Paparella: Volume I: Basic Sciences and Related Principles

Section 1: Embryology and Anatomy

Part 2: Head and Neck

Chapter 4: Neuroanatomy for the Otolaryngology - Head and Neck Surgeon

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Because of the nervous system's importance in control and management of all the organ systems, precise neuroanatomic knowledge of its structures in the head and neck are of paramount importance to the otolaryngologist - head and neck surgeon. The central nervous system is a single organ system; but for the convenience of description, it will be subdivided into the brain and the spinal cord. From these two divisions, the 12 paired cranial nerves and 31 paired spinal nerves are derived. The paired nerves, along with the autonomic nervous system and the ganglia of both, constitute the peripheral nervous system. More attention is focused on the peripheral nervous system, composed of spinal nerves, cranial nerves, and autonomic nerves, since these are the major areas of relevance to the otolaryngologist - head and neck surgeon. The discussion of the neuroanatomy of the brain is limited to its direct extensions (cranial nerves I, II, and VIII) and its blood supply.

Embryology

The differentiation of the nervous system commences between the 15th and 17th days after fertilization from a specialized area of the ectoderm. At early developmental stages, the neural streak develops into a plate, then into a groove, and finally fuses into a neural tube. This tube then differentiates into the prosencephalon (forebrain), mesencephalon (midbrain), rhombencephalon (at the cephalic end of the spinal cord).

The prosencephalon separates into the telencephalon and diencephalon. The telencephalon divides into three major portions. (1) The first portion is the rhinencephalon, which develops into the olfactory lobes, piriform lobes, hippocampus, fornix, septum pellucidum, parahippocampal gyrus, stria terminalis, and the cingulate gyrus. (2) The corpus striatum forms the second portion, which includes the internal capsule and basal ganglion. (3) The third portion of the telencephalon eventually develops into the cerebral cortex and underlying white matter.

The diencephalon gives rise to the thalamus and hypothalamus, whereas the mesencephalon forms the midbrain.

The rhombencephalon divides further into the metencephalon, which gives rise to the pons and cerebellum, and the myelencephalon, which becomes the medulla.

The spinal nerves develop from maturing neurons in the ventrolateral portion of the intermediate zone of the spinal cord, forming ventral roots, while developing neurons in the dorsal root ganglia grow into the cord to form the dorsal roots.

The autonomic nervous system has two divisions: sympathetic and parasympathetic. This two-neuron system has its first cell body or preganglionic neuron within the substance of the brain or spinal cord, whereas the second or postganglionic neuron is located more peripherally.

The development of the cranial nerves is much like that of the spinal nerves. However, cranial nerves I (olfactory), II (optic), and VIII (vestibulocochlear) are in fact outgrowths of the brain itself.

Basic Structures of the Nervous System

Neurons

The neuron is the basic unit of structure and function of the nervous system and is composed of a cell body and one or more processes called axons and dendrites. Functionally speaking, axons carry impulses away from the cell body; dendrites conduct impulses toward the cell body.

Neurones can be classified according to the number of processes they have.

Unipolar. These cells have a single process, which splits into two branches a short distance from the cell. Neurons of this type are predominantly sensory and are found almost exclusively in the peripheral nervous system.

Bipolar. These cells are fusiform and have an axon attached at one end and a dendrite at the other. They are found in the retina, in cochlear and vestibular ganglia, and in certain places in the central nervous system.

Multipolar. These cells constitute the majority of CNS neurons and are also typical of the peripheral autonomic nervous system. The cell has several poles to which usually attach several dendrites but only one axon.

Cell Body

This is the portion of neuron that contains the **nucleus.** The nucleus is surrounded by the *cytoplasm* of the cell body. The cytoplasm is composed of several components: *neurofibrils,* fine fibrils that extend throughout the cell body and out into all processes; *neuroplasm,* a semiliquid substance surrounding neurofibrils. The neuroplasm of axons is known as *axoplasm.*

Nissl Substance. Also known as *Nissl bodies,* this is clumped or particulate matter, usually scattered among the neurofibrils. It extends into the dendrites but not into the axons. It is thought to be responsible for the production of new cytoplasm, which flows continuously down the axon (axoplasmic flow).

Golgi Net and Mitochondria. These are scattered between the neurofibrils and Nissl bodies and probably function, as in other cells, in protein synthesis, respiration, and production of secretions.

Myelin - Insulating Substance of the Nervous System. Myelin is a lipid substance that probably exists in the nervous system as a lipid-protein complex. It is present in the white substance of the CNS and around the axis cylinders of most peripheral nerves. It enhances the conduction of nerve impulses that lead to delicate and precise movements.

Components of a Peripheral Nerve (Fig. 2)

Axis Cylinder. The axis cylinder consists of bundles of neurofibrils set in axoplasm.

Myelin. This substance surrounds the axis cylinders of most peripheral nerves. The notable exceptions, which are the unmyelinated fibers, are the postganglionic fibers of the autonomic nervous system, which have their cells of origin in ganglia. The myelin sheaths are interrupted at intervals by constrictions known as *nodes of Ranvier.*

Neurilemma. The neurilemma is a fine membrane of Schwann cells, also known as the *sheath of Schwann,* which surrounds all peripheral nerves, myelinated and unmyelinated. On myelinated nerves, there is one Schwann cell between each node of Ranvier. Neurilemma plays both a supporting and metabolic role for the axon. It is apparently responsible for the production of myelin in myelinated nerve fibers.

Endoneurium. Endoneurium consists of fine strands of connective tissue, which infiltrates between the individual nerve fibers.

Perineurium. This is a connective tissue sheath that surrounds groups of nerve fibers, dividing the entire nerve into bundles and fascicles.

Epineurium. Epineurium is a rather dense connective tissue that surrounds the entire nerve trunk.

Synapse

A synapse is a point of contact between neurons where chemically mediated transmission of impulses occurs. This is different from transmission along axons, which is electrically mediated. There are presynaptic structures called terminal boutons that have contact with cell bodies, dendrites, axons, or combinations of these elements. Within the bouton are mitochondria and synaptic vesicles that contain neurotransmitters. The most common of these transmitters are acetylcholine, adrenaline, dopamine, serotonin, gamma-aminobutyric acid (GABA), substance P, and glycine. Transmission occurs by way of these chemical mediators by causing excitation by increasing permeability to sodium or inhibition by increasing permeability of the postsynaptic membrane to chloride. The complexity of these contacts and transmitters forms the basis of the integrative action of the nervous system.

Degeneration and Regeneration of Neurons in Peripheral Nerves

When a peripheral nerve is injured, two types of degeneration occur, *retrograde* and *wallerian.*

Retrograde degeneration constitutes a breakdown of both myelin and the axis cylinder for a few millimeters from the site of injury back along the proximal nerve trunk toward the cell body. The Schwann cells, however, remain alive and may actually proliferate.

Wallerian degeneration refers to the disintegration and disappearance of the myelin and axis cylinders distal to the site of injury in a peripheral nerve. Schwann cells remain alive in this peripheral portion of the injured nerve and even proliferate to form a longitudinally oriented syncytium along which axoplasm may flow in the regenerative process. Under favorable conditions, axoplasm is said to flow along the distal degenerated segment of nerve at the rate of 1 to 2 mm per day. It is produced by the viable cell bodies of the nerves proximal to the injury.

Synkinesis and mass movement can occur when there is cross-innervation of muscles by regenerating fibers growing down the wrong axoplasmic tubule.

Blood Supply and Venous Drainage of the CNS

Arterial Blood Supply

Brain

The main arterial supply to the brain is through the internal carotid arteries anteriorly and the vertebral arteries posteriorly. The *internal carotid arteries* enter the skull via the carotid canals. They cross the foramen lacerum and pass into the middle cranial fossa, ascending in the carotid grooves on either side of the sphenoid bone. The carotid is encased between dural layers in this tortuous ascension along the sphenoid bone and is also enveloped by the cavernous sinus. In this segment, it gives off small branches to the hypophysis, semilunar ganglion, and the cavernous and petrosal sinuses. Occasionally, it gives off small an anterior meningeal branch here. Just as the internal carotid artery emerges from the cavernous sinus, it gives off the ophthalmic artery. At the level of the lateral cerebral fissure, the internal carotid artery divides into several branches: the anterior cerebral arteries, the middle cerebral arteries, the posterior communicating arteries and the anterior choroidal arteries.

Anterior Cerebral Arteries. The anterior cerebral arteries course rostrally and medially to the beginning of the longitudinal fissure over the optic tract. Here, the vessels of the two sides lie close together and are joined by the important anastomotic *anterior communicating artery*. Each anterior cerebral artery then arches upward and backward in the longitudinal fissure, following the dorsum of the corpus callosum and anastomosing posteriorly with branches of the posterior cerebral artery. In its course it gives off branches to the medial aspects of the frontal and parietal lobes, the anterior perforated substance, and the corpus callosum.

Middle Cerebral Arteries. These arteries are the largest branches of the internal carotid arteries. They course laterally in the lateral cerebral fissure and then arch upward and backward over the lateral portions of the hemispheres. The medial and lateral striate arteries are given off near the origin of the middle cerebral artery and these penetrate the anterior perforated substance to supply the basal ganglia and internal capsule.

Posterior Communicating Arteries. The posterior communicating arteries run backward to join the cerebral branches of the vertebrobasilar system. They supply the internal capsule and thalamus.

The *vertebral arteries* enter the skull through the foramen magnum and ascend along the lateral ventral side of the medulla. They join at the rostral end of the medulla to form the *basilar artery*. Intracranially, the vertebral arteries give off the *anterior* and *posterior spinal arteries* and the *posteroinferior cerebellar artery*. The anterior spinal arteries join to form a single vessel, which runs ventrally along the medulla and spinal cord. The posterior spinal arteries descend onto the cord along the dorsal roots of the spinal nerves. The posteroinferior cerebellar artery usually arises from the vertebral arteries just before they join to form the basilar artery, although they occasionally arise as branches of the basilar artery (Fig. 5).

The basilar artery ascends in the midline on the ventral surface of the pons and ends by dividing into the *posterior cerebral arteries*. It gives off several pontine branches, internal auditory arteries, and the anteroinferior and superior cerebellar arteries. The latter, in addition to supplying the cerebellum, also supply the superior and inferior colliculi, the pineal body, and the choroid plexus of the third ventricle. The *posterior cerebral arteries* pass laterally, and after receiving the posterior communicating artery from the internal carotid, they curve posteriorly to supply the undersurface and medial surface of the occipital and temporal lobes. They also give off branches to the choroid plexus (Fig. 6).

The circle of Willis is formed by the circular anastomotic pattern of internal carotid and vertebral systems. This rich anastomosis allows for excellent collateral circulation in the brain when one of the vertebrals or carotids becomes occluded.

Venous Drainage

Venous blood from both the brain and the meninges drains into the venous dural sinuses.

Superior Sagittal Sinus. This sinus begins anteriorly at the foramen cecum, where it receives a branch from the nasal cavity. It courses dorsally and posteriorly in the upper border of the falx cerebri, which is attached to the roof of the cranium in the midline. Most of the time, the sagittal sinus turns to the right side posteriorly at the occipital protuberance to become confluent with the transverse sinus of the right side. The sagittal sinus receives drainage from the superior cerebral veins and also from the meningeal veins. It also receives cerebrospinal fluid from the arachnoid villi and the venous lacunae.

Inferior Sagittal Sinus. The inferior sagittal sinus occupies most of the posterior portion of the inferior free margin of the falx cerebri. It ends posteriorly in the straight sinus. It receives veins from the medial surfaces of the cerebrum.

Straight Sinus. The straight sinus runs in the dural fold at the junction of the falx cerebri and the tentorium cerebelli. Posteriorly, at the occipital protuberance, it turns laterally into the transverse sinus, usually on the left side. Anteriorly, it receives the great cerebral vein (of Galen). It also receives superior cerebellar veins.

Transverse or Lateral Sinuses. These run laterally from the internal occipital protuberance in the fold of tentorium cerebelli attached to the occipital bone. At the base of the temporal bone, they turn downward and forward as the *sigmoid sinuses* to reach the jugular bulb at the jugular foramen. At the top part of the sigmoid sinus, the jugular bulb receives the superior petrosal sinus. The jugular bulb at the lower end of the sigmoid sinus receives the inferior petrosal sinus. The transverse and sigmoid sinuses also receive the inferior cerebral and cerebellar veins, the mastoid and condyloid emissary veins, and the diploic veins.

