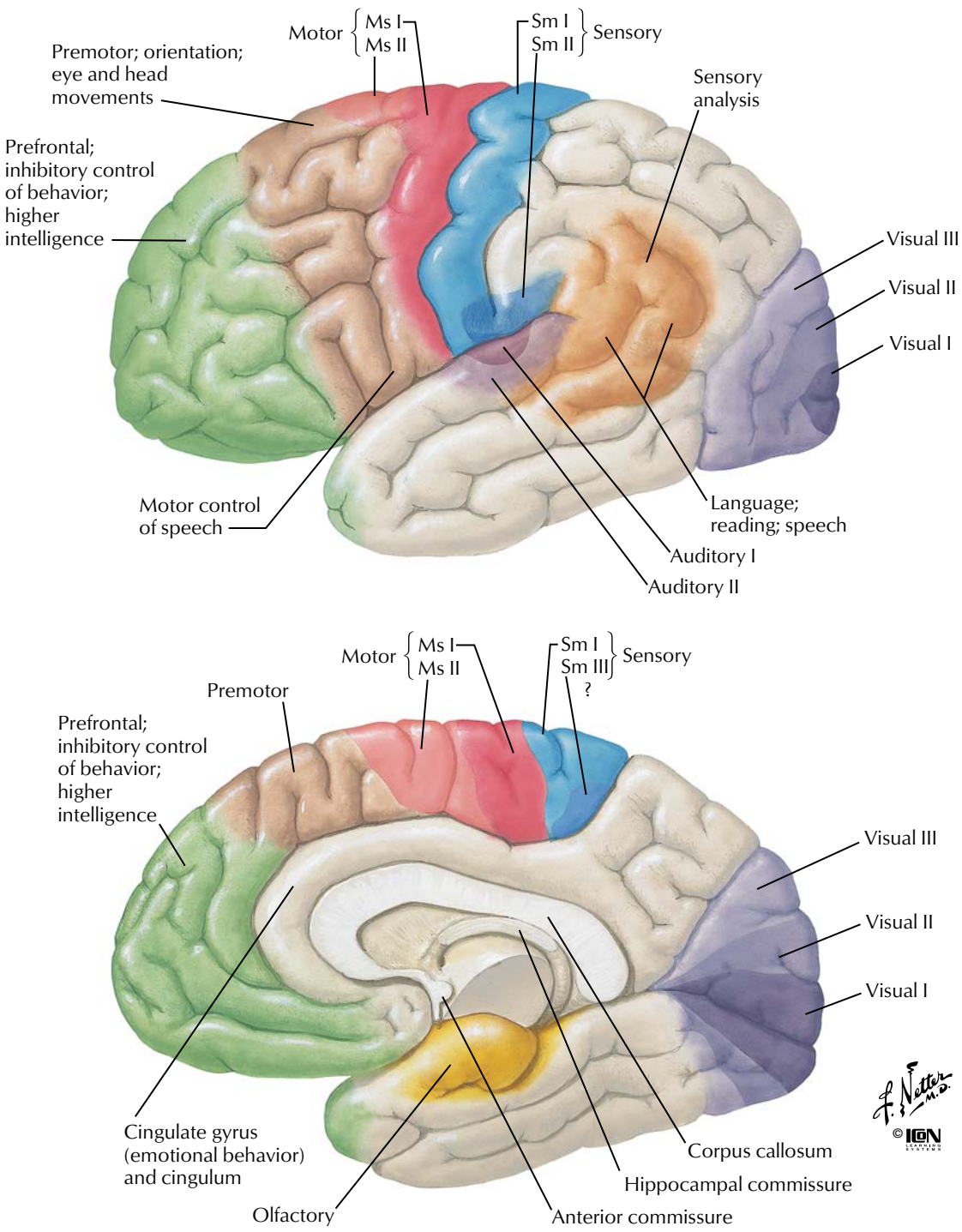


FIGURE 2.19 CEREBRAL CORTEX: LOCALIZATION OF FUNCTION AND ASSOCIATION PATHWAYS

The cerebral cortex is organized into functional regions. In addition to specific areas devoted to sensory and motor functions, there are areas that integrate information from multiple sources. The cerebral cortex participates in advanced intellectual functions, including aspects of memory storage and recall, language, higher cognitive functions, conscious perception, sensory integration, and planning/execution of complex motor activity. General cortical areas associated with these functions are illustrated.

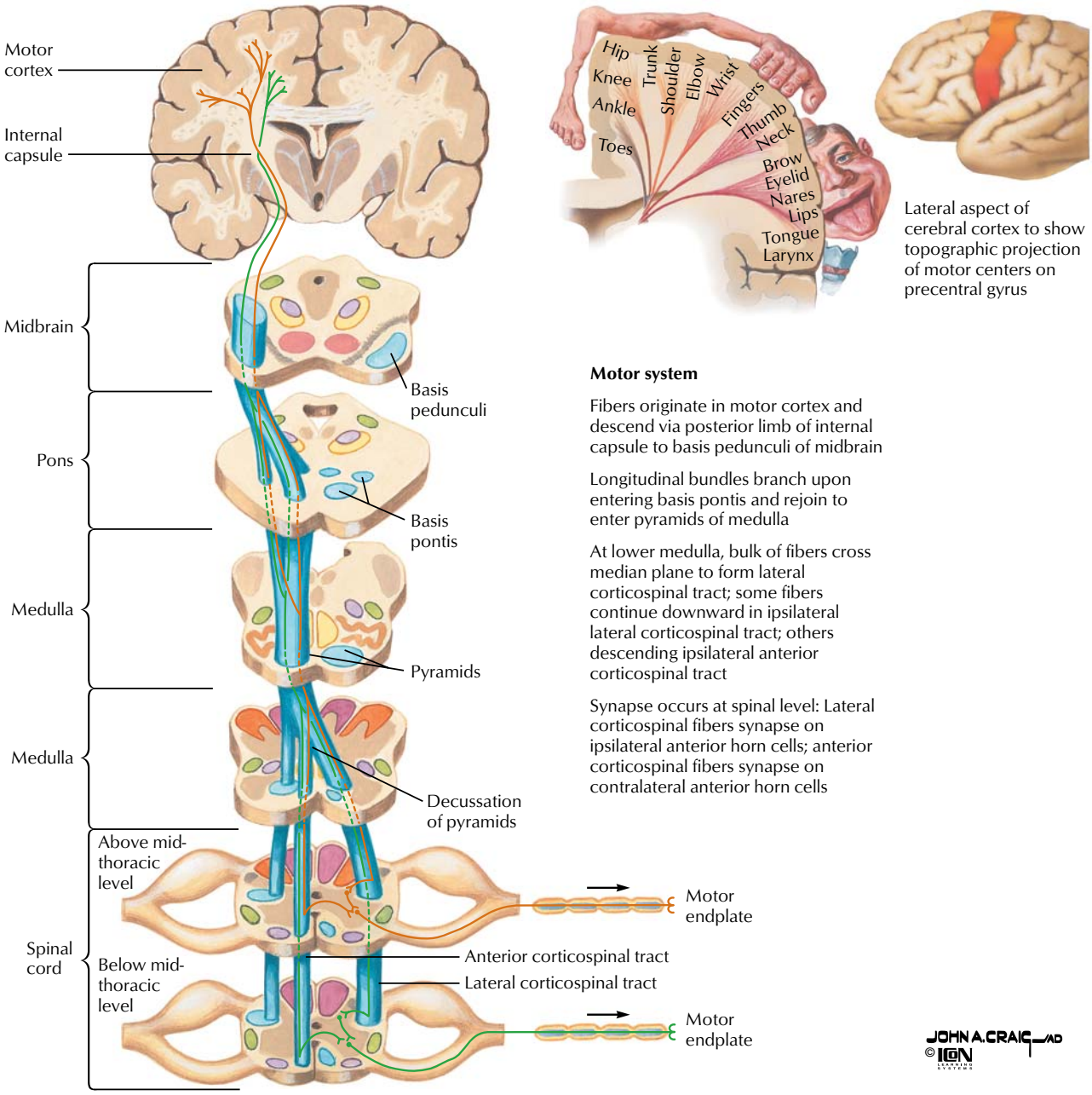


FIGURE 2.20 CORTICOSPINAL TRACTS

The corticospinal, or pyramidal, tract is the major motor tract that controls voluntary movement of the skeletal muscles, especially skilled movements of distal muscles of the limbs. All structures from the cerebral cortex to the anterior horn cells in the spinal cord constitute the upper portion of the system (upper motor neuron). The anterior horn cells and their associated axons constitute the lower portion of the system (lower motor neuron).

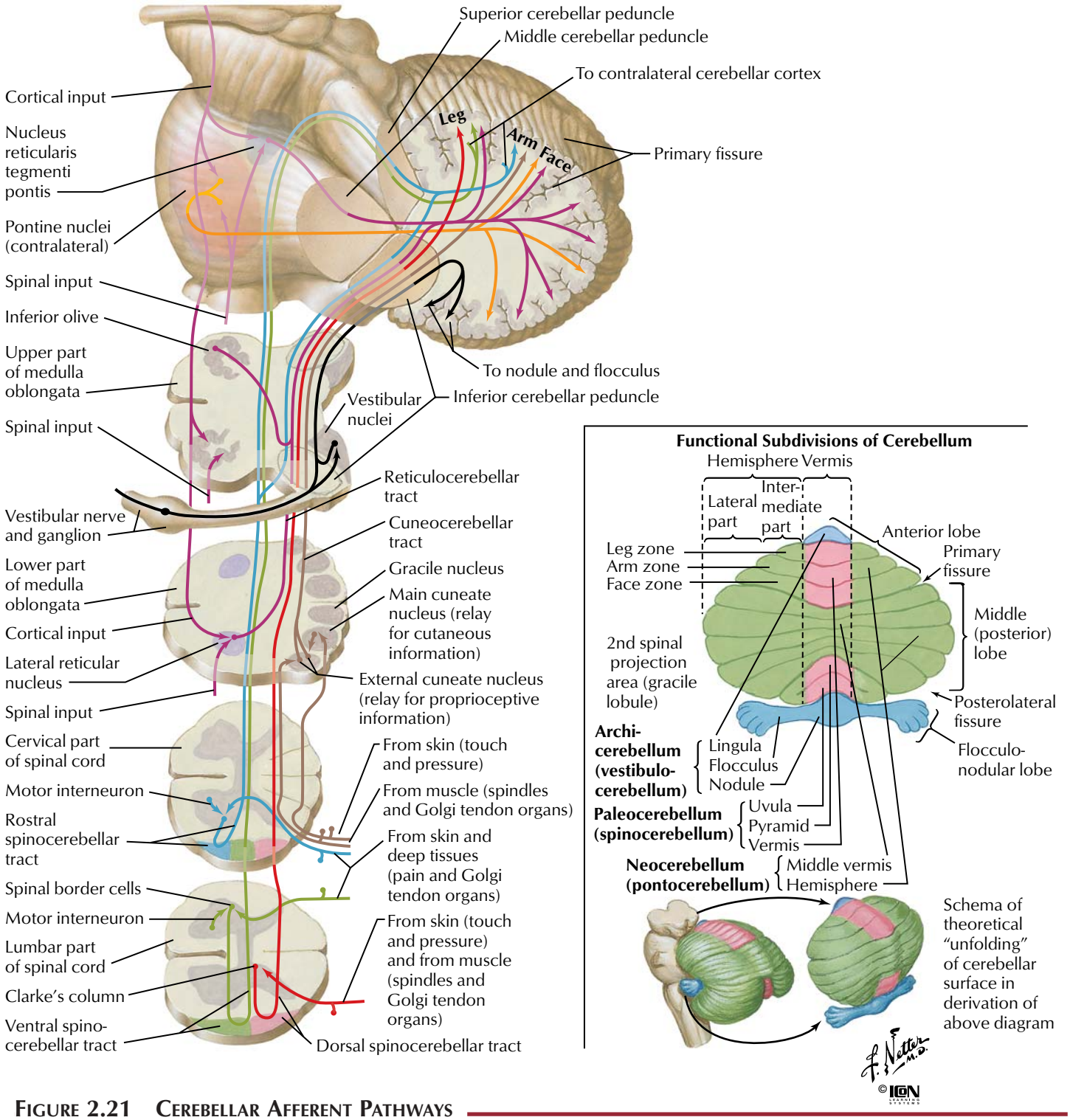


FIGURE 2.21 CEREBELLAR AFFERENT PATHWAYS

The cerebellum plays an important role in coordinating movement. It receives sensory information and then influences descending motor pathways to produce fine, smooth, and coordinated motion. The cerebellum is divided into three general areas: archicerebellum (also called vestibulocerebellum) paleocerebellum (also called spinocerebellum) and the neocerebellum (also called the cerebrocerebellum). The archicerebellum is primarily involved in controlling posture and balance, as well as the movement of the head and eyes. It receives afferent signals from the vestibular apparatus and then sends efferent fibers to the appropriate descending motor pathways. The paleocerebellum primarily controls movement of the proximal portions of the limbs. It receives sensory information on limb position and muscle tone and then modifies and coordinates these movements through efferent pathways to the appropriate descending motor pathways. The neocerebellum is the largest portion of the cerebellum, and it coordinates the movement of the distal portions of the limbs. It receives input from the cerebral cortex and thus helps in the planning of motor activity (e.g., seeing a pencil and then planning and executing the movement of the arm and hand to pick it up).

