Cranial Nerves and Autonomic Innervation in the Orbit

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Glossary

Abducens nerve – A general motor efferent which provides motor innervation to the lateral rectus muscle in the orbit. This nerve is often referred to as cranial nerve VI (CNVI).

Autonomic nervous system – This consists of motor nerve fibers that provide involuntary control of viscera, including smooth muscle, specialized conducting cells of heart muscle, as well as secretion in glandular cells. It consists of two divisions, a parasympathetic division and a sympathetic division.

Ciliary ganglion – A collection of neuronal cell bodies that give rise to the postganglionic parasympathetic nerve fibers that will innervate the ciliary and sphincter muscles of the eye. These are important for accommodation for near vision and for pupil closure in response to bright light.

Oculomotor nerve – A general motor efferent which provides motor innervation to the levator palpebrae superioris, superior rectus, medial rectus, inferior rectus, and inferior oblique muscles within the orbit. Additionally, it carries the preganglionic visceral efferents from the accessory oculomotor nucleus toward the ciliary ganglion. This nerve is often referred to as cranial nerve III (CNIII).

Parasympathetic nervous system – This consists of visceral motor nerves whose cells bodies of origin are located in craniocervical regions of the central nervous system. Four cranial nerves have parasympathetic components: oculomotor (CNIII), facial (CNVII), glossopharyngeal (CNIX), and vagus (CNX). Sacral levels S2–S4 also contain neurons that form nerve fibers which bring parasympathetic innervation to pelvic viscera.

Sympathetic nervous system – This consists of visceral motor nerves whose cell bodies of origin are located in the thoracic and upper lumbar regions of the spinal cord. The preganglionic nerve fibers exit in the spinal nerve, form white rami communicans which project into the sympathetic chain on each side of the vertebral column. The sympathetic chain runs the full length of the vertebral column, from the cervical to the sacral region. Within the sympathetic chain are sympathetic chain ganglia where the preganglionic nerve fibers synapse with postganglionic neurons. The postganglionic nerve fibers exit the sympathetic chain using gray rami communicans. These sympathetic nerve fibers join nearby nerves and blood vessels, which in turn carry them to all parts of the body.

Trigeminal nerve – This has three very large sensory roots and a small motor root. The sensory roots provide general somatic afferents to the face and the scalp anterior to the mid-auricular line and to a variety of structures within the head. This nerve is often referred to as cranial nerve V (CNV). There are three divisions of the trigeminal nerve: (1) the ophthalmic division, or V1, is sensory only and is the main sensory nerve of the orbit and the skin of the upper eyelid, forehead, and anterior half of the scalp; (2) the maxillary division, or V2, also is sensory only and provides sensory innervation to areas of the nasopharynx, parts of the nasal and oral cavities, as well as skin of the face lateral and inferior to the orbit; and (3) the mandibular division, or V3, has a sensory and a motor root. The mandibular division provides sensory innervation to parts of the oral cavity as well as to specific areas of the facial skin, including the mandibular region. The motor root innervates the muscles of mastication, as well as several other small muscles of the head.

Trochlear nerve – A general motor efferent which provides motor innervation to the superior oblique muscle in the orbit. This nerve is often referred to as cranial nerve IV (CNIV).

Weighted magnetic resonance imaging (MRI) – The signals from tissues of different densities create a difference in contrast and relaxation times (e.g., T1 and T2) and thus in the strength of the nuclear magnetic resonance signal that is produced in an MRI scanner. In a T1-weighted MRI, the white matter appears white, the gray matter, containing the neurons, appears gray, and the cerebrospinal fluid appears dark. In a T2-weighted image, the contrasts are reversed.

Complex Innervation Patterns Are Present in the Orbit

The paths of nerves found within the orbit are extremely complex, particularly when one considers the relatively small volume of each orbit. Knowledge of these patterns
of innervation is important for understanding both normal function, as well as impaired function when there is injury or disease affecting the nerve pathways. In addition, understanding the pattern of innervation can minimize injury during intraorbital surgical and/or injection procedures.

The orbit contains portions of five cranial nerves: the optic nerve or cranial nerve II, the oculomotor nerve or cranial nerve III, the trochlear nerve or cranial nerve IV, the ophthalmic division (VI) and the maxillary division (V2) which are both branches of the trigeminal nerve or cranial nerve V, and the abducens nerve or cranial nerve VI. In addition, the orbit receives autonomic nervous system innervation, and thus contains nerves that carry parasympathetic and sympathetic innervation to a number of structures. Each of these nerve pathways is described individually.