Occipital Sinus. The occipital sinus is the smallest of the sinuses and begins at the foramen magnum by the convergence of small veins and runs posteriorly and superiorly in the attached margin of the falx cerebelli. It empties into the confluence of sinuses at the internal occipital protuberance, known as the *torcular Herophili,* where the superior sagittal, straight, transverse, and occipital sinuses join. The occipital sinus receives the inferior cerebellar veins.

Cavernous Sinus. The cavernous sinus is irregular in shape and fills in the space between the body of the sphenoid bone and the dura, forming the medial boundary of the middle fossa from the superior orbital fissure to the petrous portion of the temporal bone (Fig. 7). It is broken up by trabeculae into many venous cavernous spaces; hence its name, the cavernous sinus. Within its lateral wall are incorporated the third, fourth, and first and second division of the fifth nerves. The sixth nerve and internal carotid artery are suspended more centrally in the sinus. The chief afferent vessels are the superior, and sometimes inferior, ophthalmic veins and some cerebral veins. The efferent channels are the superior and inferior petrosal sinuses and the intercavernous sinus. The intercavernous sinus connects the two cavernous sinuses across the midline. It communicates with the pterygoid plexus by several emissary veins in the base of the skull. It consists of an anterior limb, which passes in front of the hypophysis, and a posterior limb behind the hypophysis (Fig. 8). Along with the two cavernous sinuses, the intercavernous sinus forms a venous circle around the hypophysis known as the *circular sinus.*

Superior Petrosal Sinuses. These leave the cavernous sinus and run posteriorly along the petrous ridge of the temporal bone in the tentorium cerebelli. They empty into the transverse sinuses as they turn downward as the sigmoid sinuses on the inner surface of the mastoid portion of the temporal bone. The superior petrosal sinus receives cerebellar and inferior cerebral veins, and also veins from the tympanic cavity.

Inferior Petrosal Sinuses. These sinuses begin in the cavernous sinuses and course caudally along the inferior petrosal sulcus formed by the junction of the petrous part of the temporal bone and the basilar part of the occipital. They end in the anterior part of the jugular bulb. They receive the internal auditory veins and also veins from the medulla, pons, and cerebellum.

Basilar Plexus. The basilar plexus consists of several interlacing channels in the dura over the clivus, which interconnect the inferior petrosal sinuses and also communicate with the anterior vertebral venous plexus.

Diploic Veins

The diploic veins form venous plexuses in the diploë between the inner and outer tables of the skull and communicate intracranially with the meningeal veins and the venous dural sinuses and extracranially with the veins of the pericranium. They are drained by four main trunks on each side: frontal, anterior temporal, posterior temporal, and occipital.

Frontal. The frontal vein connects the supraorbital vein with the superior sagittal sinus.

Anterior Temporal. The anterior temporal vein anastomoses with the sphenoparietal sinus and one of the deep temporal veins through an aperture in the greater wing of the sphenoid bone.

Posterior Temporal. The posterior temporal vein ends in the transverse sinus through an aperture in the mastoid angle of the parietal bone or through the mastoid foramen.

Occipital. The occipital vein is the largest of the four and opens either externally into the occipital vein or internally into the transverse sinus or the confluence of sinuses.

Emissary Veins

Emissary veins connect the intracranial venous dural sinuses with extracranial veins through various foramina and openings in the skull. Blood can flow in either direction in these veins, and they therefore constitute a major pathway for the intracranial extension of extracranial infection. The principal veins are the main emissary, the parietal emissary, the foramen ovale and foramen lacerum emissary, the internal carotid plexus, and the foramen cecum emissary.

Mastoid Emissary Vein. This vein runs through the mastoid foramen, connecting transverse sinus with the posterior auricular or occipital veins.

Parietal Emissary Vein. The parietal emissary vein passes through the parietal foramen, connecting the veins of the scalp with the superior sagittal sinus.

Foramen Ovale and Foramen Lacerum Emissary Veins. These connect the cavernous sinus with the pterygoid plexus.

Internal Carotid Plexus of Emissary Veins. This accompanies the carotid artery in the carotid canal, connecting the cavernous sinus with the internal jugular vein.

Foramen Cecum Emissary Vein. This vein connects the superior sagittal sinus with the veins of the nose.

Other Anastomoses. There are other important anastomoses between the dural venous sinuses and extracranial veins that are not classed in the strict sense as emissary veins. These include the superior ophthalmic vein and basilar plexus.

The Superior Ophthalmic Vein. This vein connects the facial and angular veins with the cavernous sinus.

Basilar Plexus. The basilar plexus connects the inferior petrosal sinus with the vertebral veins.

Clinical Considerations of Cerebral Circulation

Intracranial Hemorrhages

Extradural or Epidural Bleeding. This type of bleeding occurs between the dura and the skull and is almost always arterial. It is usually the result of traumatic disruption of the middle meningeal artery.

Subdural Bleeding. Subdural bleeding occurs between the dura and the arachnoid, a noncommunicating space, and is predominantly venous. It is frequently caused by trauma.

Subarachnoid Hemorrhage. Subarachnoid hemorrhage occurs between the arachnoid and pia and directly contaminates the cerebrospinal fluid. It is usually arterial, involving the cerebral vessels. It may be traumatic or spontaneous, frequently from rupture of a cerebral arterial aneurysm.

Cerebral Hemorrhage. Cerebral hemorrhage is arterial bleeding within the brain substance and is usually spontaneous.

Peripheral Nervous System

The peripheral nervous system carries impulses between the CNS and the other structures of the body. It is composed of nerve fibers, ganglia, and end organs. Because of the many different functions the peripheral nervous system subserves and the many different structures it supplies, it is subdivided into the afferents and efferents of both the somatic and visceral systems of fibers. For descriptive purposes, the peripheral nerves may be further subdivided into (1) the cranial nerves, (2) the spinal nerves, and (3) the autonomic nervous system.

Table 1. Outline of the Cranial Nerves

Nerves
- Components
- Function
- Central Connection
- Cell Bodies
- Peripheral distribution

I. Olfactory
- Afferent; Special visceral
- Smell
- Olfactory bulb and tract
- Olfactory epithelial cells
- Olfactory nerves

II. Optic
- Afferent; Special somatic
- Vision
- Optic nerve and tract
- Ganglion cells of retina
- Rods and cones of retina

III. Oculomotor
- Efferent; Somatic
- Ocular movement
- Nucleus III
- Nucleus III
- Branches to levator palpebrae; rectus superior, medius, inferior; obliquus inferior

- Efferent; General visceral
- Contraction of pupil and accommodation
- Nucleus of Edinger-Westphal
- Nucleus of Edinger-Westphal

Ciliary ganglion; ciliaris and sphincter pupillae

Afferent; Proprioceptive
Muscular sensibility
Nucleus mesencephalicus V
Nucleus mesencephalicus V
Sensory endings in ocular muscles

IV. Trochlear

Efferent; Somatic
Ocular movement
Nucleus IV
Nucleus IV
Branches to obliquus superior

Afferent proprioceptive
Muscular sensibility
Nucleus mesencephalicus V
Nucleus mesencephalicus V
Sensory endings in obliquus superior

V. Trigeminal

Afferent; General Somatic
General sensibility
Trigeminal sensory nucleus
Trigeminal ganglion (gasserian)
Sensory branches of ophthalmic, maxillary and mandibular nerves to skin and mucous membranes of face and head

Efferent; Special visceral
Mastication
Motor V nucleus
Motor V nucleus
Branches to temporalis, masseter, pterygoid, mylohyoid, digastric, tensores tympani and palatini muscles

Afferent; Proprioceptive
Muscular sensibility
Nucleus mesencephalicus V
Nucleus mesencephalicus V
Sensory endings in muscles of mastication

VI. Abducent

Efferent; Somatic

Ocular movement
Nucleus VI
Nucleus VI
Branches to rectus lateralis

VII. Facial

Efferent; Special visceral
Facial expression
Motor VII nucleus
Motor VII nucleus
Branches to facial muscles, stapedius, stylohyoid, digastric muscles

Efferent; General visceral
Glandular secretion
Nucleus salivatorius
Nucleus salivatorius
Greater petrosal nerve, pterygopalatine ganglion, with branches of maxillary V to glands of nasal mucosa, Chorda tympani, lingual nerve, submandibular ganglion, submandibular and sublingual glands

Afferent; Special visceral
Taste
Nucleus tractus solitarius
Geniculate ganglion
Chorda tympani, lingual nerve, taste buds, anterior tongue

Afferent; General visceral
Visceral sensibility
Nucleus tractus solitarius
Geniculate ganglion
Great petrosal, chorda tympani and branches

Afferent; General somatic
Cutaneous sensibility
Nucleus spinal tract of V
Geniculate ganglion
With auricular branch of vagus to external ear and mastoid region

VIII. Vestibulocochlear

Afferent; Special somatic
Hearing
Cochlear nuclei
Spiral ganglion

Organ of Corti in cochlea

Afferent; Proprioceptive
Sense of equilibrium
Vestibular nuclei
Vestibular ganglion
Semicircular canals, saccule, and utricle

IX. Glossopharyngeal
Afferent; Special visceral
Taste
Nucleus tractus solitarius
Inferior ganglion IX
Lingual branches, taste buds, posterior tongue

Afferent; General visceral
Visceral sensibility
Nucleus tractus solitarius
Inferior ganglion IX
Tympanic nerve to middle ear, branches to pharynx and tongue, carotid sinus nerve

Efferent; General visceral
Glandular secretion
Nucleus salivatorius
Nucleus salivatorius
Tympanic, lesser petrosal nerve, otic ganglion, with auriculotemporal V to parotid gland

Efferent; Special visceral
Swallowing
Nucleus ambiguus
Nucleus ambiguus
Branch to stylopharyngeus muscle

X. Vagus
Efferent; General visceral
Involuntary muscle and gland control
Dorsal motor nucleus X
Dorsal motor nucleus X
Cardiac nerves and plexus; ganglia on heart. Pulmonary plexus; ganglia, respiratory tract. Esophageal, gastric, celiac plexuses; myenteric and submucous plexuses, muscles and glands of digestive tract down to transverse colon

Efferent; Special visceral
Swallowing and phonation
Nucleus ambiguus
Nucleus ambiguus
Pharyngeal branches, superior and inferior laryngeal nerves

Afferent; General visceral
Visceral sensibility
Nucleus tractus solitarius
Inferior ganglion X
Fibers in all cervical, thoracic, and abdominal branches; carotid and aortic bodies

Afferent; Special visceral
Taste
Nucleus tractus solitarius
Inferior ganglion X
Branches to region of epiglottis and taste buds

Afferent; General somatic

Cutaneous sensibility
Nucleus spinal tract V
Superior ganglion X
Auricular branch to external ear and meatus

XI. Accessory
Efferent; Special visceral
Swallowing and phonation
Nucleus ambiguus
Nucleus ambiguus
Bulbar portion, communication with vagus, in vagus branches to muscles of pharynx and larynx

Efferent; Special somatic
Movements of shoulder and head
Lateral column of upper cervical spinal cord
Lateral column of upper cervical spinal cord
Spinal portion, branches to sternocleidomastoid and trapezius muscles

XII. Hypoglossal
Efferent; General somatic
Movements of tongue
Nucleus XII

Nucleus XII
Branches to extrinsic and intrinsic muscles of tongue.&

Cranial Nerves

Olfactory Nerve

The olfactory nerve is *entirely afferent* and subserves exclusively the sense of smell. It consists of a number of bundles of nerve fibers that are situated in the olfactory groove of the nasal cavity and are the central processes of special neuroepithelial cells in the mucous membrane of the upper reaches of the nose. The *olfactory cells* are bipolar cells scattered throughout the other nonspecialized, columnar, supporting epithelium. The peripheral process of these bipolar cells extends to the surface of the epithelial membrane, where it sends out a tuft of fine *olfactory hairs* beyond the surface. The central process extends through the basal lamina and joins the neighboring process to create a submucosal unmyelinated plexus. These finally unite into the 20 nerves, which pass through the opening in the cribriform plate as the *fila olfactoria.* These central processes terminate in the glomeruli of the olfactory bulb, synapsing here with the mitral and tufted cells. The mitral and tufted cells send their axons into the olfactory tract and end in the central olfactory areas.