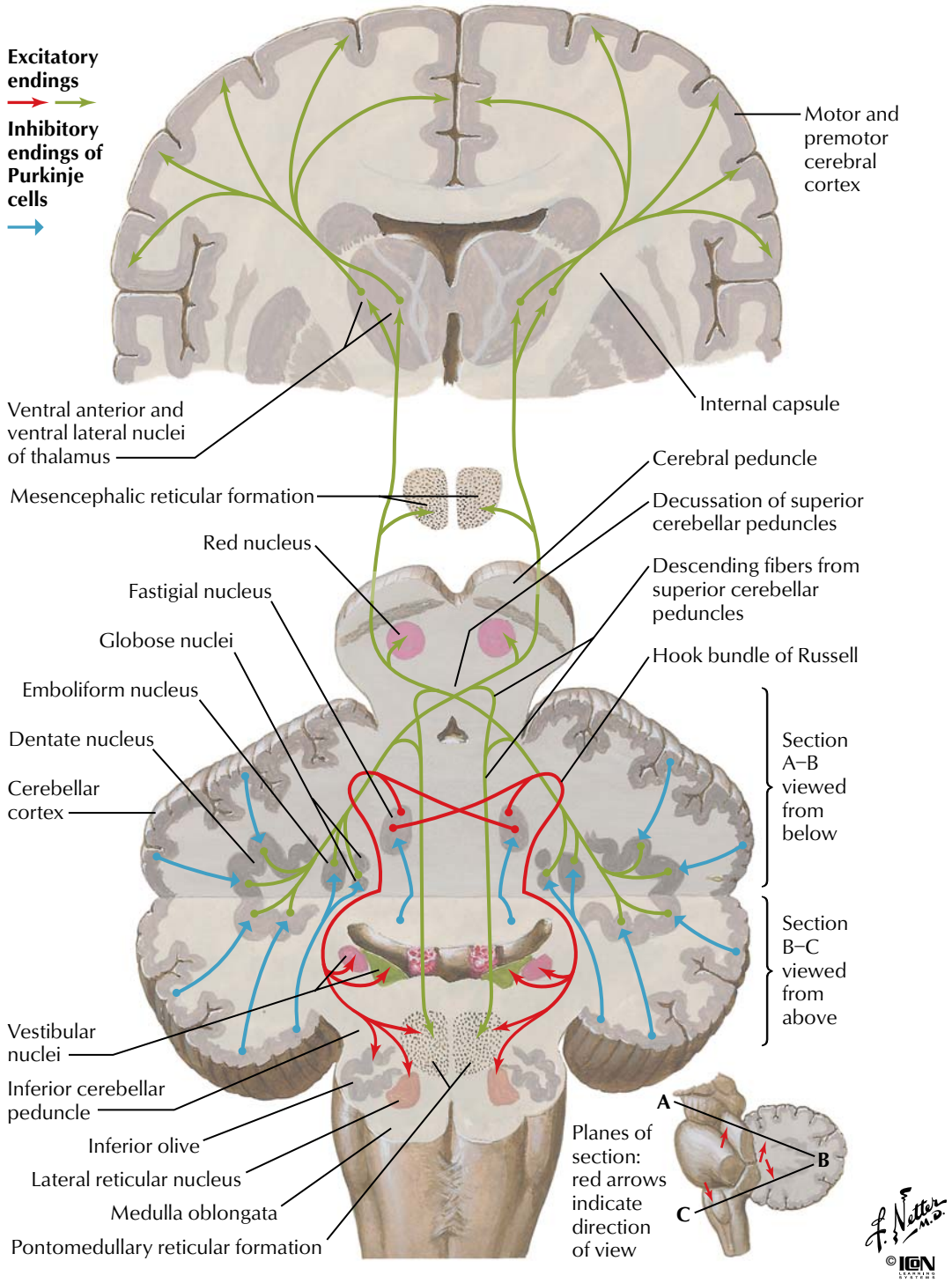


FIGURE 2.22 CEREBELLAR EFFERENT PATHWAYS

The cerebellum plays an important role in coordinating movement. It influences descending motor pathways to produce fine, smooth, and coordinated motion. The archicerebellum is primarily involved in controlling posture and balance and movement of the head and eyes. It sends efferent fibers to the appropriate descending motor pathways. The paleocerebellum primarily controls movement of the proximal portions of the limbs. It modifies and coordinates these movements through efferent pathways to the appropriate descending motor pathways. The neocerebellum coordinates the movement of the distal portions of the limbs. It helps in the planning of motor activity (e.g., seeing a pencil and then planning and executing the movement of the arm and hand to pick it up).

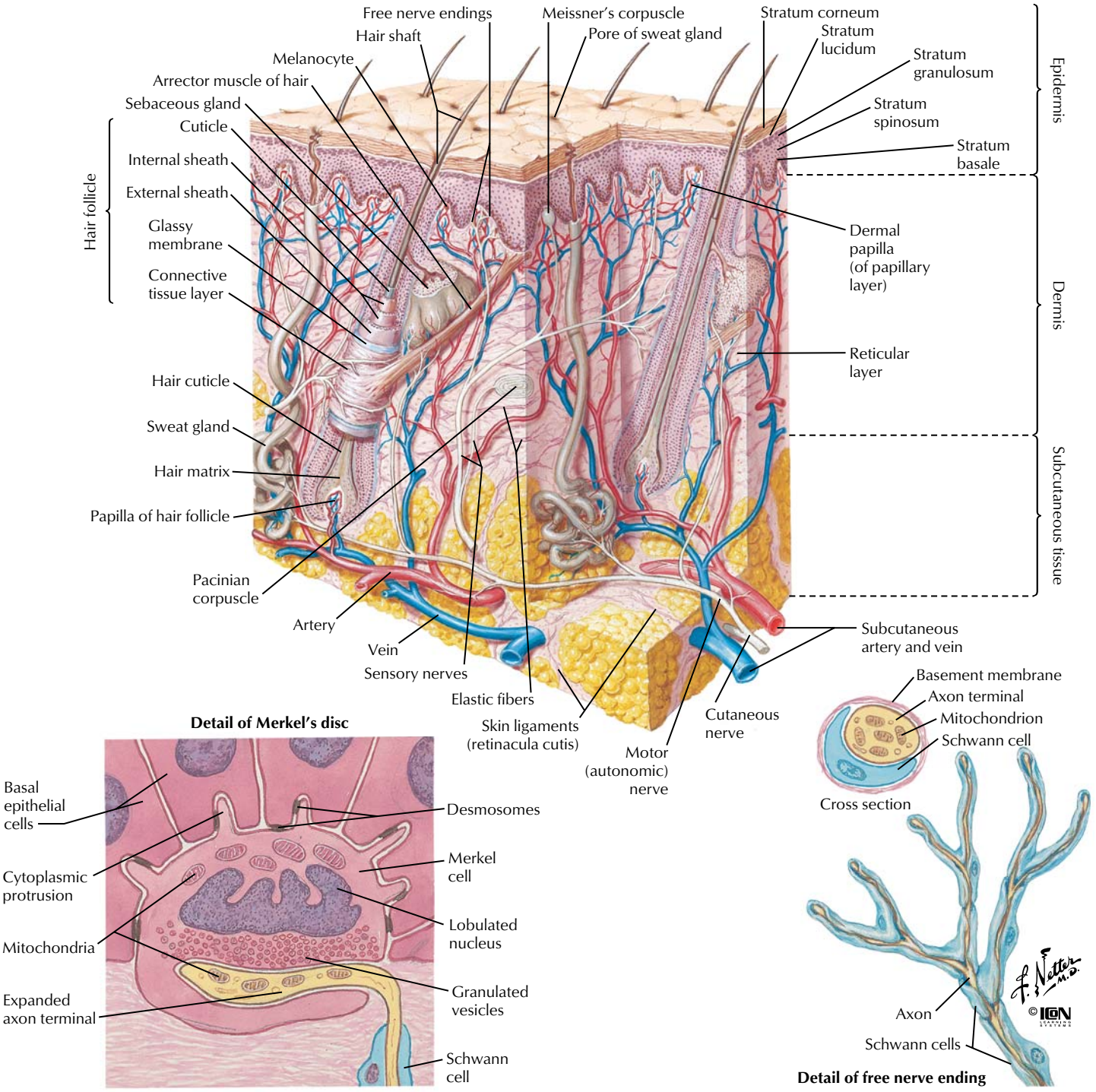


FIGURE 2.23 SKIN AND CUTANEOUS RECEPTORS

Cutaneous receptors respond to touch (mechanoreceptors), pain (nociceptors), and temperature (thermoreceptors). Several different types of receptors are present in skin. Meissner's corpuscles have small receptive fields and respond best to stimuli that are applied at low frequency (i.e., flutter). The pacinian corpuscles are located in the subcutaneous tissue and have large receptive fields. They respond best to high-frequency stimulation (i.e., vibration). Merkel's discs have small receptive fields and respond to touch and pressure (i.e., indenting the skin). Ruffini's corpuscles have large receptive fields, and they also respond to touch and pressure. Free nerve endings respond to pain and temperature.