**Sensory Nerves**

**The Optic Nerve or Cranial Nerve II**

The optic nerve is a special sensory nerve that carries information from the visual world to the brain. Embryologically, the optic nerve is derived from an outgrowth of the forebrain; therefore, it is part of the central nervous system (CNS) and is composed of CNS fiber tracts. It is surrounded by all the meningeal layers of the brain and has a subarachnoid space that contains cerebrospinal fluid. There are four parts to the optic nerve: intraocular or optic nerve head, intraorbital, interosseus, and intracranial. The optic nerve is formed as axons of the retinal ganglion cells exit the retina through the optic disc. This intraocular portion is approximately 1 mm in length and consists of unmyelinated ganglion cell axons. The intraorbital portion of the optic nerve contains mainly myelinated optic axons. The length of the optic nerve is greater than the distance from the optic nerve head to its entry into the optic foramen. The intraorbital portion of the nerve is approximately 30 mm long, while the distance from the posterior globe to the optic foramen is only 20 mm long (Figure 1). This generally gives the optic nerve an S shape within the orbit, and it is hypothesized that this extra length allows free movement of the globe without injuring the optic nerve. The optic nerve leaves the bony orbit via the optic foramen located within the lesser wing of the sphenoid bone. It travels through the optic canal and enters the intracranial space before joining with the contralateral optic nerve to form the optic chiasm.

**Trigeminal Nerve or Cranial Nerve V**

The trigeminal nerve is responsible for carrying general sensory information from the entire face, including the orbit and eyelids, to the brain. The cell bodies of origin of the sensory components of this large nerve are found in the trigeminal ganglion located in a cavity within layers of dura near the apex of the petrous portion of the temporal bone (Figure 2). Medial to the ganglion is the posterior cavernous sinus and the internal carotid artery. The human trigeminal ganglion contains approximately 27,000 sensory neurons. The central projections carry general sensory information to the sensory trigeminal nerve nuclei, which extend the whole length of the midbrain and medulla. There are three distinct nuclei from rostral to caudal: the mesencephalic nucleus involved in proprioception, the chief sensory nucleus involved in two-point touch discrimination, and the spinal trigeminal nucleus which mainly receives touch, pain, and temperature information. Three large divisions emanate from the trigeminal ganglion, each of which runs in a distinctly different direction and distributes to different parts of the face. These afferent branches are named for the region to which they form corrections: the ophthalmic division, often referred to as V1; the maxillary division, often referred to as V2; and the mandibular division, often referred to as V3 (Figure 2). Only the ophthalmic and maxillary divisions of the trigeminal nerve have branches within the orbit, and these are discussed individually.

**Ophthalmic Division of the Trigeminal Nerve**

The ophthalmic division is considered the first branch of the trigeminal nerve as it is the superior-most branch of the trigeminal nerve (Figure 2). It conveys general...
sensory afferents that subserve pain, touch, and temperature sensitivity to the brain. As a sensory nerve, it is important to remember that the nerve branch consists of sensory afferents, with the information traveling into the brain. However, it makes the most sense to describe the complex branching pattern of the ophthalmic division of the trigeminal nerve starting from the apex of the orbit and working peripherally.

Separate branches of the ophthalmic division of the trigeminal nerve pass through the superior orbital fissure, as they do not coalesce into a single division until within the wall of the cavernous sinus intracranially. The superior orbital fissure is located between the lesser and greater wings of the sphenoid bone, and three distinct branches of the ophthalmic division of CNV can be seen traversing through this foramen (Figure 3).

**Figure 3** Photograph of the bony orbit in a dry skull from the anterior view. Medial is to the right and superior is at the top. The large opening between the greater and lesser wings of the sphenoid bone is at the top, and there is a tendinous annulus at the posterior of the orbit, attaching to orbital bones medially and laterally. The rectus muscles take their origin from this connective tissue structure. The tendinous annulus separates the nerves entering the orbit into two groups: those that enter (1) superior to the annulus and (2) within the annular ring. A large number of nerves and veins pass through the superior orbital fissure superior to the annulus. From superior to inferior they are the superior ophthalmic veins, which are branches of the ophthalmic division of the trigeminal nerve; and the trochlear nerve which innervates the superior oblique muscle. A large number of nerves enter the orbit within the annulus, and these are often referred to as intracanal. The optic nerve (yellow circle) and ophthalmic artery (red circle) enter the orbit through the optic foramen. The superior division of the oculomotor nerve, which innervates the superior rectus and levator palpebrae superioris muscles, and the inferior division of the oculomotor nerve, which innervates the medial rectus, the inferior rectus, and the inferior oblique muscles, pass through the superior orbital fissure. The nasociliary nerve, the third branch of the ophthalmic division of the trigeminal nerve, also enters via the superior orbital fissure. The final structure which enters the orbit is the abducens nerve, which innervates the lateral rectus muscle.