Optic Nerve

This nerve of sight consists mainly of the axons of the cells in the ganglionic layer of the retina. These converge toward the optic disc, where they then gather into bundles and pierce the choroid and scleral coats through the multiple openings in the lamina cribrosa of the sclera. From this point centrally they are jointly known as the optic nerve. The nerve passes through the posterior portion of the orbit for a distance of 2 to 3 cm, and throughout this length it is covered by dura, arachnoid, and pia. It exits from the orbit through the optic foramen and then curves toward the midline to converge with the nerve of the opposite side as the optic *chiasm.* The optic chiasm resembles an X, with the optic nerves in front and the optic tracts behind. It rests upon the tuberculum sellae of the sphenoid bone and on the diaphragma sellae of the dura. Just posterior to it is the stalk of the hypophysis, and just lateral to it on each side are the internal carotid arteries. Within the optic chiasm, some of the fibers of the optic nerves cross and some remain uncrossed. Those fibers in the medial aspect of the nerve, which arise in the nasal half of the retina, cross at the chiasm; whereas the fibers in the lateral aspect of the nerve, which arise from the temporal half of the retina, remain uncrossed and continue on in the tract of the same side.

Because of its embryonic origin and structure, the optic nerve corresponds more to a central tract of brain fibers than to a peripheral cranial nerve. Embryologically, it develops from the lateral aspect of the forebrain. It is supported by neuroglia instead of Schwann cells and has meningeal coverings like those of the brain. Further, the optic nerve is actually a third order neuron of the brain from the actual receptors in the retina, the rods and the cones. Beyond the chiasm, the fibers continue in the diverging *optic tracts.* Most of the fibers of the optic tract end in the lateral geniculate body and are then relayed to the visual cortex and other lower nuclei, which mediate reflex responses to ocular stimuli.

The ganglion cells of the optic nerve are actually not the primary receptor cells of the retina but rather are connected through the layers of the retina with the actual receptor cells, the *rods* and *cones,* by numerous bipolar cells.

Oculomotor Nerve

The oculomotor nerve is primarily a somatic motor nerve. It also carries parasympathetic fibers to the ciliary ganglion and some afferent proprioceptor fibers from the ocular muscles. It supplies the levator palpebrae superioris muscle, all the extrinsic ocular muscles except the superior oblique and lateral rectus, and all the intrinsic muscles except the dilator pupillae.

The somatic motor fibers arise in the oculomotor nucleus in the midbrain just ventral to the cerebral aqueduct and are both crossed and uncrossed. The fibers pass ventrally to emerge from the oculomotor sulcus medial to the cerebral peduncle in the posterior fossa. The nerve then passes forward to pierce the dura of the lateral wall of the cavernous sinus. After traversing the lateral wall of the cavernous sinus, it passes forward into the superior orbital fissure and divides into *superior* and *inferior divisions.* The superior division passes mediad, sending branches to the *superior rectus* and the *levator palpebrae superioris muscles.* The inferior division supplies the *medial* and *inferior recti muscles* and the *inferior oblique muscle.* It also sends a *root* to the ciliary ganglion.

The parasympathetic fibers arise in the *autonomic nucleus of the oculomotor nerve,* which is just rostral and dorsal to the somatic motor nucleus and is known as the *Edinger-Westphal nucleus.* Its fibers remain uncrossed and join the inferior division in the superior orbital fissure and enter the ciliary ganglion as its preganglionic fibers. The vast majority of these fibers are for the innervation of the ciliary muscle of the iris, while only a few are for the pupillary sphincter muscles.

The *ciliary ganglion* is a small parasympathetic ganglion that lies in the orbit about 1 cm anterior to the optic foramen near the lateral aspect of the optic nerve. Its preganglionic fibers enter the *root* of the ciliary ganglion from the inferior division of the oculomotor nerve; its postganglionic fibers pass out through the *short ciliary nerves* to innervate the ciliary muscle of the iris and the pupillary sphincter muscle. The ciliary ganglion receives two important *communications:* (1) one from the *nasociliary nerve,* carrying sensory fibers from the fifth nerve to the cornea, iris, and ciliary body; and (2) one with the *sympathetics* from the cavernous plexus, which innervate the pupillary dilator muscle and the blood vessels of the globe. These communications pass directly through the ganglion without synapsing with the ganglion cells and join the *short ciliary nerves* to the globe.

The branches of the ciliary ganglion are 8 to 10 *short ciliary nerves* that pass forward into the globe along with the long ciliary nerves from the nasociliary.

The proprioceptor fibers in the oculomotor nerve are probably from the mesencephalic nucleus of the fifth nerve.

The cortical fibers controlling eye movement end mostly in the nuclei of the reticular substance of the midbrain where conjugate movements of the eyes are integrated. Internuncial neurons then carry these cortical impulses to the nuclei of the eye muscles. The eye muscle nuclei also receive connections through the medial longitudinal fasciculus from the vestibular nuclei (crossed and uncrossed), from various other nuclei of the reticular formation, from interconnections between eye muscle nuclei and nuclei controlling head and neck movements, from proprioceptors in the cervical cord, and from the superior colliculi.

The superior colliculus is the center for coordination of eye movements. It receives (1) fibers from the optic tract; (2) sensory fibers from the spinal cord through the spinotectal tract; (3) sensory fibers from the trigeminal nerve; (4) auditory fibers from the lateral lemniscus for reflex movements of the eyes in response to sound; (5) fibers from the visual cortex through corticotectal tracts; and (6) fibers from the thalamic nuclei for primary and cortical olfactory associations. The descending efferent fibers of the superior colliculus cross mostly in the *fountain decussation of Meynert* in the dorsal portion of the tegmentum and continue caudally as the tectobulbar and tectospinal tracts. The tectobulbar tracts give off connections to the eye muscle nuclei and to the nucleus of the facial nerve. The tectospinal tracts connect with the ventral horn cells of the spinal cord, especially the cervical cord, to coordinate head and neck movements with eye movements.

Trochlear Nerve

The trochlear nerve is a somatic motor nerve that innervates the *superior oblique muscle* of the eye. It arises in the midbrain from the trochlear nucleus, which is just ventral to the cerebral aqueduct, adjacent to the midline, and at the level of the inferior colliculus. The fibers curve dorsad and cross to the opposite side in the roof of the cerebral aqueduct as it becomes the fourth ventricle. It then emerges just lateral to this dorsal decussation and just posterior to the inferior colliculus. It runs forward and pierces the dura along the lateral border of the cavernous sinus. It continues forward through the cavernous sinus and enters the orbit through the superior orbital fissure. It then courses medially and enters the superior oblique muscle.

In the wall of the cavernous sinus the trochlear nerve forms connections with the cavernous plexus of sympathetics and with the ophthalmic division of the fifth nerve.

Trigeminal Nerve

The trigeminal nerve is the largest of all the cranial nerves. It is the great sensory nerve for the skin of the face and the mucous membranes and other internal structures of the head; it is also the motor nerve for the muscles of mastication. It contains proprioceptive fibers.

The sensory nucleus of the fifth nerve is quite extensive. It has a large rostral head, the *main sensory nucleus*, and a tapering caudal portion, the *spinal tract*, which is continuous with the substantia gelatinosa (of Rolando) of the spinal cord. The main sensory nucleus is primarily for discriminative sense, whereas the spinal tract is primarily a sensory nucleus for pain and temperature.

The main sensory nucleus receives its afferents from the semilunar ganglion, called the sensory root, through the lateral part of the ventral surface of the pons. Its axons then cross to the opposite side and ascend to the thalamic nuclei where they are then relayed to the postcentral cerebral cortex. The descending sensory root fibers from the semilunar ganglion course through the pons and medulla in the spinal tract of the fifth nerve and end in nuclei of this tract as far down as the second cervical segment. The axons of these spinal tract nuclei cross to the opposite side and ascend to the thalamic nuclei in the spinothalamic tract and are relayed from there to the cerebral cortex. The sensory trigeminal nuclei also have many connections with the motor nuclei of the pons and medulla. In addition to receiving the sensory fibers of the trigeminal nerve, the descending tract probably also receives the somatic sensory fibers of the vagus, glossopharyngeal, and facial nerves.

The proprioceptor fibers of the trigeminal nerve arise in the muscles of mastication and probably also in the extraocular muscles. They terminate in the *mesencephalic root of the fifth nerve.* These mesencephalic root cells form collaterals with the motor nuclei of the nerve.

The *motor nucleus* lies near the lateral angle of the fourth ventricle in the rostral part of the pons. It receives cortical fibers for voluntary motor control from the pyramidal tracts, mostly crossed, but some uncrossed. It also receives reflex input from the sensory nucleus and the mesencephalic root of the fifth nerve. The axons emerge from the lateral aspect of the pons as the *motor root* just anterior to the sensory root and pass anterior with the sensory root to the semilunar ganglion.

Trigeminal Ganglion (Semilunar Ganglion; Gasserian Ganglion)

It is the great sensory ganglion of the fifth nerve that contains the cell bodies of the sensory fibers of the three main divisions of the trigeminal nerve. The ganglion lies within folds of dura, known as Meckel's cave, and sits in the trigeminal impression in the petrous apex. Anteriorly, it receives the three large sensory divisions: ophthalmic, maxillary, and mandibular. The central sensory root fibers leave the posterior aspect of the ganglion to pass to their insertion into the pons. The motor root fibers pass beneath the ganglion, between it and the petrous bone, and join the sensory mandibular division as it exits from the skull through the foramen ovale. The ganglion also receives sympathetic filaments from the carotid plexus and gives out small branches to the dura.

Accessory ganglia of the trigeminal nerve consist of several small parasympathetic ganglia and are anatomically, but not functionally, associated with the trigeminal nerve. They are (1) the ciliary ganglion with the ophthalmic nerve, which actually receives its preganglionic fibers from the oculomotor nerve; (2) the pterygopalatine (sphenopalatine) with the maxillary nerve, which receives its fibers from the facial nerve; and (3) the otic and submandibular ganglia with the mandibular nerve, which receive their fibers from the glossopharyngeal and facial nerves, respectively.

Ophthalmic Nerve. The ophthalmic nerve courses anteriorly from the gasserian ganglion in the dura of the lateral wall of the cavernous sinus. It receives sympathetic filaments from the cavernous plexus and also communicating branches from the third, fourth, and fifth nerves. Just before it exits from the skull in the superior orbital fissure, it gives off a branch to the dura and then divides into three branches: frontal, lacrimal, and nasociliary.

Frontal Nerve. The frontal nerve is the largest branch of the ophthalmic nerve. It courses between the levator palpebrae superioris and the periorbita, and about halfway through the orbit it divides into a large supraorbital and a small supratrochlear branch.

Supraorbital Nerve. The supraorbital nerve leaves the orbit through the supraorbital notch or foramen. It sends branches to the upper lid and then turns upward over the forehead beneath the frontalis muscle, dividing into medial and lateral branches. These nerves supply the scalp as far back as the lambdoid suture.

Supratrochlear Nerve. The supratrochlear nerve passes medially in the orbit, gives off branches to the conjunctiva and upper lid, and then exits from the orbit deep to the frontalis and corrugator muscles to supply the skin of the lower and medial part of the forehead.

Branch to the Frontal Sinus. This nerve pierces the floor of the frontal sinus in the supraorbital notch and supplies the mucous membrane of the frontal sinus.

Lacrimal Nerve. The lacrimal nerve passes through the lateral, narrow portion of the superior orbital fissure and courses between the rectus lateralis and the periorbita to the lacrimal gland. It gives off branches to the gland and to the conjunctiva before piercing the orbital fascia to supply the skin of the upper lid.

In the orbit, the lacrimal nerve receives a communication from the zygomatic branch of the maxillary nerve, which carries postganglionic parasympathetic secretory fibers from the sphenopalatine ganglion to the lacrimal gland. The preganglionic fibers for lacrimation reach the sphenopalatine ganglion via the greater petrosal and vidian nerves from the seventh nerve.