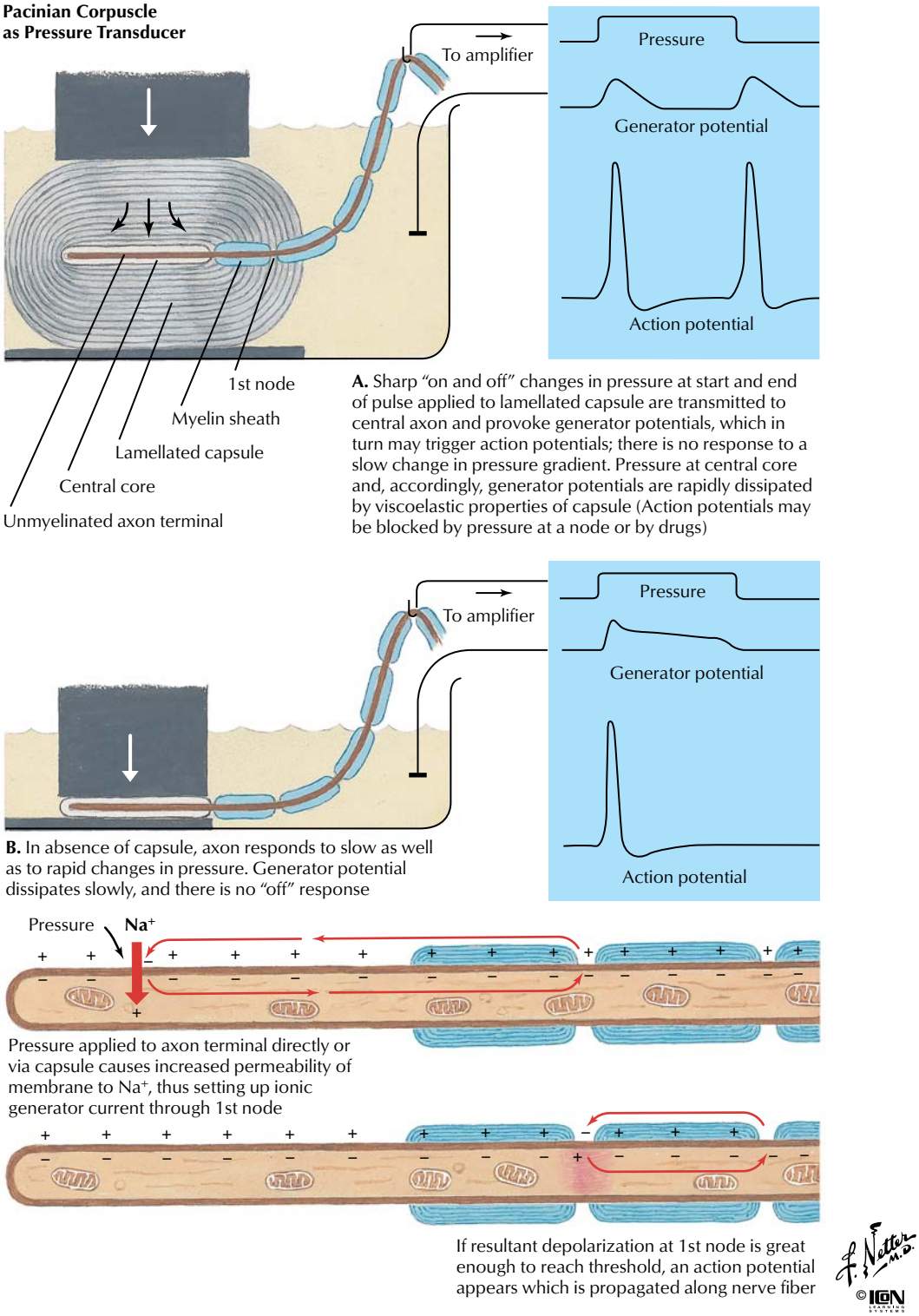


FIGURE 2.24 PACINIAN CORPUSCLE

Pacinian corpuscles are mechanoreceptors that transduce mechanical forces (displacement, pressure, vibration) into action potentials that are conveyed centrally by afferent nerve fibers. As the viscoelastic lamellae are displaced, the unmyelinated axon terminal membrane's ionic permeability is increased until it is capable of producing a "generator potential." As demonstrated in the figure, pacinian corpuscles respond to the beginning and end of a mechanical force while the concentric lamellae dissipate slow changes in pressure. In the absence of the capsule, the generator potential decays slowly and yields only a single action potential.

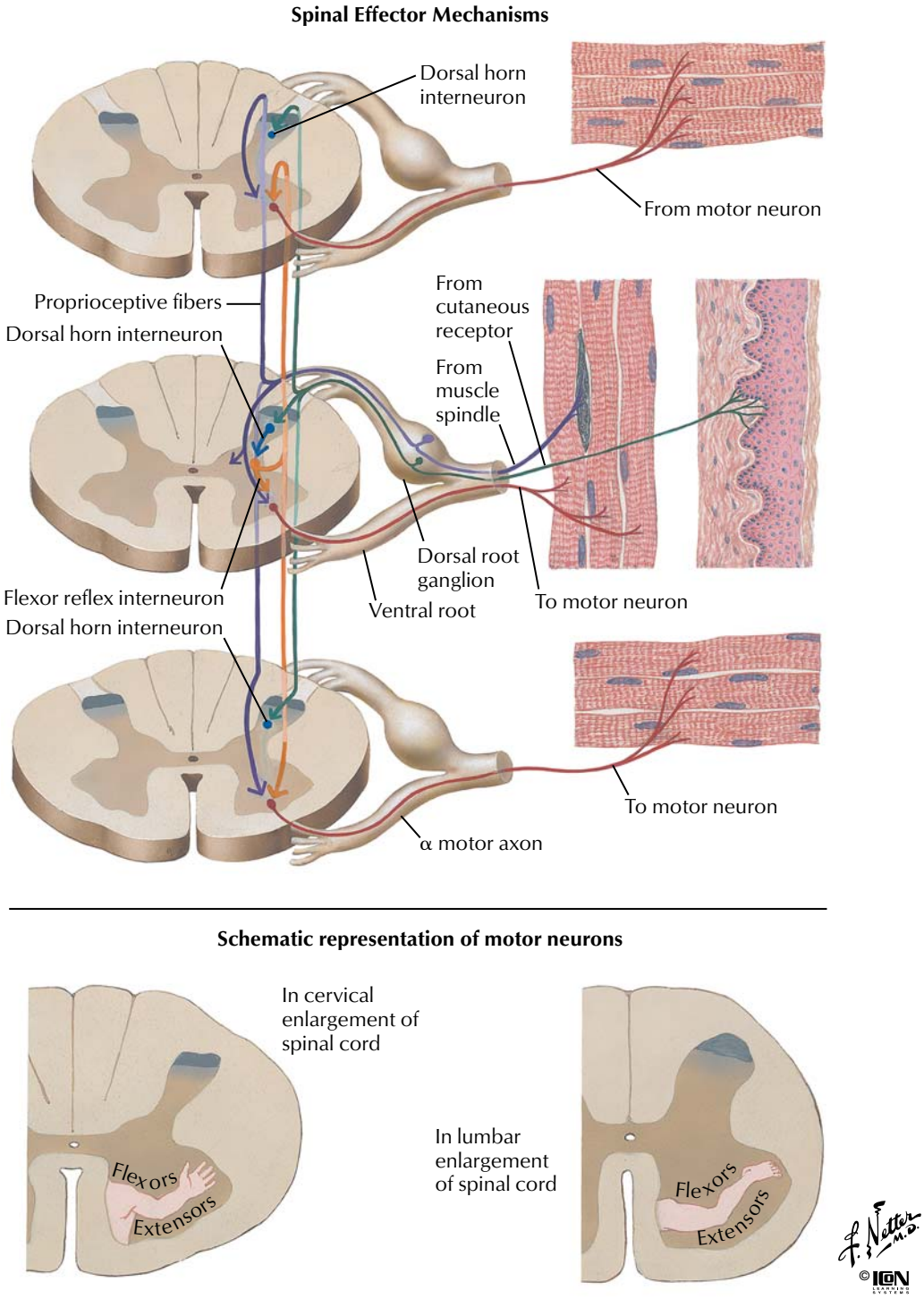


FIGURE 2.25 PROPRIOCEPTION: SPINAL EFFECTOR MECHANISM

Position sense or proprioception involves input from cutaneous mechanoreceptors, Golgi tendon organs, and muscle spindles (middle figure of upper panel). Both monosynaptic reflex pathways (middle figure of upper panel) and polysynaptic pathways involving several spinal cord segments (top and bottom figures of upper panel) initiate muscle contraction reflexes. The lower panel shows the somatotopic distribution of the motor neuron cell bodies in the ventral horn of the spinal cord that innervate limb muscles (flexor and extensor muscles of upper and lower limbs).

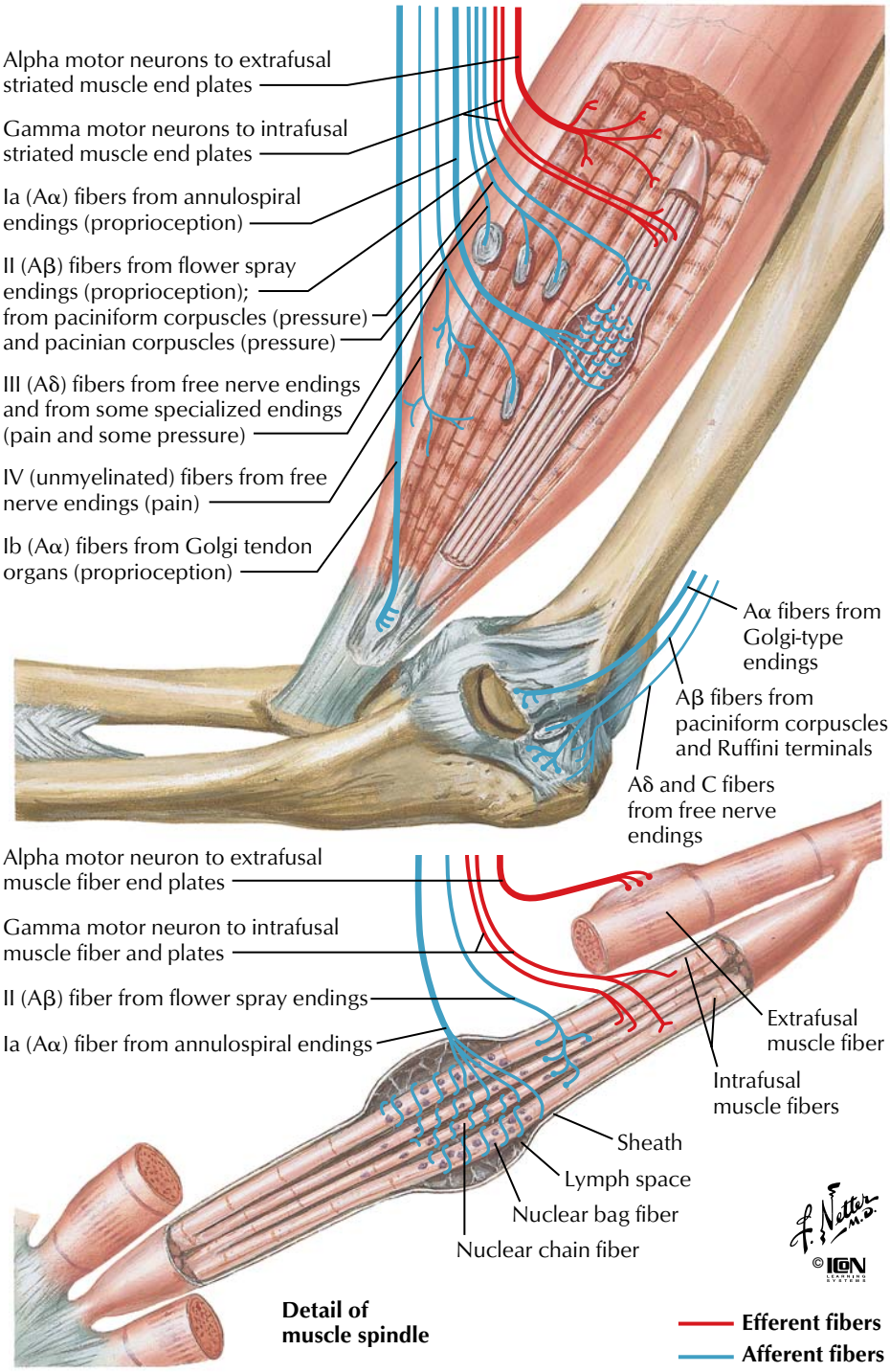


FIGURE 2.26 MUSCLE AND JOINT RECEPTORS

Muscle spindles and Golgi tendon organs send afferent signals to the brain to convey the position of limbs and help coordinate muscle movement. Muscle spindles convey information on muscle tension and contraction (dynamic forces) and muscle length (static forces). The nuclear bag fibers respond to both dynamic and static forces, whereas the nuclear chain fibers respond to static forces. Intrafusal fibers maintain appropriate tension on the nuclear bag and nuclear chain fibers. If the muscle tension is too great (e.g., overstretching of muscle or too heavy a load), activation of the Golgi tendon organ causes a reflex relaxation of the muscle.

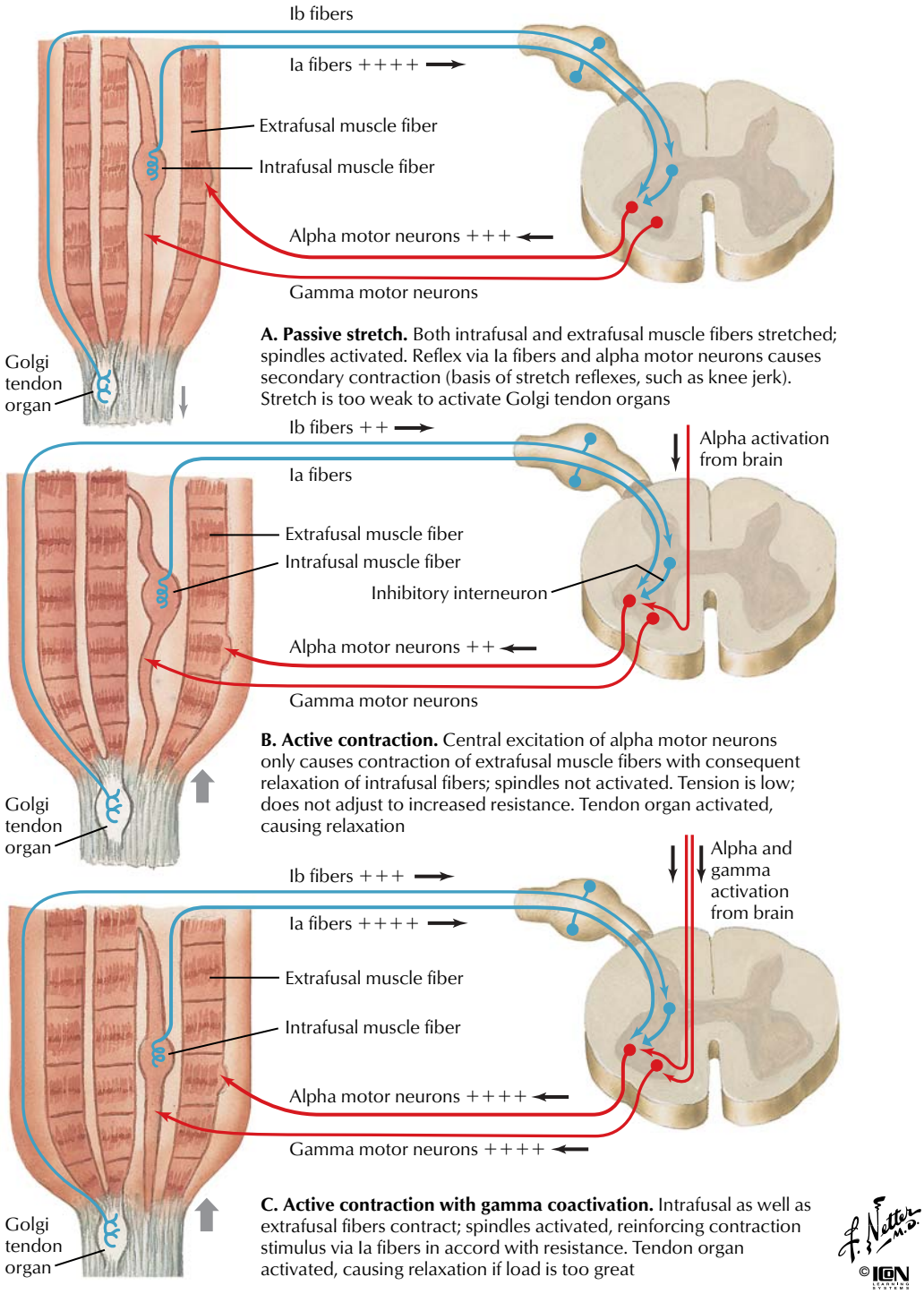


FIGURE 2.27 PROPRIOCEPTIVE REFLEX CONTROL OF MUSCLE TENSION

Interaction of the muscle spindle and Golgi tendon organ during passive stretch of a muscle (panel A) and during a contraction (panels B and C).

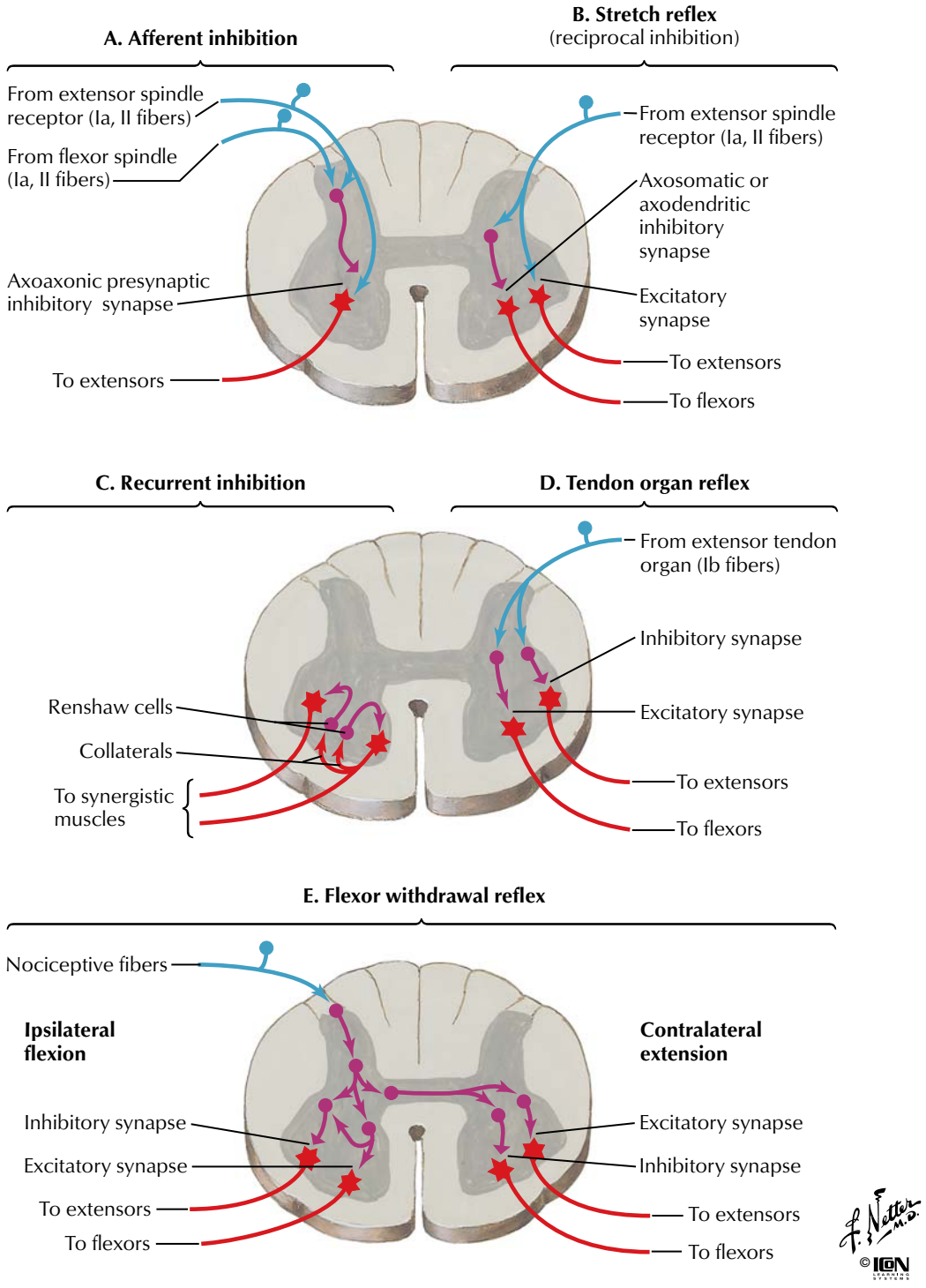


FIGURE 2.28 SPINAL REFLEX PATHWAYS

Summary of the spinal reflex pathways.

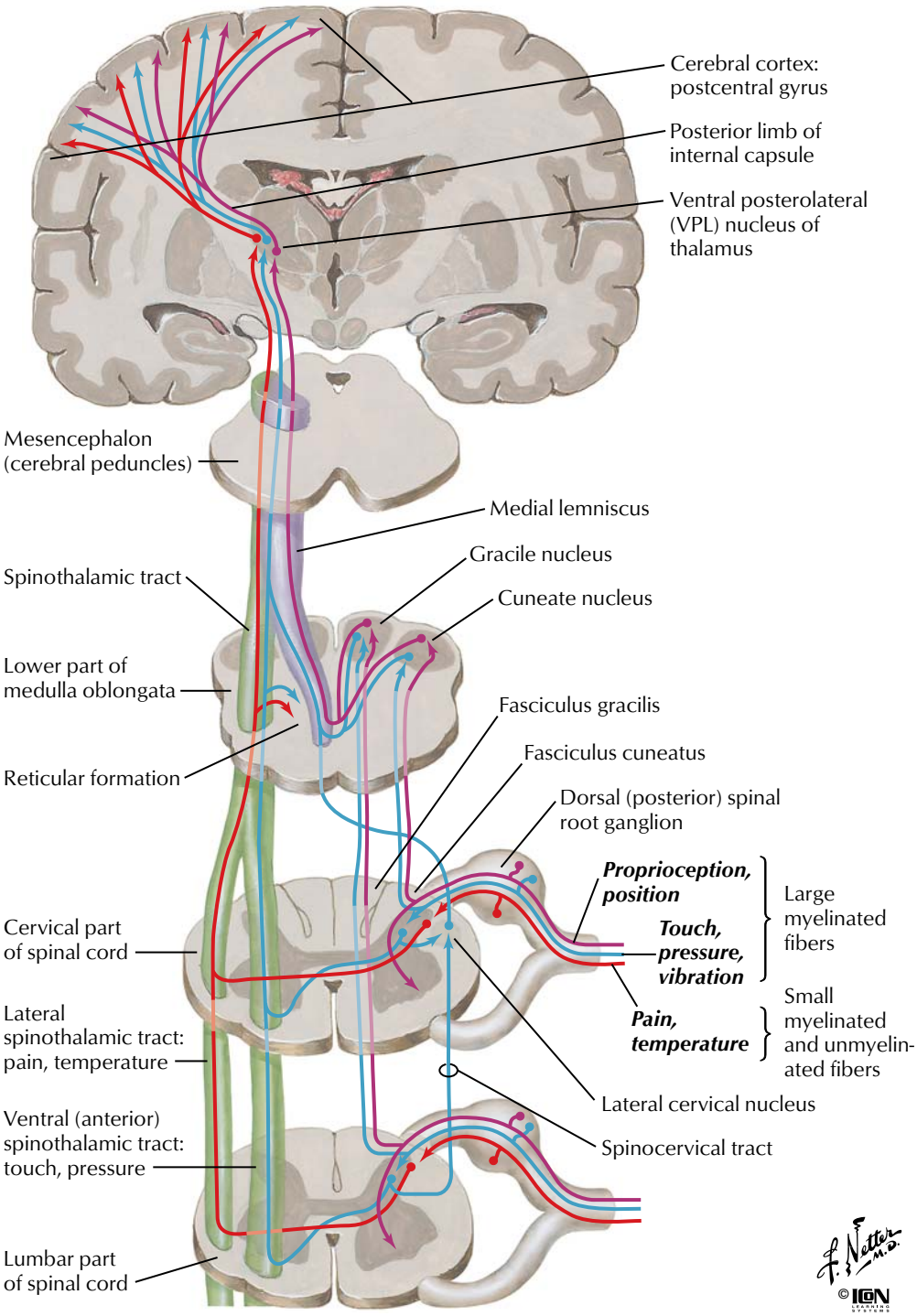


FIGURE 2.29 SOMESTHETIC SYSTEM OF THE BODY

Pain, temperature, and pressure sensations below the head ultimately are conveyed to the primary somatosensory cortex (postcentral gyrus) by the anterolateral system (spinothalamic and spinoreticular tracts). The fasciculus gracilis and cuneatus of the spinal lemniscal system convey proprioceptive, vibratory, and tactile sensations to the thalamus (ventral posterolateral nucleus), whereas the lateral cervical system mediates some touch, vibratory, and proprioceptive sensations (blue and purple lines show these dual pathways). Ultimately, these fibers ascend as parallel pathways to the thalamus, synapse, and ascend to the cortex.