Nasociliary Nerve. The nasociliary nerve, after entering the orbit through the superior orbital fissure, passes to the medial wall of the orbit. Here, it passes through the anterior ethmoid foramen as the *anterior ethmoidal nerve,* entering the intracranial cavity just above the cribriform plate. It then runs forward along the cribriform plate and finally drops down into the nasal cavity through a slit alongside the crista galli. Here, along with its intranasal branches, it supplies the mucous membrane of the upper and anterior part of the nasal septum, the lateral wall of the nose, and the frontal and anterior ethmoidal sinuses. It then slips downward between the nasal bone and the upper lateral cartilage to emerge as the *external nasal branch,* which supplies the skin of the ala and nasal tip.

As the nasociliary nerve enters the orbit, it gives off a *communicating branch to the ciliary ganglion,* which carries sensory fibers right through the ganglion to the globe without synapsing. It supplies sensation to the cornea, iris, and ciliary body.

The *long ciliary nerves* are two or three in number and are also given off by the nasociliary nerve toward the back of the orbit. They course with the short ciliary nerves from the ciliary ganglion to the back of the globe, where they pierce the sclera and pass forward to the iris and cornea, giving sensation to these parts. Also, from the cavernous plexus they carry sympathetic filaments, which innervate the pupillary dilator muscle.

Prior to entering the anterior ethmoidal foramen, two more branches are given off, the *posterior ethmoidal nerve* and the *infratrochlear nerve.* The posterior ethmoidal passes through the posterior ethmoidal foramen and supplies the posterior ethmoidal and sphenoid sinuses. The infratrochlear nerve passes forward to the medial angle of the eye to supply the skin of the lids and the side of the nose, the conjunctiva, and the lacrimal sac.

The Maxillary Nerve. The maxillary division of the trigeminal nerve, like the ophthalmic, is also entirely sensory. It supplies the middle third of the face and the mucous membranes of the upper portions of the mouth and pharynx, the maxillary sinus, as well as the upper teeth. As it leaves the semilunar ganglion anteriorly, it passes forward in the dura of the lower lateral wall of the cavernous sinus, then forward under the dura to reach the foramen rotundum, through which it exits from the cranial cavity. It then crosses the pterygopalatine fossa to enter the inferior orbital fissure where it becomes the *infraorbital nerve.* In the posterior part of the orbit, it lies in the infraorbital groove, but anteriorly it enters the infraorbital canal. It emerges on the face of the maxilla from the infraorbital foramen and divides into several branches which supply the skin of the cheek, nose, lower eyelid, and upper lip.

Prior to entering the foramen rotundum, a dural branch is given off, called the *middle meningeal nerve,* which accompanies the middle meningeal artery. In the pterygopalatine fossa, three major branches are given off: *zygomatic nerve, pterygopalatine (sphenopalatine) nerves,* and *posterior superior alveolar nerves.*

Zygomatic Nerve. The zygomatic nerve enters the orbit through the inferior orbital fissure and divides into the *zygomaticotemporal* and *zygomaticofacial branches.* The zygomaticotemporal branch runs along the lateral wall of the orbit. Here, it gives off a communication to the lacrimal nerve, which carries postganglionic parasympathetic fibers from the sphenopalatine ganglion for lacrimation. It then leaves the orbit through a small foramen to enter the temporal fossa, where it finally pierces the temporal fascia an inch above the zygomatic arch to innervate the skin of the side of the forehead. The zygomaticofacial branch courses more inferiorly in the orbit and then traverses the zygomatic bone to emerge on the cheek, where it supplies the skin of that area.

Pterygopalatine (Sphenopalatine) Nerves. These are two short trunks, which unite the *sphenopalatine ganglion* with the maxillary division of the trigeminal nerve. They transmit mostly afferent sensory fibers of the maxillary nerve from the nose, palate, and pharynx, which pass through but do not synapse in the ganglion. They also carry important postganglionic parasympathetic secretory fibers from the ganglion to the maxillary nerve, where they pass in a retrograde fashion for a short distance to the zygomatic nerve, out of which they flow to the lacrimal nerve and lacrimal gland. The preganglionic fibers are derived from the seventh nerve via the grater petrosal and vidian nerves. In addition to giving off secretory fibers to the lacrimal gland, the sphenopalatine ganglion also sends postganglionic secretory fibers to the glands of the nasal cavity, pharynx, and palate through other branches of the pterygopalatine nerves. Sympathetic fibers also pass through the ganglion without synapsing and are derived from the carotid plexus and pass to the ganglion via the deep petrosal and vidian nerves. They pass on to the nose and palate through branches of the pterygopalatine nerves.

Branches of the Sphenopalatine Nerves

Orbital

1. Filaments to the periosteum of orbit through the inferior orbital fissure.

2. Sphenoethmoidal fibers, which supply the mucous membrane of the posterior ethmoidal and sphenoid sinuses.

Greater Palatine Nerve. The greater palatine nerve descends through the pterygopalatine canal and emerges upon the posterior aspect of the hard palate through the greater palatine foramen. It divides into several branches and passes forward to supply the mucosa of the hard palate. In its descending portion in the pterygopalatine canal, it usually gives off *posterior inferior nasal branches,* which supply the posterior aspects of the inferior turbinate and middle and inferior meatus. It also gives off lesser *palatine nerves,* which emerge from the lesser palatine foramen and disperse over the soft palate, uvula, and tonsil.

Posterior Superior Nasal Branches. These branches enter the posterior part of the nasal cavity through the sphenopalatine foramen and supply the mucous membrane of the superior and middle turbinates, the posterior ethmoidal sinuses, and the posterior part of the nasal septum.

Pharyngeal Branch. The pharyngeal branch passes through the pharyngeal canal to the nasopharynx posterior to the eustachian tube.

Posterior Superior Alveolar Nerves. These are usually two in number and supply the mucosa and gums of the posterior cheek and alveolar ridge. They enter the posterior alveolar canals and send twigs to each molar tooth.

In the infraorbital canal two additional alveolar branches are given off, the *middle* and *anterior superior alveolar nerves.* The middle superior nerve supplies the two premolar teeth and the anterior superior nerve supplies the incisor and canine teeth. It also gives off a nasal branch that supplies the inferior meatus and the floor of the nose anteriorly. The nerves descend from the infraorbital canal in the wall of the maxillary antrum. All the alveolar nerves form a superior dental plexus.

Mandibular Nerve. The mandibular nerve is the third division of the trigeminal nerve and the largest of the three divisions. It has mixed motor and sensory fibers. The motor fibers innervate the following muscles: (1) muscles of mastication, (2) mylohyoid, (3) anterior belly of digastric, (4) tensor tympani, and (5) tensor veli palatini.

The sensory fibers supply the skin of the lower one-third of the face and the temporal region, the anterior ear, and the external auditory canal; the mastoid air cells; the mucous membranes of the cheek, tongue, and floor of the mouth; the lower gums and teeth; the mandible and temporomandibular joint; and part of the dura and skull.

Just below the foramen ovale the *otic ganglion* lies close to the medial surface of the nerve and is connected by several communications with branches of the mandibular nerve.

The branches of the main trunk of the mandibular nerve are: (1) recurrent meningeal, (2) medial pterygoid, (3) masseteric, (4) deep temporal, (5) lateral pterygoid, (6) buccal, (7) auriculotemporal, (8) lingual, and (9) inferior alveolar.

Recurrent Meningeal Branch. This branch supplies the dura and enters the skull through the foramen spinosum with the artery.

Medial Pterygoid Nerve. This nerve supplies the medial pterygoid muscle after passing through the otic ganglion without synapsing. It also gives off branches to the tensor veli palatini muscle and the tensor tympani muscle, which also pass without synapsing through the otic ganglion.

Masseteric Nerve. The masseteric nerve passes through the mandibular notch to innervate the masseter muscle. It also sends a twig to the temporomandibular joint.

Deep Temporal Nerves. These nerves are usually two in number, the anterior and posterior, and supply the temporalis muscle.

Lateral Pterygoid Nerve. This nerve supplies the lateral pterygoid muscle.

Buccal Nerve. The buccal nerve passes between the two heads of the lateral pterygoid muscle and beneath the anterior border of the masseter muscle. It divides into upper temporal and lower buccinator branches, which are entirely sensory to the skin of the cheek and the mucous membranes of the mouth and gums.

Auriculotemporal Nerve. The auriculotemporal nerve usually begins as two roots, which encircle the middle meningeal artery near the base of the skull. It then runs as a single trunk posteriorly and laterally to the medial aspect of the neck of the mandible and emerges superficially between the ear and the condyle of the mandible deep to the parotid gland. It continues superiorly with the superficial temporal artery over the root of the zygomatic arch and divides into superficial temporal branches. The auriculotemporal nerve has important communications and branches from the standpoint of the otolaryngologist:

Communications with the facial nerve in the parotid gland accompany the facial fibers to supply the skin over the facial muscles.

Communications with the otic ganglion join the roots of the auriculotemporal nerve near the base of the skull and contain postganglionic parasympathetic fibers carrying secretory impulses to the parotid gland. The preganglionic fibers to the otic ganglion are supplied by the ninth nerve through the lesser petrosal nerve.

Anterior auricular branches supply the helix and tragus of the ear.

External auditory meatus branches enter the canal through the bony-cartilaginous junction and supply the skin of the canal and part of the tympanic membrane.

Articular branches supply the temporomandibular joint.

Parotid branches carry the postganglionic secretory fibers to the parotid gland.

Lingual Nerve. The lingual nerve runs parallel to the inferior alveolar nerve and is joined by the chorda tympani nerve near the maxillary artery. It courses forward and medially between the hyoglossus muscle and the deep portion of the submandibular gland alongside the tongue. As it passes forward beneath the floor of the mouth, it crosses over the submandibular duct to run lateral to it immediately beneath the mucous membrane. Here, it is vulnerable to injury in dissections of the duct, either from within the mouth or through an external approach. The most important communications of the lingual nerve are the chorda tympani nerve and the submandibular ganglion. The chorda tympani nerve carries preganglionic parasympathetic secretory fibers destined for the submandibular and sublingual glands via the submandibular ganglion. The chorda tympani also carries special sensory fibers supplying taste to the anterior two-thirds of the tongue. The communications of the lingual nerve with the submandibular ganglion are several short roots that carry pre- and postganglionic secretory fibers for the submandibular and sublingual glands. The ganglion lies in close proximity to the submandibular gland. Besides secretory and taste fibers, which the lingual nerve carries from the chorda tympani nerve, it supplies its own important sensory fibers to the mucous membranes of the anterior two-thirds of the tongue, the floor of the mouth, and the gums.

Inferior Alveolar Nerve. The inferior alveolar nerve accompanies the inferior alveolar artery into the mandibular foramen on the medial aspect of the ascending ramus of the mandible.

It continues in the mandible through the mandibular canal to the mental foramen, where it divides into terminal branches.

Branches of the Inferior Alveolar Nerve

Mylohyoid Nerve. The mylohyoid nerve leaves the inferior alveolar nerve just before the latter enters the mandibular foramen. It then passes downward and forward in a deep groove on the medial surface of the mandible to reach the mylohyoid muscle. It supplies motor fibers to the mylohyoid muscle and also to the anterior belly of the digastric muscle.

Dental Branches. The dental branches arise from the intracanalicular portion of the nerve and supply the molar and premolar teeth.

Incisive Branch. This is one of the terminal branches at the mental foramen, which continues anteriorly within the bone to supply the canine and incisor teeth.

Mental Nerve. The mental nerve is the other terminal branch, which exits through the mental foramen to supply the lower lip and chin.

Abducent Nerve

The abducent nerve supplies motor innervation to the lateral rectus muscle of the eye. It also probably contains proprioceptive fibers to the mesencephalic nucleus of the fifth nerve. Its main motor nucleus lies close to the floor of the fourth ventricle. The motor fibers pass ventrolaterally to emerge in the furrow between the inferior border of the pons and the superior end of the pyramid of the medulla. It passes forward to pierce the dura at the dorsum sellae of the sphenoid bone. It then passes below the posterior clinoid process to enter and traverse the cavernous sinus and finally to enter the orbit through the superior orbital fissure. It enters the medial aspect of the lateral rectus muscle after passing through the two heads of the muscle.

The abducent nucleus receives voluntary impulses via the corticobulbar tracts and has rich reflex connections with the medial longitudinal fasciculus and other tracts and nuclei of the brain stem and spinal cord similar to the oculomotor and trochlear nuclei.