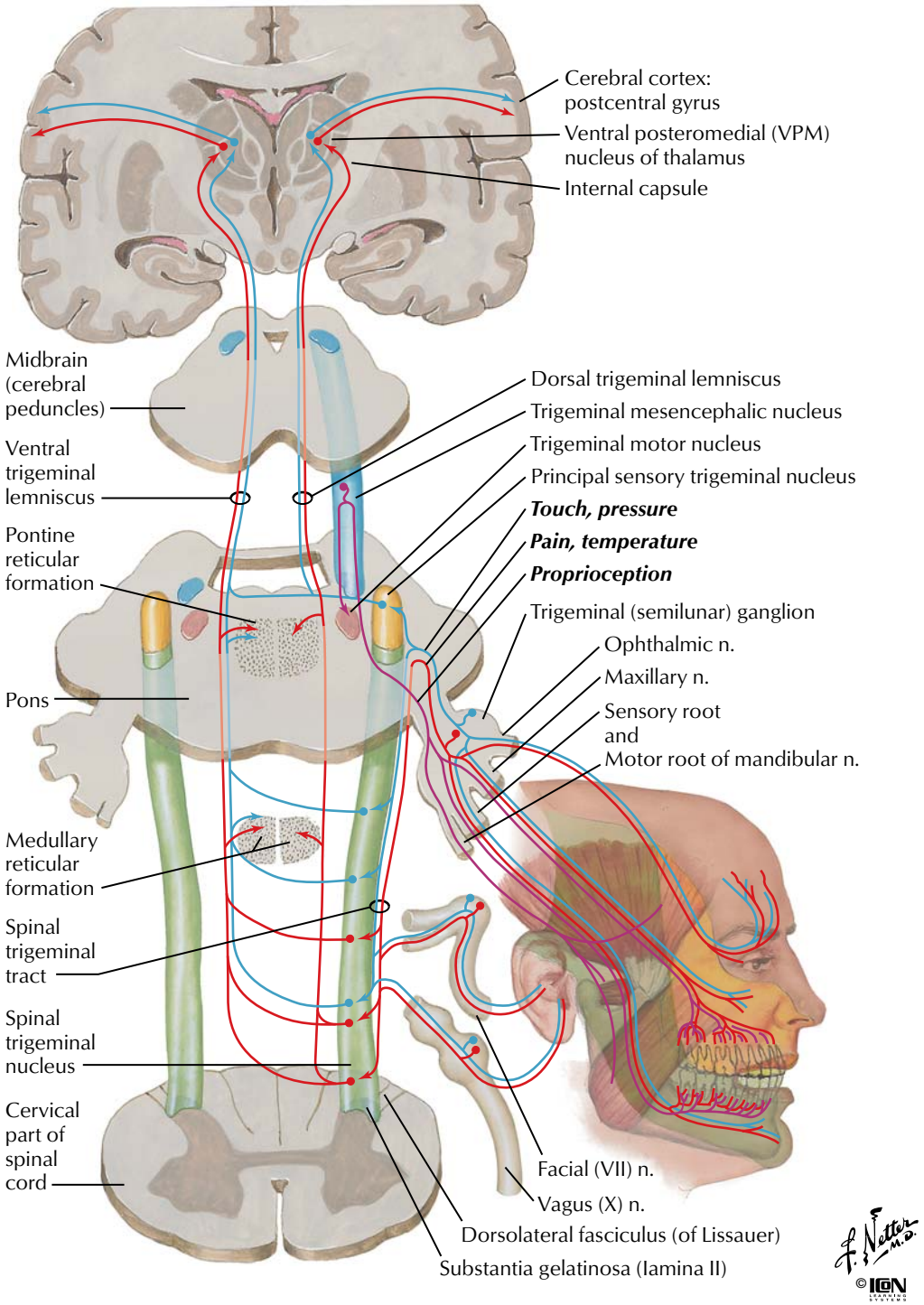
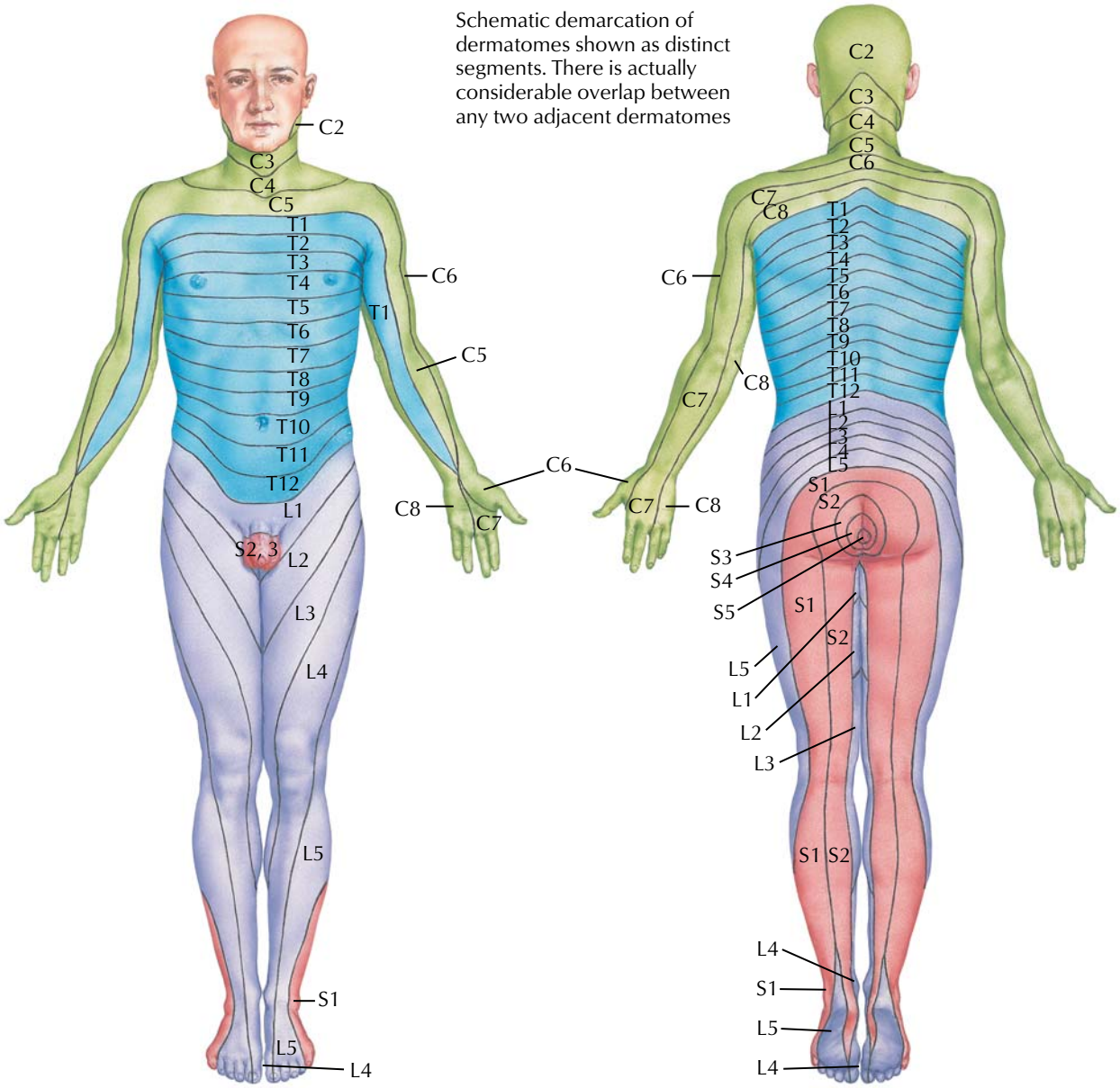


FIGURE 2.30 SOMESTHETIC SYSTEM OF THE HEAD

Nerve cells bodies for touch, pressure, pain, and temperature in the head are in the trigeminal (semilunar) ganglion of the trigeminal (CN V) nerve (blue and red lines in figure). Neuronal cell bodies mediating proprioception reside in the mesencephalic nucleus of CN V (purple fibers). Most relay neurons project to the contralateral VPM nucleus of the thalamus and thence to the postcentral gyrus of the cerebral cortex, where they are somatotopically represented.



Levels of principal dermatomes

C5	Clavicles
C5, 6, 7	Lateral parts of upper limbs
C8, T1	Medial sides of upper limbs
C6	Thumb
C6, 7, 8	Hand
C8	Ring and little fingers
T4	Level of nipples
T10	Level of umbilicus
T12	Inguinal or groin regions
L1, 2, 3, 4	Anterior and inner surfaces of lower limbs
L4, 5, S1	Foot
L4	Medial side of great toe
S1, 2, L5	Posterior and outer surfaces of lower limbs
S1	Lateral margin of foot and little toe
S2, 3, 4	Perineum

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FIGURE 2.31 DERMATOMES

Sensory information below the head is localized to specific areas of the body, which reflect the distribution of peripheral sensory fibers that convey sensations to the spinal cord through the dorsal roots (sensory nerve cell bodies reside in the corresponding dorsal root ganglion). The area of skin subserved by afferent fibers of one dorsal root is called a dermatome. This figure shows the dermatome segments and lists key dermatome levels used by clinicians. Variability and overlap occur, so all dermatome segments are only approximations.

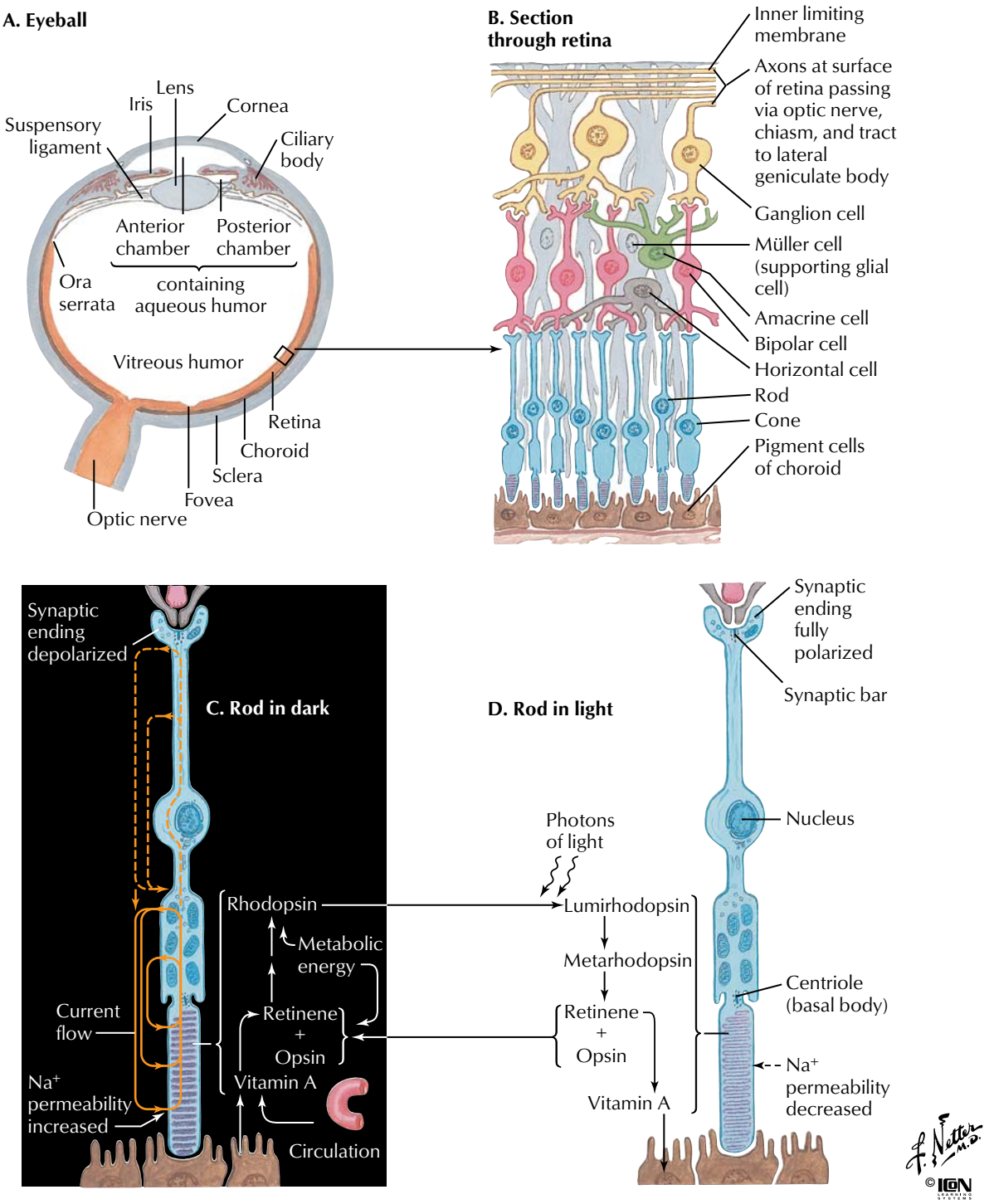


FIGURE 2.32 VISUAL RECEPTORS

The rods and cones of the retina transduce light into electrical signals. As illustrated for the rod, light is absorbed by rhodopsin, and through the second messenger cGMP (not shown), Na^+ channels in the membrane close and the cell hyperpolarizes. Thus, in the dark the cell is depolarized, but it is hyperpolarized in the light. This electrical response to light is distinct from other receptor responses, in which the response to a stimulus results in a depolarization of the receptor cell membrane.

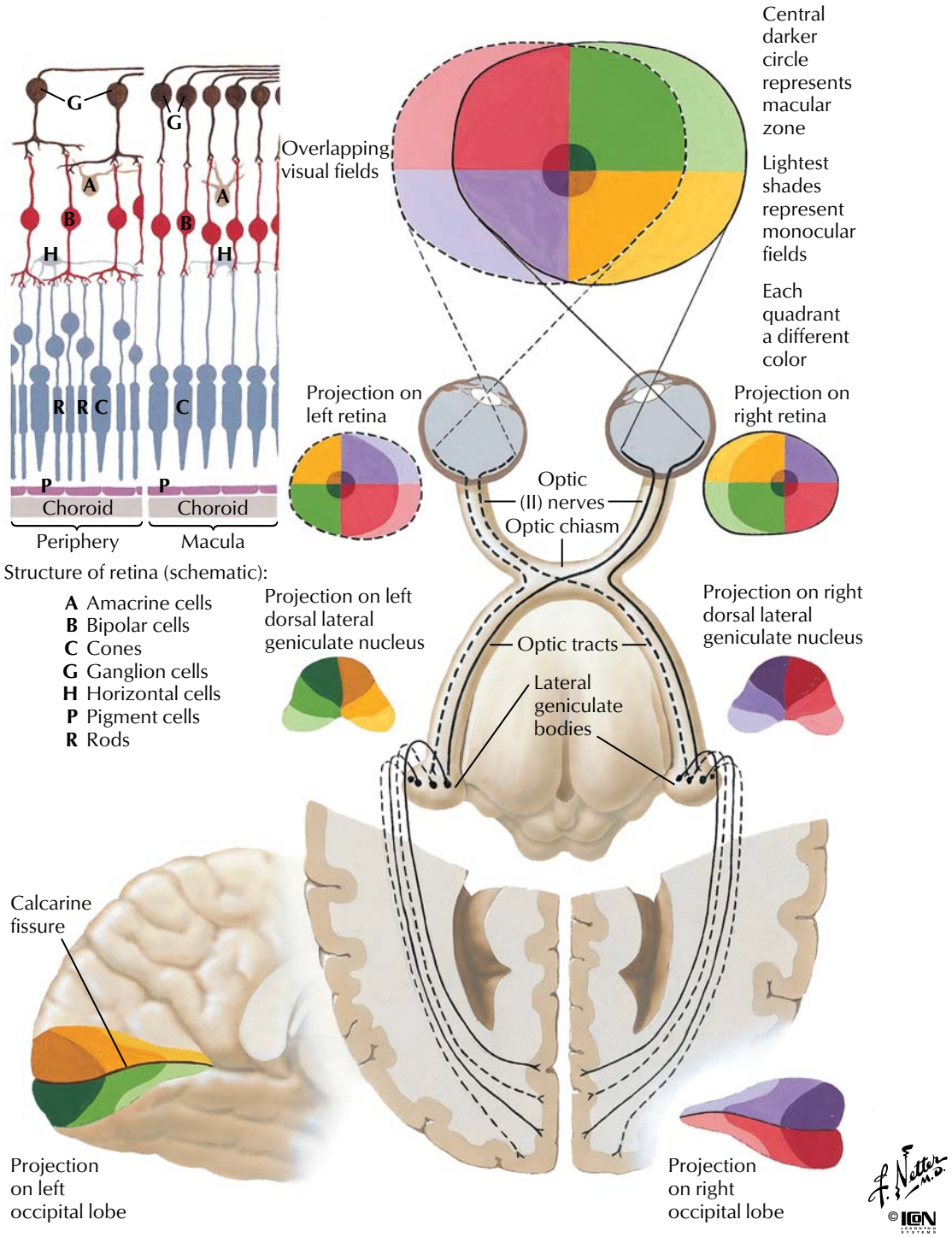


FIGURE 2.33 RETINOGENICULOSTRIATE VISUAL PATHWAY

The retina has two types of photoreceptors: cones that mediate color vision and rods that mediate light perception but with low acuity. The greatest acuity is found in the region of the macula of the retina, where only cones are found (upper left panel). Visual signals are conveyed by the ganglion cells whose axons course in the optic nerves. Visual signals from the nasal retina cross in the optic chiasm while information from the temporal retina remains in the ipsilateral optic tract. Fibers synapse in the lateral geniculate nucleus (visual field is topographically represented here and inverted), and signals are conveyed to the visual cortex on the medial surface of the occipital lobe.

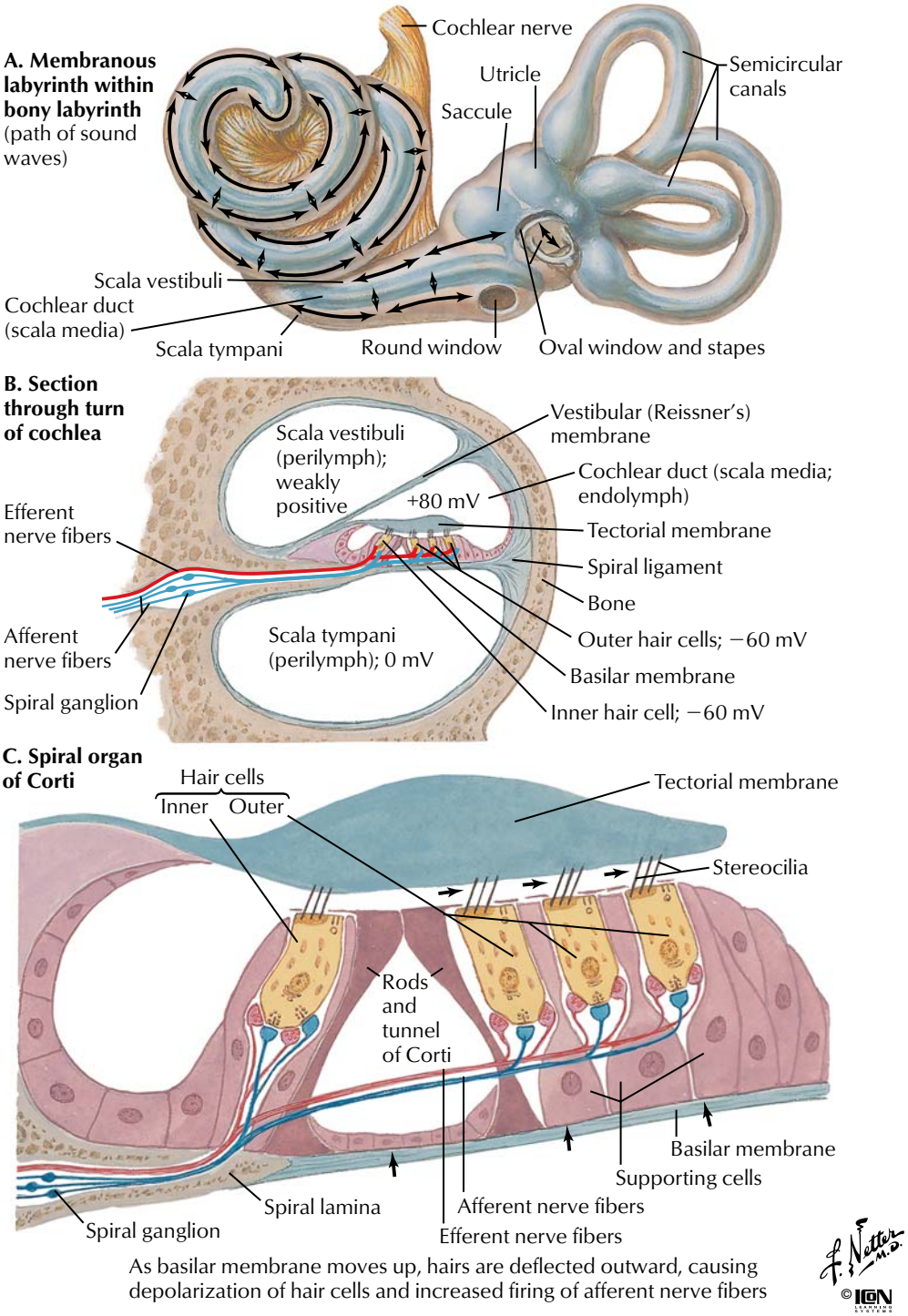


FIGURE 2.34 COCHLEAR RECEPTORS

The cochlea transduces sound into electrical signals. This is accomplished by the hair cells, which depolarize in response to vibration of the basilar membrane. The basilar membrane moves in response to pressure changes imparted on the oval window of the cochlea in response to vibrations of the tympanic membrane.

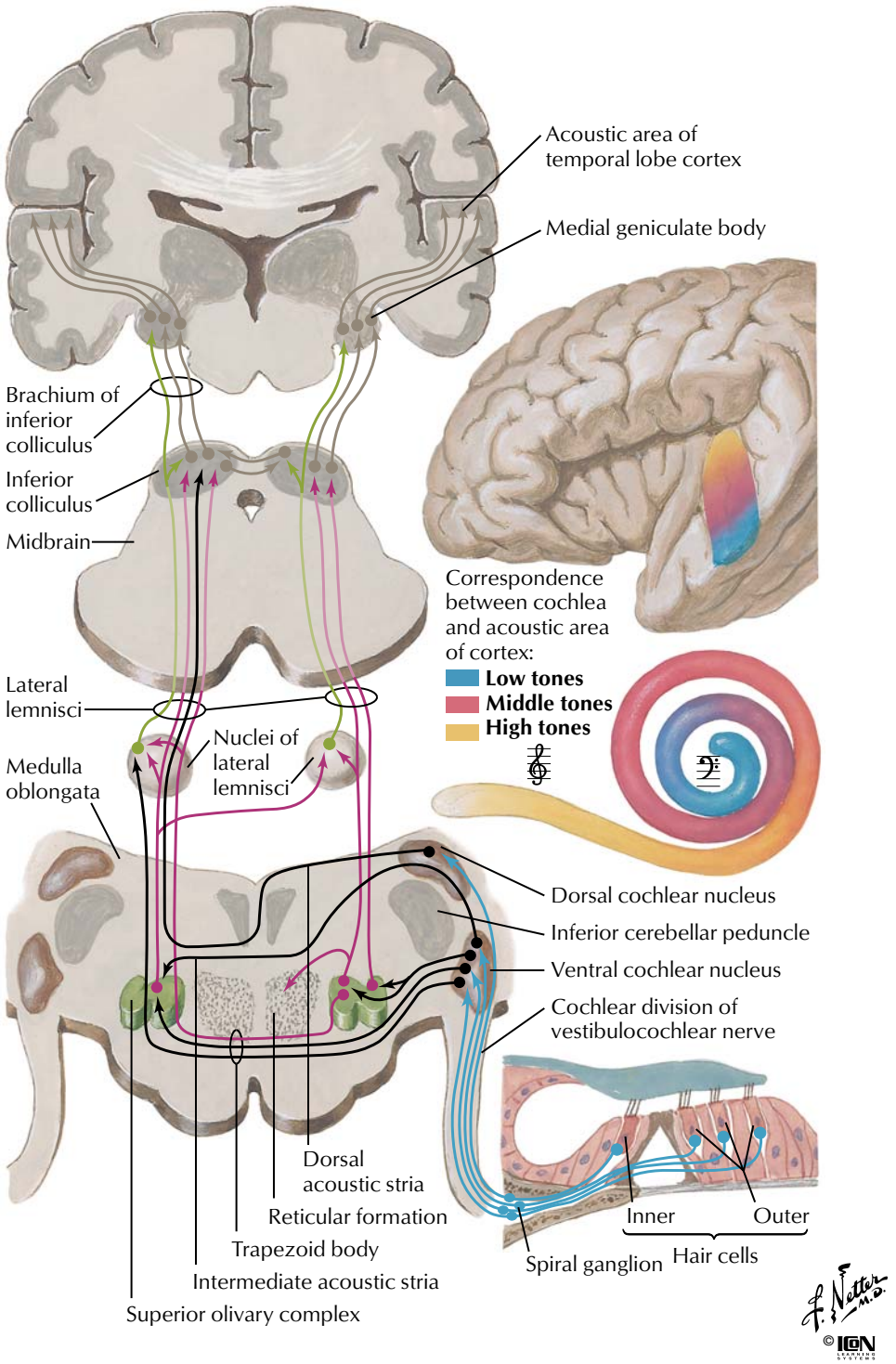


FIGURE 2.35 AUDITORY PATHWAYS

The cochlea transduces sound into electrical signals. Axons convey these signals to the dorsal and ventral cochlear nuclei, where it is tonotopically organized. Following a series of integrated relay pathways, the ascending pathway projects to the thalamus (medial geniculate bodies) and then the acoustic cortex in the transverse gyrus of the temporal lobe, where information is tonotopically represented (low, middle, and high tones).