Facial Nerve

The facial nerve has two roots, the larger being the main motor root that supplies the facial muscles, and the smaller being the *nervus intermedius* (nerve of Wrisberg), which contains special sensory fibers of taste from the tongue, and parasympathetic secretomotor fibers to the submandibular and sublingual salivary glands, the nasal and palatine glands, and the lacrimal gland. In addition, the seventh nerve carries a few general somatic and visceral afferent fibers. The somatic afferent join the auricular branch of the vagus to supply sensation to the external acoustic meatus. The cell bodies of these fibers are in the geniculate ganglion and centrally they probably end in the spinal tract of the fifth nerve. The visceral afferents probably innervate the mucous membranes of the nose, palate, and pharynx through the greater petrosal nerve. They also have their cell bodies in the geniculate ganglion and connect centrally with the tractus solitarius.

The main motor nucleus of the seventh nerve lies deep in the reticular formation of the pons just rostral to the nucleus ambiguus of the tenth nerve. Its axons pass dorsally and continue dorsomedially to the floor of the fourth ventricle, where they turn sharply to run for a short distance in a rostral direction dorsal to the medial longitudinal fasciculus and medial to the abducent nucleus. The fibers then make an abrupt turn laterally to arch over the abducent nucleus, producing an elevation in the floor of the fourth ventricle called the facial colliculus. This part of the facial nerve, which arches abruptly over the sixth nerve nucleus, is known as the internal genu of the nerve. From this genu, the axons pass ventrolaterally and also slightly caudad to emerge from the brain stem at the caudal border of the pons in a recess between the olive and inferior cerebellar peduncle.

The primary central connections of the motor cells of the facial nucleus are with the corticobulbar fibers of the aberrant pyramidal tracts. The corticobulbar fibers reaching the motor nuclei of the lower part of the face are entirely crossed, whereas those connecting with the cells of the upper part of the face are both crossed and uncrossed. This difference in the corticobulbar fibers supplying the upper and lower facial muscles accounts for the sparing of the forehead movements in supranuclear lesions of the seventh nerve. The main motor nucleus also has many reflex connections with other cranial nerve nuclei, namely the fifth and eight, and with other nuclei of the reticular formation of the pons and medulla. Emotional facial expression is largely mediated through these latter reticular reflex connections.

The parasympathetic secretory fibers of the nervus intermedius arise from cell bodies in the superior olivary nucleus, which is dorsomedial to the facial nucleus. These fibers are preganglionic and are distributed to the submandibular ganglion via the chorda tympani nerve for innervation of the submandibular and sublingual glands, and to the sphenopalatine ganglion via the greater petrosal nerve for innervation of the lacrimal, nasal, and palatine glands.

Taste fibers from the anterior two-thirds of the tongue reach their cell bodies in the geniculate ganglion via the chorda tympani nerve and connect centrally with the nucleus of the tractus solitarius. This nucleus has reflex connections with the salivary nucleus, the nucleus ambiguus and dorsal nucleus of the vagus, and the hypoglossal nucleus, and with spinal cord nuclei through the reticulospinal tract.

Both the motor and intermediate roots exit from the brain stem at the posterior border of the pons and pass laterally with the acoustic nerve into the internal acoustic meatus, the motor root of the facial being more medial, the acoustic being lateral, and the intermedius being in between the two. At the lateral extremity of the internal auditory canal, the facial and intermediate nerves separate from the acoustic nerve and enter the bony facial canal (fallopian canal). The nerve continues laterad in the first part of the fallopian canal between the cochlea and semicircular canals to reach the anterosuperior part of the medial wall of the tympanic cavity. Here, it turns sharply posterior to run horizontally along the medial wall of the middle ear just above the oval window. As the nerve makes its sharp bend posteriorly at the upper anterior aspect of the medial wall of the middle ear, the nerve becomes swollen as it incorporates the geniculate ganglion. This sharp posterior bend is sometimes called the *geniculum.*

Just posterior to the oval window and beneath the overhanging horizontal semicircular canal, the facial nerve again makes a very distinct turn, this time in a downward direction. It then courses downward in a vertical direction just posterior to the posterior bony tympanic annulus and exits through the stylomastoid foramen just medial to the mastoid tip and posterior to the styloid process. As the nerve emerges from the stylomastoid foramen, it passes lateral to the root of the styloid process in an anterior direction to enter the parotid gland. Within the gland, it shortly divides into its two primary divisions, the upper temporofacial division and the lower cervicofacial division. Each of these divisions breaks up into several terminal branches that interconnect with each other in a plexiform arrangement, usually within the substance of the parotid gland but sometimes anterior to the gland. These terminal facial branches innervate the various facial and scalp muscles.

The myelinated axons of the facial nerve are gathered into fascicles. The intratemporal facial nerve can be divided into anatomic segments: the meatal segment extends from the brain stem to the internal acoustic meatus; the labyrinthine segment extends from the meatal segment to the exit of the superficial petrosal nerve; and the tympanic segment extends from the labyrinthine segment (distal to the geniculate to where the nerve turns inferiorly and becomes the mastoid segment). The arrangement of fascicles in the facial nerve caries with the particular segment. There is a single fascicle in the meatal, labyrinthine, and tympanic segments. This then divides into two or three separate fascicles in the distal mastoid portion and six to ten fascicles in the temporal portion.

Branches of the Facial Nerve

From the Geniculate Ganglion

Greater Petrosal Nerve. This branch leaves the geniculate ganglion anteriorly, passing for a short distance in the anterior part of the petrous bone before emerging through the hiatus of the facial canal into the middle cranial fossa. It passes beneath the dura in a groove on the anterior surface of the petrous apex and runs rostrally to the foramen lacerum, where it joins with the deep petrosal nerve to form the *nerve of the pterygoid canal* or the *vidian nerve.* The vidian nerve traverses the pterygoid canal and, upon exiting, crosses the pterygopalatine fossa to enter the sphenopalatine ganglion.

The greater petrosal nerve is a mixed nerve, containing sensory and parasympathetic fibers. The parasympathetics are preganglionic secretomotor fibers from the nervus intermedius, which pass through the geniculate ganglion without synapsing. They connect with postganglionic fibers in the sphenopalatine ganglion, which ultimately innervate the lacrimal, nasal, palatine, and pharyngeal glands. The bulk of the greater petrosal nerve consists of sensory fibers that take origin from cell bodies within the geniculate ganglion and are distributed to the soft palate through the lesser palatine nerves. A few sensory filaments are given off to the eustachian tube.

Branches within the Fallopian Canal

Nerve to the Stapedius Muscle. This nerve arises from the facial nerve as it begins its vertical course in the posterior aspect of the middle ear. The stapedial branch reaches the muscle through a small opening in the base of the pyramid.

Chorda Tympani Nerve. The chorda tympani nerve arises from the vertical portion of the facial nerve in the mastoid, just before it exits from the stylomastoid foramen. As the chorda arises about 6 mm from the stylomastoid foramen, it passes craniadad in the opposite direction of the facial nerve, paralleling the facial nerve for a distance in the posterior wall of the middle ear and then diverging to emerge through a small aperture (*iter chordae posterius*) between the base of the pyramid and the bony tympanic annulus. It then courses anteriorly across the lateral aspect of the tympanic membrane, crossing the neck of the malleus, and exits anteriorly through the *iter chordae anterius.* It traverses the *canal of Huguier* in the petrotympanic fissure and emerges from the skull on the medial surface of the spine of the sphenoid bone. It then joins the lingual nerve between the internal and external pterygoid muscles. The majority of the fibers of the chorda tympani nerve are special afferents for taste, which have their cell bodies in the geniculate ganglion and which are distributed to the anterior two-thirds of the tongue. The chorda also contains preganglionic parasympathetic secretory fibers, which end by synapsing in the submandibular ganglion and which carry impulses destined for the submandibular and sublingual salivary glands as well as other minor salivary glands and mucous glands in the floor of the mouth.

Submandibular Ganglion. This is a 3 to 4 mm ganglion lying just above the deep lobe of the submandibular gland of the hyoglossus muscle near the posterior border of the mylohyoid muscle. It is suspended from the lingual nerve by two 0.5 cm nerve filaments. These connecting filaments carry both parasympathetic and sympathetic fibers to and from the ganglion. The proximal communicating filament consists mainly of preganglionic secretory parasympathetics, which join the lingual nerve from the nervus intermedius via the chorda tympani. In the submandibular ganglion, these preganglionic fibers synapse with cell bodies whose postganglionic fibers pass directly into the submandibular gland. Some pass back to the lingual nerve through the distal communicating filament and are distributed along with the peripheral branches of the lingual nerve to the sublingual glands and other minor salivary glands in the floor of the mouth.

The submandibular ganglion also receives some sympathetic communication from the sympathetic plexus accompanying the facial artery, but these pass through the ganglion without synapsing.

A few visceral afferent fibers also pass through the ganglion en route to their cell bodies in the geniculate ganglion via the lingual and chorda tympani nerves. They have no synapses in the submandibular ganglion.

Branches of the Facial Nerve in the Face and Neck

Posterior Auricular Nerve. This nerve supplies the posterior auricular muscle, the muscles of the posterior aspect of the pinna, and the occipital muscle. It leaves the facial nerve just outside the stylomastoid foramen and runs upward between the external auditory meatus and the mastoid tip and thence to its muscles of distribution.

Digastric Branch. The digastric branch also arises close to the stylomastoid foramen and supplies the posterior belly of the digastric muscle.

Stylohyoid Branch. The stylohoid branch innervates the stylohyoid muscle and arises near, or in conjunction with, the digastric branch.

Parotid Plexus. The most peripheral part of the facial nerve becomes a plexiform branching of the nerve within the substance of the parotid gland, the ultimate terminals of which supply somatic motor innervation to the facial muscles. The main trunk of the facial nerve divides into *temporofacial* and *cervicofacial divisions,* which, in turn, subdivide into the specific branches that innervate the various facial muscles. Five main subdivisions are usually identifiable.

Temporal Branches. The temporal branches are the uppermost branches, which cross the zygomatic arch and supply the anterior and the superior auricular muscles, the frontalis, the orbicularis oculi, and the corrugator.

Zygomatic Branches. Zygomatic branches also arise from the temporofacial division and run parallel to the zygomatic arch to innervate the orbicularis oculi. The lower branches often join with the buccal branches to form an infraorbital plexus, which innervates the muscles of the midface.

Buccal Branches. The main buccal branch may arise from either the temporofacial division or the cervicofacial division. Its branches usually communicate freely with the zygomatic branches above and the mandibular branches below, innervating the muscles of the midface, including the procerus, orbicularis oculi, zygomaticus, levator anguli oris, levator labii superioris, buccinator, orbicularis oris, nasalis, and depressor septi.

Mandibular Branch. This branch usually dips inferior to the horizontal ramus of the mandible and deep to the platysma as it runs forward to innervate the depressor anguli oris, orbicularis oris, depressor labii inferioris, mentalis, and risorius.

Cervical Branch. The cervical branch is the lowest branch from the cervicofacial division and runs deep to the platysma muscle, which it innervates.

Acoustic Nerve

The acoustic nerve consists of two distinct sets of fibers, the cochlear and the vestibular. The peripheral portions of the cochlear and vestibular nerves join to form the common acoustic nerve at the lateral portion of the internal auditory canal, where they are also joined by the facial nerve in the internal auditory canal.

Cochlear Nerve

Ascending Auditory Pathways. This pathway is also referred to as the classic or projective system or the afferent acoustic pathway. It transmits impulses from the organ of Corti to the auditory cortex.

The receptor cells are the hair cells that lie along the entire length of the organ of Corti in the cochlear duct. Unmyelinated nerve fibers pass from the hair cells to the bony modiolus of the cochlea, where the fibers become myelinated. After a short course in the modiolus, the peripheral process joins its cell body located in the *spiral ganglion.* This is the first of four neurons between the cochlea and the cerebrum. From the ganglion cells, the central fibers of these bipolar neurons enter the internal acoustic meatus to be joined by the fibers from the vestibular division of the eight nerve. They traverse the auditory canal and meatus and enter the posterior cranial fossa, where they immediately enter the brain stem in the cerebellopontine angle.