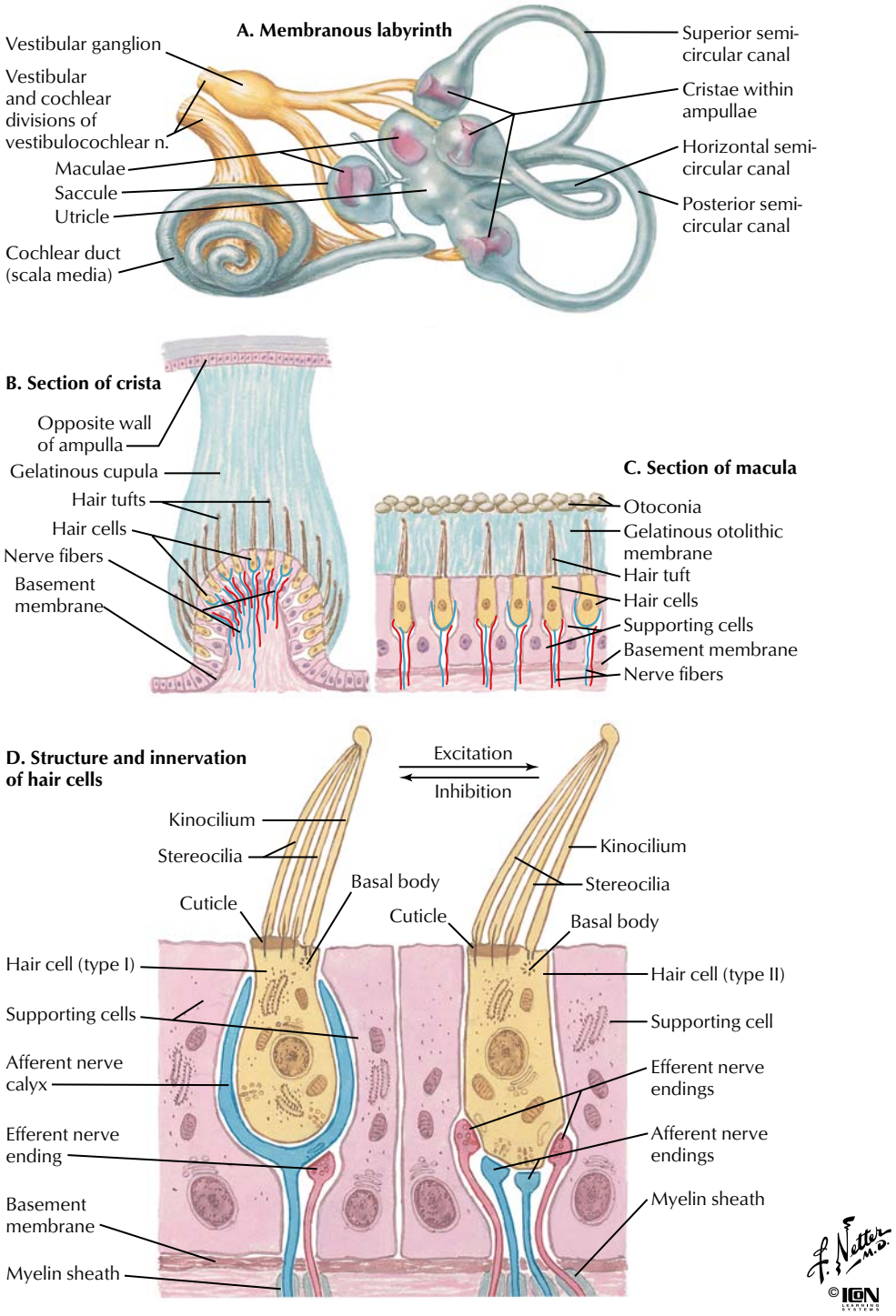


FIGURE 2.36 VESTIBULAR RECEPTORS

The vestibular apparatus detects movement of the head in the form of linear and angular acceleration. This information is important for the control of eye movements so that the retina can be provided with a stable visual image. It is also important for the control of posture. The utricle and saccule respond to linear acceleration, such as the pull of gravity. The three semicircular canals are aligned so that the angular movement of the head can be sensed in all planes. The sensory hair cells are located in the maculae of the utricle and saccule and in the cristae within each ampullae.

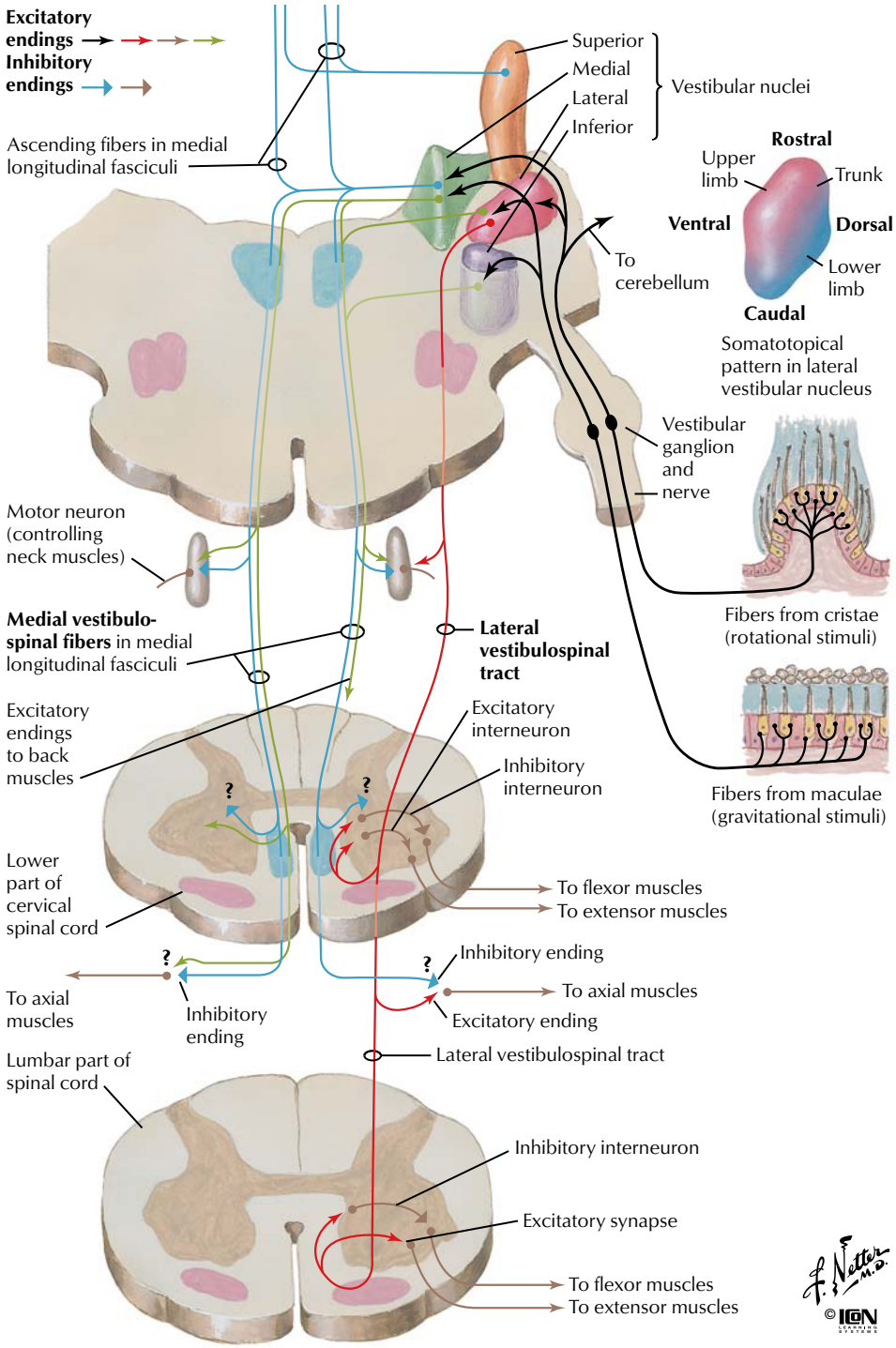


FIGURE 2.37 VESTIBULOSPINAL TRACTS

Sensory input from the vestibular apparatus is used to maintain stability of the head and to maintain balance and posture. Axons convey vestibular information to the vestibular nuclei in the pons, and then secondary axons distribute this information to five sites: spinal cord (muscle control), cerebellum (vermis), reticular formation (vomiting center), extraocular muscles, and cortex (conscious perception). This figure shows only the spinal cord pathways.

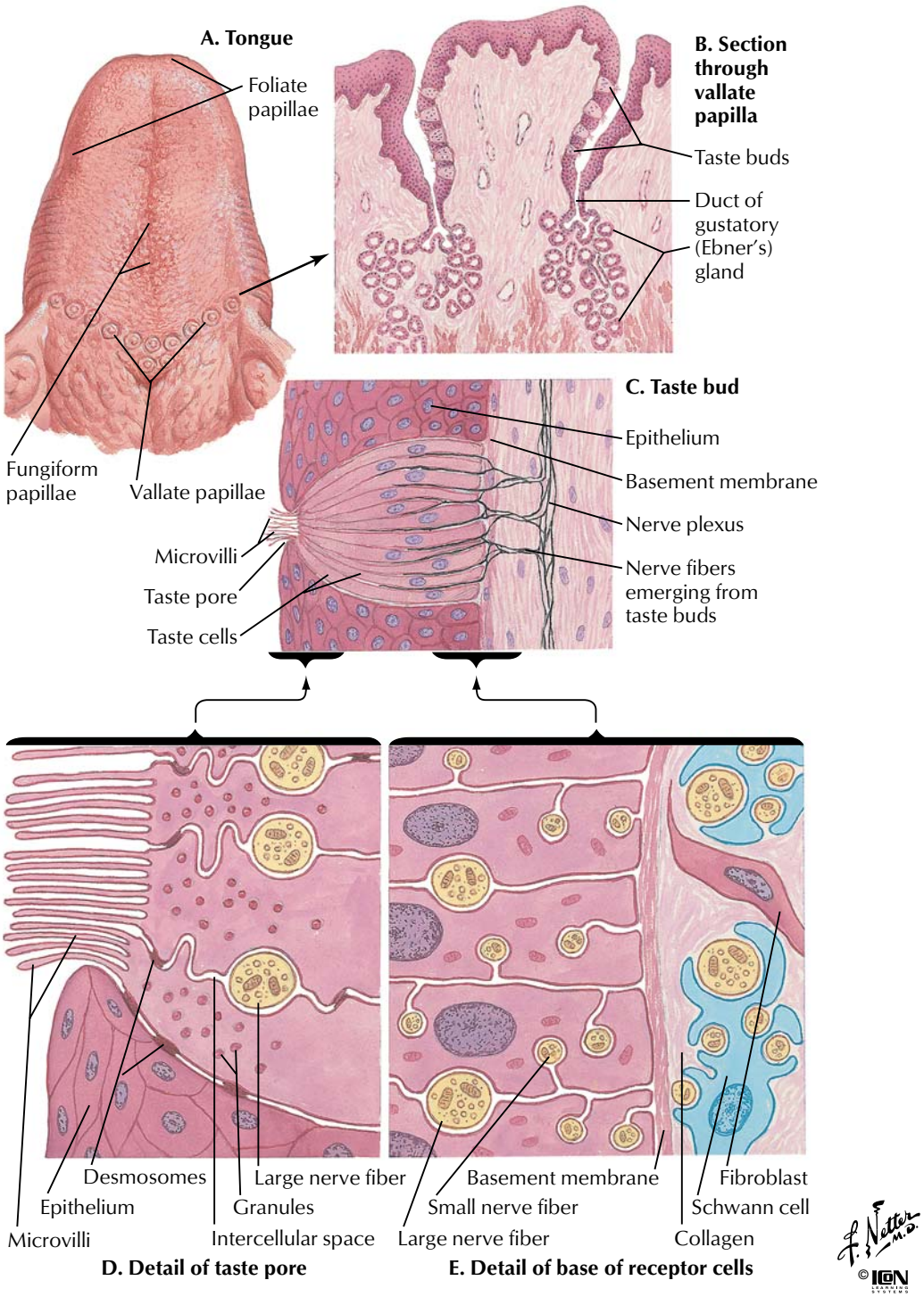


FIGURE 2.38 TASTE RECEPTORS

Taste buds on the tongue respond to various chemical stimuli. Taste cells, like neurons, normally have a net negative charge internally and are depolarized by stimuli, thus releasing transmitters that depolarize neurons connected to the taste cells. A single taste bud can respond to more than one stimulus. The four traditional taste qualities that are sensed are sweet, salty, sour, and bitter.