After entering the brain stem, the cochlear fibers divide into two main bundles. One group passes lateral and dorsal to the restiform body to terminate in the dorsal cochlear nucleus. The other group remains slightly ventral and medial to the restiform body and ends in the ventral cochlear nucleus. It has been found that the fibers coming from the basal coils of the cochlea terminate in the dorsal part of the dorsal cochlear nucleus. Those fibers arising in the apical coils end in the ventral part of the dorsal cochlear nucleus and in the ventral nucleus. However, some fibers pass to higher order neurons farther along the pathway before they synapse.

The cell bodies of the second order neurons lie in the dorsal and ventral cochlear nuclei. The axons from these cells follow two alternate pathways, the direct route and the indirect relay circuit (Fig. 17). By the direct route, fibers from the ventral cochlear nucleus, and perhaps most of the fibers from the dorsal cochlear nucleus that cross through the dorsal and intermediate trapezoid bodies, bend rostrally and continue in the lateral lemniscus of the other side. They do not terminate in the superior olivary nucleus but continue on directly to the medial geniculate body of the thalamus, bypassing the inferior colliculus. It is believed that the uncrossed fibers from the dorsal nucleus, which pass in the ipsilateral lemniscus, also go directly to the medial geniculate body.

The indirect relay circuit begins in the ventral cochlear nucleus, the axons passing medially in the ventral trapezoid body, with some of them terminating in the nucleus of that body where a third order neuron arises. The superior olive is an important relay station, receiving fibers from both of the cochlear nuclei and from the nucleus of the trapezoid body. From the olives, fibers ascend in the lateral lemniscus, some synapsing in its nucleus and others continuing on to the inferior colliculus. Some of these fibers probably reach the medial geniculate body without synapsing in the inferior colliculus. From the inferior colliculus, the fibers eventually terminate in the medial geniculate nucleus of the thalamus. This nucleus is divided into a small ventral and a large dorsal portion. It is the latter that receives most of the auditory impulses directed toward the cortical level.

The cell bodies of the fourth order neurons are located in the dorsal parts of the medial geniculate body. Their axons, called auditory radiations or the geniculotemporal tract, pass laterally to terminate in the transverse temporal gyri of the cerebral hemispheres. Tones of different frequencies have specific reception areas in the auditory cortex.

The ascending auditory pathways make numerous connections with nuclei throughout the central nervous system as part of a complex auditory reflex system (Fig. 18).

Descending Auditory Pathways. Besides the conscious and reflex afferent auditory pathways, there are also descending efferent auditory pathways. The descending pathways, in general, have an inhibiting effect upon the ascending fibers and thereby tend to provide some degree of self-regulation to the auditory system. Each relay station of the auditory pathway has been considered to be dually innervated, thus providing a way for incoming impulses to be internally influenced, negated, or modified.

The Vestibular Nerve

The vestibular nerve arises from bipolar cells in the vestibular ganglion (Scarpa's ganglion) situated in the upper part of the lateral end of the internal auditory meatus. The peripheral fibers divide into three branches:

1. The *superior branch* supplies the macula of the utricle and the cristae in the ampullae of the superior and lateral semicircular canals.

2. The *inferior branch* supplies the macula of the saccule.

3. The *posterior branch* traverses the foramen singulare and supplies the crista in the ampulla of the posterior semicircular duct.

Medially the vestibular fibers join the common acoustic nerve and traverse the internal auditory canal and posterior fossa to enter the medulla, where they divide into ascending and descending branches. The ascending branches pass to the medial, lateral, and superior vestibular nuclei, to the fastigial nuclei, and to the vermis of the cerebellum. The descending branches form the spinal root of the vestibular nerve and terminate in the inferior (spinal) vestibular nucleus. The connections of the second order vestibular neurons are diffuse and participate in a complex reflex system for maintaining the position of the eyes and body in relation to changes in orientation of the head. The second order neurons from the medial vestibular nucleus make widespread connections throughout the medulla and pons to the nuclei of the reticular formation and to motor nuclei of the cranial nerves and autonomic centers. They also contribute many ascending and descending fibers to the medial longitudinal fasciculi. Connections from the superior vestibular nucleus are particularly associated with the cerebellum. The lateral nucleus sends second order neurons via the reticular formation into the important direct vestibulospinal tract, which is probably the chief antigravity mechanism of the central nervous system. The lateral nucleus also contributes fibers to the medial longitudinal fasciculus. The inferior (spinal) nucleus has widespread connections with the nuclei of the reticular formation of the medulla and pons. It contributes fibers to the medial longitudinal fasciculus and some of its fibers also form the crossed vestibulospinal spinal tract (Fig. 19).

There are important descending association connections between the cerebellum and the vestibular nuclei through which the cerebellum exerts its coordinating influence directly upon the vestibular nuclei.

The conscious vestibular pathways are apparently not well understood nor uniformly agreed on. Some believe that the ascending vestibular pathways to consciousness follow those of auditory pathways.

Glossopharyngeal Nerve

The ninth nerve is a mixed sensory and motor nerve (Fig. 20). The sensory components consist of somatic afferents supplying sensation to the mucous membranes of the pharynx, tonsillar region, and back of the tongue; special visceral afferents, which supply taste to the posterior part of the tongue; and general visceral afferents, which supply the blood pressure receptors of the carotid sinus and carotid body. The motor components of the glossopharyngeal nerve include the motor innervation of the stylopharyngeus muscle and the secretomotor innervation of the parotid gland and other minor salivary and mucous glands of the posterior tongue and adjacent pharynx.

The special visceral afferent fibers for taste of the ninth nerve have their cell bodies in the *inferior (petrosal) ganglion* at the base of the skull and terminate centrally in the nucleus solitarius via the tractus solitarius in the medulla. The motor fibers to the stylopharyngeus arise in the cephalic end of the nucleus ambiguus. Somatic afferents have their cell bodies in the *inferior (petrosal) ganglion.* The central processes pass into the tractus solitarius, where they become widely distributed. Many synapse in the nucleus of the tractus solitarius. The special visceral afferents from the carotid body and sinus join the main trunk of the nerve and end with the rest of the visceral afferents in the tractus solitarius. From here they are distributed to the dorsal motor nucleus of the vagus and to the vasomotor and respiratory centers in the brain stem. The secretomotor fibers to the salivary and mucous glands arising in the inferior salivatory nucleus reach their glandular destinations via relays in the otic ganglion. The salivatory nucleus has many connections with other central pathways and nuclei, particularly with the nucleus and tractus solitarius.

The superficial origin of the glossopharyngeal nerve from the brain stem is by three or four rootlets in the groove between the olive and inferior peduncle. It passes laterally along the lower border of the petrous bone and exits from the skull through the jugular foramen. It then runs anteriorly between the internal carotid artery and the internal jugular vein, following the posterior border of the stylopharyngeus muscle for a few centimeters before crossing over the stylopharyngeus to penetrate deeply into the pharyngeal terminations at the posterior border of the hyoglossus muscle. As the glossopharyngeal nerve exits through the jugular foramen, it has a pair of ganglionic swellings, the superior (jugular) ganglion and the inferior (petrosal) ganglion. The superior is very small and inconstant. The ganglia contain the cell bodies for the sensory fibers of the nerve. The ninth nerve communicates with the vagus nerve, the superior sympathetic ganglion, and the facial nerve.

Branches of the Glossopharyngeal Nerve

Tympanic (Jacobson's) Nerve. The tympanic nerve has both sensory and secretory fibers. It supplies sensory fibers to the middle ear and parasympathetic secretory fibers to the parotid gland via the otic ganglion. It arises from the main trunk of the petrosal ganglion and penetrates the floor of the middle ear through a small foramen in the base of the petrous between the carotid canal and the jugular fossa. It continues upward in a groove on the promontory, where it enters into the tympanic plexus. It reenters a small bony canal near the cochleariform process, passes medial to the semicanal of the tensor tympani muscle, and continues on as the lesser petrosal nerve.

The *tympanic plexus* lies in grooves on the promontory of the middle ear and is made up of tympanic branches of the ninth nerve and the caroticotympanic nerves from the sympathetic plexus surrounding the carotid artery. The tympanic plexus communicates with the greater petrosal nerve.

Sensory Branches. These branches are given off to the epithelium of the middle ear and its accessory chambers.

Lesser Petrosal Nerve. The lesser petrosal nerve is the continuation of the tympanic branch of the ninth nerve beyond the tympanic plexus as it courses medial to the semicanal for the tensor tympani and reenters the cranial cavity on the superior surface of the petrous, just lateral to the hiatus of the facial canal. It then leaves the cranial cavity again after a short anterior course, exiting through a small opening in the region of the suture line between the petrous and the greater wing of the sphenoid. Here, it communicates with the geniculate ganglion of the seventh nerve by a small filament. Just outside the skull it joins the otic ganglion.

Otic Ganglion. The otic ganglion measures 2 to 4 mm in diameter and closely approximates the medial surface of the mandibular division of the fifth nerve just below the foramen ovale (Fig. 21). The motor root of the otic ganglion is made up of the preganglionic parasympathetic fibers of the lesser petrosal nerve. The postganglionic parasympathetic fibers arising from the cell bodies in the otic ganglion are distributed mainly to the parotid gland via communications with the auriculotemporal nerve and its branches. Some postganglionics pass via the other nerves to the mucous and minor salivary glands in the mouth and pharynx. Other branches of communication with the otic ganglion are the following: *sympathetic*, from the middle meningeal plexus; the *medial pterygoid nerve* via trigeminal motor fibers, which pass on through the ganglion as the motor fibers to the tensor tympani and tensor veli palatini muscles; the *mandibular nerve* via trigeminal sensory branches; the *sphenoidal branch* from the vidian nerve; and the chorda tympani communication. All these communicating branches pass without synapsing through the otic ganglion.

The *carotid sinus nerve* arises from the main trunk of the glossopharyngeal nerve just beyond the jugular foramen. It runs down the internal carotid artery to the carotid bifurcation, where it terminates in the blood pressure receptors in the walls of the carotid sinus. It sends a branch to the intercarotid plexus, which is made up largely of vagal and sympathetic fibers. This intercarotid plexus terminates in the chemoreceptors of the carotid body.

Pharyngeal Branches. Pharyngeal branches are several in number and join vagal and sympathetic fibers at the level of the middle pharyngeal constrictor muscle to form the *pharyngeal plexus.* This plexus supplies the muscles and mucous membranes of the pharynx.

Branch too the Stylopharyngeus Muscle. This is the only muscular branch of the glossopharyngeal muscle.

Tonsillar Branches. The tonsillar branches supply sensory fibers to the faucial tonsils and their surrounding palatal and pillar membranes.

Lingual Branches. These supply afferent fibers for taste and general sensation to the posterior aspect of the tongue and secretomotor fibers to the mucous glands of the posterior tongue.

Vagus Nerve

The vagus nerve is the longest of the cranial nerves and has the widest distribution. It contains both somatic and visceral afferents and both general and special visceral efferent fibers. The somatic sensory fibers supply the external auditory canal and the posterior aspect of the pinna. The visceral afferent fibers supply the mucous membranes of the pharynx, larynx, bronchi, lungs, heart, esophagus, intestines, stomach, and kidneys. The general visceral efferents are parasympathetic and go to the heart and nonstriated muscle and glands of the esophagus, stomach, trachea, bronchi, biliary tract, and most of the intestine. Special visceral efferents supply the striated muscles of the larynx, pharynx, and palate.

The afferent fibers in general have their cell bodies in the jugular and nodose ganglia of the vagus nerve at the base of the skull. Their central connections vary with the different types of afferents. The somatic sensory fibers from the external ear probably join the spinal tract of the fifth nerve and have connection with the thalamus, sensory cortex, and medullary and spinal nuclei. The visceral afferent fibers join the tractus solitarius and end in its nucleus. These, in turn, make associations with other centers in the reticular formation, much as did those of the glossopharyngeal nerve; namely, with the respiratory, vasomotor, cardiac, vomiting, and swallowing centers (Fig. 22). These are then relayed to medullary and spinal nuclei as well as to the dorsal motor nucleus of the vagus. A few special visceral afferent taste fibers of the vagus, from a few receptors on the epiglottis and in the larynx, end in the tractus and nucleus solitarius.

The special visceral efferent fibers of the vagus, which innervate the striated muscle of the pharynx and larynx arise in the nucleus ambiguus in the medulla, then turn ventrally and laterally to join the sensory fibers in a common emergence from the brain stem. The nucleus ambiguus connects with corticobulbar fibers from the same and opposite sides as well as with other central tracts from the trigeminal, glossopharyngeal, vagus, and spinal nerves. It is this crossed as well as uncrossed cortical representation in the nucleus ambiguus that probably accounts for the rarity of vocal paralysis on the basis of isolated central nervous system lesions.

The general visceral efferents of the vagus are preganglionic parasympathetics for smooth muscle and glands of the gastrointestinal tract and lungs as well as inhibitory fibers to the heart (Fig. 23). They arise in the *dorsal nucleus of the vagus.* The nucleus has extensive connections with other central nuclei and tracts, particularly those of the reticular formation.

The common superficial origin of the combined sensory and motor fibers of the vagus nerve is by 8 to 10 rootlets from the dorsolateral aspect of the medulla in the same groove between the olive and the inferior peduncle shared more rostrally by the glossopharyngeal nerve and more caudally by the spinal accessory nerve. The rootlets merge and pass laterally to exit from the skull through the jugular foramen in a common dural sheath with the spinal accessory nerve. In the jugular fossa, the vagus has two ganglionic swellings, which are the sensory ganglia of the nerve.

The superior (jugular) ganglion is in the jugular foramen and is less than 0.5 cm in diameter. Most of the peripheral sensory fibers of the cells of this ganglion make up the auricular branch of the vagus, with a few going to the pharyngeal branches. *The inferior (nodose) ganglion* is much bigger, measuring 2.5 cm in length, and lies about 1 cm distal to the superior ganglion. The peripheral processes of the inferior ganglion supply the larynx, esophagus, trachea and bronchi, and other thoracic and abdominal organs.

Branches of the Vagus Nerve

In the Jugular Fossa

Meningeal Branch. The meningeal branch arises at the superior ganglion and reenters the cranium through the jugular foramen to supply the dura of the posterior fossa.

Auricular Branch. The auricular branch arises from the superior ganglion and enters the mastoid canaliculus in the lateral aspect of the jugular fossa. It exits again through the tympanomastoid suture to reach the surface, where it supplies sensation to the posterior aspects of the pinna and to the posterior part of the external auditory meatus. It communicates with the seventh and ninth cranial nerves.

Branches in the Neck

Pharyngeal Branches. The pharyngeal branches arise from the inferior ganglion and contain both sensory and motor fibers, the latter contributed by the accessory nerve. They join the *pharyngeal plexus,* made up of branches from the glossopharyngeal, vagus, and sympathetic nerves. Branches of the plexus are distributed to the muscles and mucous membranes of the pharynx and palate, except for the tensor palatini. Vagal filaments from the pharyngeal plexus also join glossopharyngeal and sympathetic fibers to form the *intercarotid plexus* at the carotid bifurcation. The vagal fibers are visceral afferents that end in the carotid body and mediate impulses set up by the chemoreceptors in that body that are sensitive to changes of carbon dioxide and possibly oxygen tensions in the blood.

Superior Laryngeal Nerve. This nerve arises from the inferior ganglion and passes downward and medially, deep to the internal carotid artery, to the lateral aspect of the thyrohyoid membrane, where it divides into internal and external branches.

Internal Branch. The internal branch pierces the thyrohyoid membrane with the superior laryngeal artery and veins and supplies sensory fibers to the mucous membrane and parasympathetic secretory fibers to the glands of the epiglottis, base of the tongue, aryepiglottic folds, and intrinsic parts of the larynx as far down as the vocal cords. It communicates with the recurrent nerve inferiorly.

External Branch. The external branch extends caudally outside the larynx to give motor innervation to the cricothyroid muscle and inferior constrictor muscle of the pharynx. It communicates with the pharyngeal plexus and the cervical sympathetics.

Superior Cardiac Branches. These branches arise from the vagus both high and low in the neck and are two or three in number. They follow the course of the carotid artery downward to join the cardiac plexuses in the thorax.

Recurrent Laryngeal Nerve. The recurrent laryngeal nerve arises in the root of the neck, curves around the great vessels in the root of the neck or upper thorax, and then ascends again to its ultimate termination, the larynx. The origin and course of the nerve are different on the two sides. On the right side, the recurrent nerve arises in the root of the neck as the vagus crosses the first part of the subclavian artery. The recurrent branch loops under the subclavian artery and passes deep to the common carotid artery to follow along the tracheoesophageal groove beneath the lateral lobe of the thyroid gland. On the left side, the recurrent nerve actually arises in the cervical thorax as the vagus crosses the left of the arch of the aorta. The recurrent branch loops around the aorta just distal to the ligamentum arteriosum and then, like its fellow on the right side, follows the tracheoesophageal groove upward to the larynx. Both left and right nerves come into close but variable relationships with the inferior thyroid artery. They finally dip under the inferior border of the inferior pharyngeal constrictor muscle and enter the larynx through the cricothyroid membrane. This entry is usually just posterior to the articulation of the inferior cornu of the thyroid cartilage with cricoid cartilage. Either just before or just after entry into the larynx, the recurrent nerve breaks up into muscular branches and supplies all the intrinsic muscles of the larynx (except the cricothyroideus).

Branches of the Recurrent Laryngeal Nerve

Cardiac Branches. These branches are given off as the nerve loops around the subclavian artery and aorta and contribute to the cardiac plexuses.

Tracheal and Esophageal Branches. These branches arise all along the nerve and supply both muscular and sensory fibers to the mucous membranes and muscular coats of these structures and the subglottic region of the larynx.

Pharyngeal Branches. Pharyngeal branches are motor fibers to the inferior pharyngeal constrictor muscle.

Inferior Laryngeal Nerves. These are the terminal muscular branches to the intrinsic laryngeal muscles (excluding the cricothyroid muscle).

Esophageal Branches. The esophageal branches arise superiorly from the recurrent nerves in the midthorax from the main trunks of the vagus; inferiorly, they arise from the esophageal plexus. The motor efferents from the recurrent nerve end for the most part directly in the striated muscle of the upper one-third of the esophagus. The efferents from the esophageal plexus in the lower one-third of the esophagus are almost exclusively preganglionic parasympathetics that synapse with groups of ganglion cells in the Auerbach-Meissner plexus in the wall of the esophagus. The postganglionics of the plexus innervate the muscle and mucous glands of the esophagus. The middle third of the esophagus, which has an admixture of striated and nonstriated muscle, is innervated by both general somatic efferent fibers and parasympathetics. The visceral afferents of these branches and plexus have their cell bodies in the inferior ganglion of the vagus.

The *esophageal plexus* is formed by the left vagus posteriorly and the right vagus anteriorly, as both main trunks tend to break up into multiple strands below the bifurcation of the trachea. The plexus also includes sympathetics in its makeup. Just above the diaphragm, the plexuses gather into one or two main strands to form the anterior and posterior vagus nerves, which then penetrate the diaphragm along with the esophagus.

Spinal Accessory Nerve

The accessory nerve is entirely motor and has both cranial and spinal origins.

Cranial Origin

The cranial part of the eleventh nerve is indeed accessory to the vagus nerve. It has an origin in the nucleus ambiguus like the vagus; it joins the vagus immediately upon leaving the cranium; and its fibers are distributed with the branches of the vagus. The cells of origin in the caudal part of the nucleus ambiguus appear to be cranial extensions of the anterior horn cells of origin of the spinal part of the nerve. The nucleus ambiguus makes central connections with crossed pyramidal fibers and also with other sensory cranial nuclei. The axons of the cranial portion pass ventral to the spinal tract of the fifth nerve and emerge in the posterior lateral sulcus of the medulla in series with the emergence of the vagal fibers more rostrally. They then pass laterally to the jugular foramen where they are joined by the fibers from the spinal origin. The two joined portions then exit from the cranium through the jugular foramen in a common dural sheath with the vagus. At the level of the nodose ganglion, the spinal and cranial portions again divide from each other. The cranial fibers join the vagus and are distributed to the muscles of the pharynx, larynx, and esophagus.

Spinal Origin

The spinal part of the accessory nerve arises from the lateral cell groups in the anterior horn of the first five or six cervical segments of the spinal cord. These anterior horn cells connect with pyramidal fibers. They also connect with fibers from the medial longitudinal fasciculus and the rubrospinal and vestibulospinal tracts for the coordination of head and eye movements, and with spinal and cranial sensory muscles and tracts. The spinal fibers emerge from the lateral funiculus of the cord and join each other as they pass craniad alongside the cord and enter the posterior cranial fossa through the foramen magnum. They join the cranial portion at the jugular foramen but again separate after exiting from the skull through the jugular foramen.

The spinal part of the accessory nerve pierces the anterior border of the cranial portion of the sternocleidomastoid muscle, courses through the upper one-third of the muscle, and emerges from the posterior border in its midportion. It then courses obliquely downward across the posterior triangle of the neck just beneath the superficial layer of the deep cervical fascia. It is in this area that the nerve is particularly vulnerable to injury from relatively minor surgical procedures or lacerations. The nerve then enters the anterior border of the trapezius muscle. It continues on the deep surface of the trapezius almost to its caudal border and forms a plexiform arrangement, with communications from the second, third, and fourth cervical nerves. The branches of the spinal portion are the sternomastoid and trapezius, which innervate the respective muscles.

Hypoglossal Nerve

The twelfth nerve is the motor nerve of the tongue (Fig. 25). The hypoglossal nucleus lies near the central canal in the caudal closed part of the medulla. The axons of the nucleus pass ventrally through the reticular substance, medial to the inferior olive, and emerge from the medulla as multiple rootlets in the ventral lateral sulcus between the inferior olive and the pyramid. The nuclei of each side communicate with each other across the midline via their dendrites. They also have rich central connections with crossed and uncrossed pyramidal fibers and with secondary sensory pathways from the trigeminal, facial, glossopharyngeal, and vagus nerves.

The rootlets from the brain stem merge into a main trunk, which exits from the skull through the hypoglossal canal. The main trunk of the nerve passes downward along the carotid sheath to the level of the occipital artery, where it hooks beneath this artery and passes sharply forward superficial to the internal and external carotid arteries. It turns slightly craniad just above the hyoid bone and passes deep to the tendon of the digastric muscle and forward between the mylohyoid and hyoglossus muscles into the intrinsic muscles of the tongue, which it innervates. The true fibers of the hypoglossal nerve also innervate the styloglossus, hyoglossus, and genioglossus muscles.

Branches of Twelfth Nerve

Dural Branches. Dural branches to the posterior cranial fossa are given off in the hypoglossal canal and are probably contributed by the cervical sensory communications.

Descending Hypoglossal Branch. This is derived from fibers from the first cervical nerve, leaves the hypoglossal nerve as it loops around the occipital artery, and descends in the lateral neck to form the loop, the *ansa hypoglossi (ansa cervicalis)*, with the lateral arm of the loop from the second and third cervical segments, the descending cervical nerve. The branches from this loop supply the inferior strap muscles.

Thyrohyoid and Geniohyoid Branches. These are muscular branches and are also made up of fibers from the first cervical nerve. They leave the hypoglossal nerve near the posterior border of the hyoglossus muscle.

Muscular Branches. Muscular branches are the true hypoglossal fibers, which terminate in the styloglossus, hyoglossus, and genioglossus muscles as well as the intrinsic muscles of the tongue. These branches also contain proprioceptor fibers, probably contributed by the cervical root communications.

Primary Divisions of the Spinal Nerves

The spinal nerve divides into two primary division, ventral and dorsal, almost as soon as the two roots have joined to form a single spinal nerve. Each primary division receives fibers from both roots.

Dorsal Primary Divisions of the Spinal Nerves

With only a few exceptions, the dorsal primary divisions supply the muscles and skin of the dorsal part of the neck and trunk.

Cervical Nerves. The dorsal primary division of the first cervical (suboccipital) nerve is usually entirely motor, supplying deep muscles in the suboccipital triangle.

The dorsal division of the second cervical nerve is the largest of the cervical dorsal divisions and is both motor and sensory. It emerges between the atlas and axis and divides into a large medial branch, the *greater occipital nerve,* and a smaller *lateral branch.* The greater occipital nerve gives off a few muscular fibers and then becomes subcutaneous near the nuchal line to supply sensation to the scalp posteriorly and superiorly. The smaller lateral branch gives off muscular fibers.