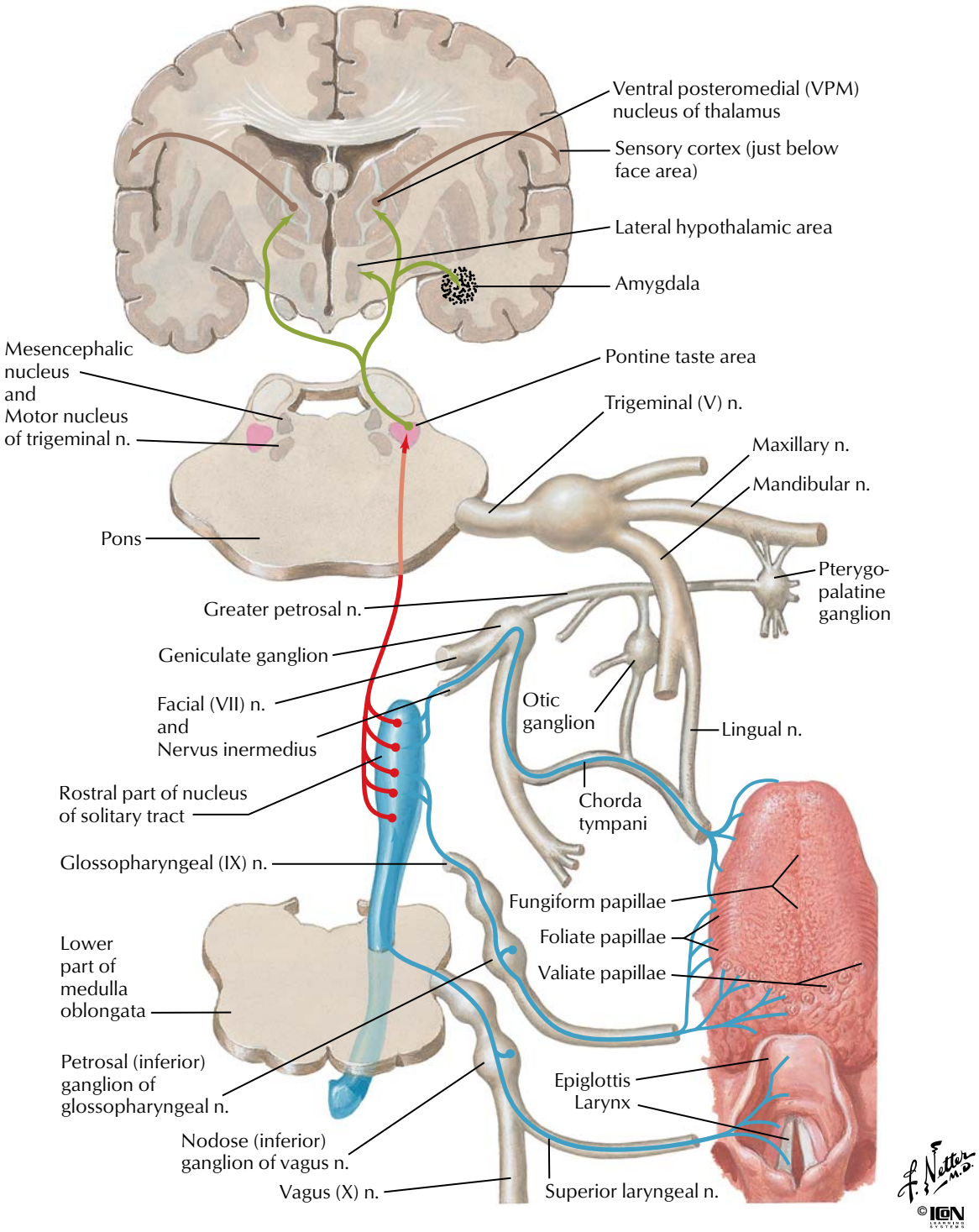


FIGURE 2.39 TASTE PATHWAYS

Depicted here are the afferent pathways leading from the taste receptors to the brainstem and, ultimately, to the sensory cortex in the postcentral gyrus.

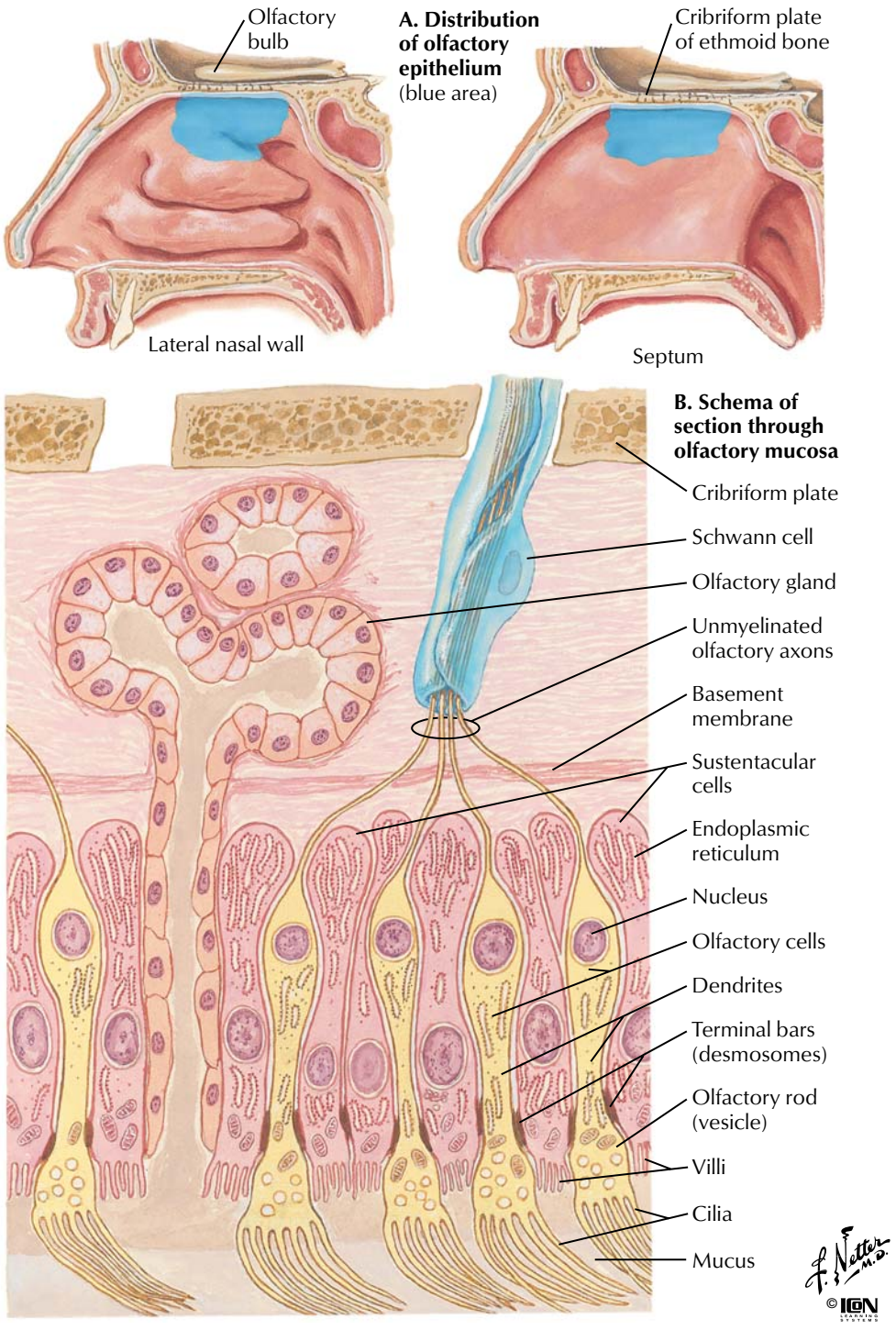


FIGURE 2.40 OLFACTORY RECEPTORS

The sensory cells that make up the olfactory epithelium respond to odorants by depolarizing. Like taste buds, an olfactory cell can respond to more than one odorant. There are six general odor qualities that can be sensed: floral, ethereal (e.g., pears), musky, camphor (e.g., eucalyptus), putrid, and pungent (e.g., vinegar, peppermint).

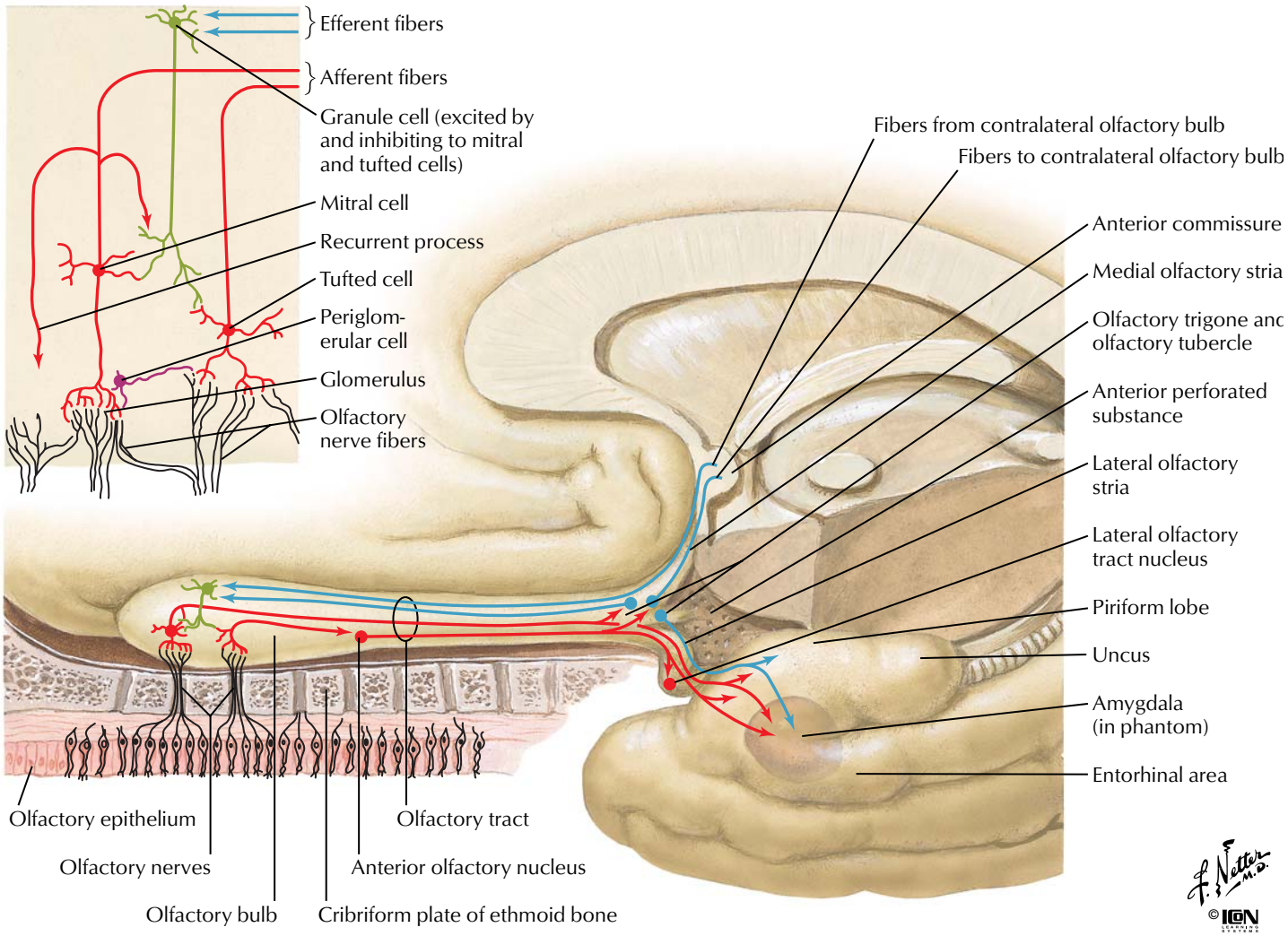


FIGURE 2.41 OLFACTORY PATHWAY

Olfactory stimuli are detected by the nerve fibers of the olfactory epithelium and conveyed to the olfactory bulb (detailed local circuitry shown in upper left panel). Integrated signals pass along the olfactory tract and centrally diverge to pass to the anterior commissure (some efferent projections course to the contralateral olfactory bulb, blue lines) or terminate in the ipsilateral olfactory trigone (olfactory tubercle). Axons then project to the primary olfactory cortex (piriform cortex), entorhinal cortex, and amygdala.

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