The dorsal division of the third cervical nerve is also mixed motor and sensory and supplies sensation to the scalp over the lower occipital region. The dorsal divisions intercommunicate rather freely, forming what is sometimes called the *posterior cervical plexus.* The dorsal primary divisions of the fourth through eight cervical nerves are all mixed, supplying the deep paraspinous muscles and the skin over the back of the neck.

Thoracic Nerves. The dorsal primary divisions of all the thoracic nerves are mixed motor and sensory and supply the large deep muscles of the back and the skin over the back as far down as the buttocks.

Ventral Primary Divisions of the Spinal Nerves

The ventral primary divisions of the spinal nerves supply the ventral and lateral parts of the trunk and all the extremities. In the cervical, lumbar, and sacral regions, they unite to form plexuses.

Cervical Nerves. The ventral primary divisions of the first four cervical nerves form the cervical plexus, while the last four cervical nerves together with the first thoracic form the brachial plexus.

Cervical Plexus. The cervical plexus originates high in the neck opposite the upper four vertebral bodies (Fig. 26). It emerges anterior to the deep prevertebral muscle but deep and posterior to the sternocleidomastoid muscle.

Superficial or Cutaneous Branches

Smaller Occipital Nerve. This ascends along the posterior aspect of the upper part of the sternomastoid muscle and supplies the skin of the side of the head behind the ear.

Great Auricular Nerve. The great auricular nerve winds around the posterior border of the sternomastoid muscle in its midportion and ascends on the surface of the muscle, dividing into anterior and posterior branches.

The *anterior (facial) branch* is distributed to the skin over the parotid gland.

The *posterior (mastoid) branch* supplies the skin over the mastoid process and the back of the ear.

Anterior (Cervical) Cutaneous Nerve. This nerve bends around the posterior border of the sternomastoid muscle at its midportion and passes forward on the surface of the muscle, dividing into ascending and descending branches. The ascending branches supply the skin of the submandibular region and the anterior and lateral parts of the neck. The descending branches supply the skin of the lateral and anterior aspects of the lower part of the neck as far down as the sternum.

Supraclavicular Nerves. These nerves emerge from beneath the posterior border of the sternomastoid muscle at about its midportion and descend across the posterior triangle under the superficial layer of the deep cervical fascia. Near the clavicle, they pierce the fascia in three groups of supraclavicular nerves: *medial (anterior), intermediate,* and *lateral (posterior);* these nerves supply the skin over the upper anterior chest and shoulder.

Deep or Muscular Branches. These include numerous branches, which go two large groups of muscles, the deep prevertebral muscles in the lateral neck and the strap muscles, including the geniohyoideus. The communications of these nerves with the hypoglossal nerve in supplying the strap muscles and forming the ansa cervicalis (ansa hypoglossi) have already been described under the discussion of hypoglossal nerve.

The *phrenic nerve* is an important deep branch of the cervical plexus and carries some sensory as well as motor fibers. It is the main motor nerve to the diaphragm, although the diaphragm is also innervated by the lower thoracic nerves. The phrenic nerve originates mainly from the fourth cervical but also receives fibers from the third and fifth nerves. It courses downward and medially on the anterior surface of the anterior scalene muscle into the chest. It phases ventral to the root of the lung and then along the lateral aspect of the pericardium until it reaches the diaphragm. It receives a communication with the sympathetic at the root of the neck.

Branchial Plexus. The brachial plexus supplies the nerves, both motor and sensory, to the upper limb. It is formed by the ventral primary divisions of the fifth through the eight cervical nerves and by the first thoracic nerve. It courses across the lower lateral neck deep to the prevertebral fascia, emerging from beneath the lateral border of the anterior scalene muscle and running beneath the clavicle into the axilla.

The Autonomic Nervous (Visceral Efferent) System

The autonomic nervous system is the motor system that regulates the organs (viscera) of the body, including the smooth (involuntary) muscles, cardiac muscles, and glands. The basic morphologic difference between this visceral motor system and the somatic motor system is that two neurons (preganglionic and postganglionic) are required to transmit an impulse from the central nervous system (CNS) to the active effector organ in the viscera, whereas only a single neuron is required to carry impulses from the CNS to skeletal muscle. The autonomic nervous system is composed of two divisions or systems, the *sympathetic (thoracolumbar)* and *parasympathetic (craniosacral),* which differ morphologically and which are for the most part physiologically antagonistic to each other. The sympathetic system is connected with the CNS through the thoracic and upper lumbar segments of the spinal cord, and its ganglia tend to be more centrally situated near the spinal column. The parasympathetic system is connected with the CNS through certain cranial nerves and through the middle three sacral segments of the spinal cords; its ganglia tend to be more peripherally located near the organs innervated. The sympathetic and parasympathetic systems both innervate many of the same organs, both systems usually being antagonistic to each other physiologically in the respective organs. The two systems frequently travel together, particularly in the thorax, abdomen, and pelvis, where they form great autonomic plexuses.

Sympathetic Systems

The cells of origin of this system lie in the lateral gray column of the thoracic and lumbar segments of the spinal cord. The axons of these cells leave the cord through the ventral roots of the spinal nerves and reach the paraspinal sympathetic chain by traversing the white rami communicantes. They either terminate in the ganglia of this chain or may pass on through to terminate in the collateral ganglia of the prevertebral plexuses. These are preganglionic fibers and are mostly myelinated. The postganglionic fibers are usually unmyelinated and are distributed to the viscera via communications with other cerebrospinal nerves and various plexuses and by some of their own visceral branches.

Sympathetic Trunk

This consists of a chain of ganglia connected by intervening cords that extends along the lateral aspect of the vertebral column from the base of the skull to the coccyx. The trunk is also generally considered to include the preganglionic and postganglionic fibers as well. Both types of fibers may run up and down the trunk for a few or many segments. The ganglia of the trunk (chain ganglia) measure in length anywhere from 1 to 10 mm in diameter and may fuse with one another as in the cervical ganglia (Fig. 27). The roots of the ganglia are the white rami communicantes, so named because of the preponderance of myelinated fibers in their makeup. Many of the preganglionic fibers in the lower thoracic and upper lumbar levels pass out of the trunk through the splanchnic nerves to synapse in the celiac and related collateral ganglia (Fig. 27).

Branches of the Sympathetic Trunk. Branches of distribution of the sympathetic trunk may be made up of either postganglionic fibers (gray rami) or preganglionic fibers, which have passed through without synapses on their way to collateral ganglia in the abdomen. These branches may be distributed in a number of ways by (1) spinal nerves, (2) cranial nerves, (3) arteries, (4) separate branches to individual organs, and (5) great autonomic plexuses.

Cephalic Portions of the Sympathetic System. This part of the sympathetic system contains no ganglia of its own but is essentially a direct extension of the superior cervical ganglion through the internal and external carotid plexus fibers as well as of fibers along the vertebral arteries. Within the cranial cavity, the internal carotid plexus gives off branches that form the cavernous plexus.

Branches of the Internal Carotid Plexus

1. Communication to the trigeminal nerve.

2. Communication to the abducent nerve.

3. The *deep petrosal nerve* leaves the carotid plexus at the foramen lacerum and joins the greater petrosal nerve to form the vidian nerve.

4. The *caroticotympanic nerves* join the tympanic plexus on the promontory of the middle ear.

Branches of the Cavernous Plexus

1. Communication with the oculomotor nerve.

2. Communication with the trochlear nerve.

3. Communication with the ophthalmic division of the trigeminal nerve.

4. Nerve fibers to the *dilator pupillae muscle* pass to the iris of the eye via the communication with the ophthalmic nerve, which joins the nasociliary nerve and the long ciliary nerves to the posterior part of the bulb, where they pierce the sclera and pass forward to the iris.

5. Communication with the *ciliary ganglion* via the nasociliary nerve or via the branch of its own through the superior orbital fissures.

6. Fibers to the pituitary gland.

7. Terminal filaments along anterior and middle cerebral arteries and ophthalmic arteries.

Branches of the External Carotid Plexus. The external carotid filaments follow along the many branches of this artery to their terminations in the erector pilae muscles and sweat glands of the skin as well as in the smooth muscle in the arterial walls themselves. They give off several distinct communications with facial ganglia.

1. Filaments to the *submandibular ganglion* from the facial artery.

2. Filaments to the *otic ganglion* from the middle meningeal artery.

3. Communication with the *geniculate ganglion* via the *external petrosal nerve.*

Branches of the Middle Cervical Ganglion

1. *Gray rami communicantes* to the fifth and sixth cranial nerves.

2. The *middle cardiac nerve* is the largest of the three cardiac nerves in the neck. It follows the carotid artery into the thorax, where it joins the deep cardiac plexus.

3. *Thyroid nerves* form a plexus on the inferior thyroid artery and communicate with the superior and inferior laryngeal nerves.

The trunk between the middle and inferior ganglia is always double, encircling the subclavian artery and supplying the artery with branches. This encirclement of the subclavian is known as the *ansa subclavia.*

Inferior Cervical Ganglion. The inferior cervical ganglion is usually fused with the first thoracic ganglion, in which case it is known as the *stellate ganglion.* The inferior ganglion lies between the base of the transverse process of the seventh cervical vertebra and the neck of the first rib on the medial side of the costocervical artery. It has no white ramus but receives its preganglionic fibers through the trunk from the upper thoracic nerves. When it is fused with the first thoracic ganglion as the stellate ganglion, it receives the white ramus communicans of the first thoracic nerve.

Branches of the Inferior Cervical Ganglion

1. *Gray rami communicantes* to the sixth, seventh, and eight cervical nerves, and also to the first thoracic in the case of a stellate ganglion. Most of the sympathetics to the upper extremities are provided by the stellate ganglion through the eight cervical and first thoracic nerves.

2. *Inferior cardiac nerves* may arise from the inferior ganglion, the first thoracic ganglion, the stellate ganglion, or the ansa subclavia. It runs down the anterior surface of the trachea to the deep cardiac plexus.

3. *Vertebral nerves* accompany the vertebral artery through the vertebral foramina and into the cranial cavity on the basilar, posterior cerebral, and cerebellar arteries.

Oculomotor Nerve. The oculomotor nerve contains visceral efferents for the nonstriated muscle of the ciliary and pupillary sphincter muscles of the eye. The preganglionic nerve fibers arise in the Edinger-Westphal nucleus in the anterior part of the oculomotor nucleus in the midbrain. They course through the inferior division of the third nerve to the ciliary ganglion. The postganglionics pass in the short ciliary nerves to the eyeball.

Facial Nerve. The facial nerve contains parasympathetic efferents to the lacrimal, submandibular, and sublingual glands and to the many mucous and minor salivary glands of the nose, palate, and tongue. The preganglionic fibers arise in the superior salivatory nucleus in the reticular formation of the pons and pass out of the brain stem in the nervus intermedius.

Sphenopalatine Ganglion. Those preganglionics of the nervus intermedius that leave the facial nerve at the geniculate ganglion via the greater petrosal nerve pass via the vidian nerve to terminate in the sphenopalatine ganglion. Postganglionics then pass to the lacrimal gland via the maxillary, zygomatic, and lacrimal nerves, while others accompany branches of the maxillary nerve to the glands of the nose, nasopharynx, palate, and tonsils.

Submandibular Ganglion. The preganglionic fibers leaving the facial nerve via the chorda tympani nerve join the lingual nerve to terminate in the submandibular ganglion. The postganglionics pass to the submandibular and sublingual glands.

Glossopharyngeal Nerve. The ninth nerve contains efferent parasympathetics to the parotid gland and also to mucous and minor salivary glands in the buccal mucosa, tongue, and floor of the mouth. The preganglionic fibers arise in the inferior salivatory nucleus in the medulla, leave the glossopharyngeal in the tympanic nerve, and traverse the lesser petrosal nerve to terminate in the otic ganglion. Most of the postganglionic fibers join the auriculotemporal nerve and are distributed to the parotid gland. Other branches reach the smaller glands of the oral and lingual mucous membranes via the branches of the mandibular nerve.

Vagus Nerve. The tenth nerve contains efferents to the nonstriated muscle and gland of the tracheobronchial tree, the alimentary tract as far as the transverse colon, the gallbladder, bile ducts and pancreas, and the inhibitory fibers to the heart. The preganglionic fibers arise from cells in the dorsal motor nucleus of the vagus in the medulla and course in the vagus nerve and its branches to ganglia in or near the organs innervated.