**Lacrimal nerve**

The most superior and laterally placed is the smallest branch, the lacrimal nerve (Figure 4). The lacrimal nerve enters the orbit via the superior orbital fissure, outside the tendinous annulus formed by the origins of four extraocular muscles at the apex of the bony orbit (Figure 3). The nerve courses on the superior aspect of the lateral rectus muscle to enter the lacrimal gland. Prior to entry into the lacrimal gland, it receives a communicating branch from the zygomatic nerve which carries secretomotor innervation from the parasympathetic nervous system. The lacrimal nerve terminates on the conjunctiva and skin of the lateral part of the upper lid where it receives general sensory information.
Frontal nerve

The frontal nerve is the largest of the sensory branches of the ophthalmic division of the trigeminal nerve, entering the orbit within the uppermost part of the superior orbital fissure outside the tendinous annulus (Figure 3). It runs anteriorly between the periorbita, a dense connective tissue covering the orbital bones, and the levator palpebrae superioris muscle (Figure 5). Variably along its length, it divides into two terminal branches, the supratrochlear and supraorbital nerves (Figure 5). The small supratrochlear nerve runs superior to the trochlea, a cartilaginous structure attached superiomedially to the bony orbit, and exits the orbit anteriorly to supply the skin of the medial forehead, upper eyelid, and conjunctiva. The supraorbital branch is larger and continues anteriorly on the superior surface of the levator to exit the orbit through the supraorbital foramen or notch to provide sensory innervation to the conjunctiva and skin of the upper eyelid, forehead, and scalp anterior to the midauricular line. The supraorbital notch is located in the frontal bone which forms the superior orbital margin and is located approximately 31 mm from the midline bilaterally.

Nasociliary nerve

The nasociliary nerve passes through the superior orbital fissure between the two branches of the oculomotor nerve, running within the tendinous annulus (Figure 3). The course of this nerve in the orbit is particularly long and complicated (Figure 6). In the majority of cases, the nasociliary nerve turns medially and courses with the ophthalmic artery superior to the optic nerve, but deep to the superior rectus muscle. As it continues anteriorly, its path runs between the superior oblique and medial rectus muscles and in the process gives off five branches: sensory root of the ciliary ganglion, long ciliary nerves, posterior ethmoidal nerve, anterior ethmoidal nerve, and infratrochlear nerve.

Sensory root of the ciliary ganglion

These branches carry sensory information through the ciliary ganglion without synapsing. They run in both the short and long ciliary nerves, which pierce the sclera when they reach the globe. The sensory nerves here are very thin and vary between 5 and 12 mm in length.
Long ciliary nerves

These nerves vary in number, although commonly there are two or three. These nerves course toward the globe, pierce the sclera, and extend anteriorly to provide sensory innervation to the iris, ciliary muscles, and cornea (Figure 7).

Posterior ethmoidal nerve

This is a small and variable branch that emerges off the nasociliary nerve, a branch of the ophthalmic division of the trigeminal nerve (note that the bony orbit posteriorly has been dissected open). The nasociliary nerve enters the orbit superior and lateral to the optic nerve, but rapidly moves medially and anteriorly where two sets of branches emerge: the posterior and the anterior ethmoidal nerves (lifted by the scissor tips and blunt probe). These enter the ethmoid air cells, which are part of the nasal sinuses in the mid-region of the head.

Anterior ethmoidal nerve

The anterior ethmoidal nerve runs anteriorly between the superior oblique and medial rectus muscles (Figure 6). It exits the orbit with the anterior ethmoidal artery through the anterior ethmoidal canal, which is located between the ethmoid and frontal bones. It carries sensory innervation from the anterior and middle ethmoidal air cells as well as from the frontal sinus. The anterior ethmoidal nerve terminates by dividing to form internal and external nasal nerves, and the latter supplies the skin of the dorsum of the nose.

Infraorbital nerve

This is the termination of the nasociliary nerve on the face, where it provides sensory innervation of the medial canthal area, the root of the nose, and the lacrimal sac and canaliculi. If this nerve is absent, the supratrochlear or anterior ethmoidal nerves provide the sensory innervation for these areas.

Maxillary Division of the Trigeminal Nerve

The maxillary division is considered the second branch of the trigeminal nerve, and similar to the ophthalmic division of CNV, it brings sensory information into the CNS via nerves whose cell bodies are located in the trigeminal ganglion. The maxillary division enters the pterygopalatine fossa via the foramen rotundum (Figure 2). It continues to course anteriorly and enters the inferior orbital fissure on the floor of the orbit within the maxillary bone. Within the fissure, two branches are formed: the zygomatic and infraorbital nerves. Only these two nerves, of the many branches of the maxillary division, are germane to a discussion of innervation within the orbit.
Zygomatic nerve

The zygomatic nerve emerges from the inferior orbital fissure and courses superiorly on the lateral orbital wall. Current dogma indicates that postganglionic parasympathetic fibers from the facial nerve (CNVII) run in this nerve, branch off in the lateral orbit, and enter the lacrimal nerve to provide secretomotor innervation to the lacrimal gland. Recent studies in nonhuman primates and humans indicate, however, that the parasympathetic nerves run directly to the lacrimal gland as 5–10 separate rami lacrimales (Figure 8). This is discussed in further detail in the section on the autonomic nervous system.

The zygomatic nerve divides into two terminal branches, the zygomaticotemporal and the zygomaticofacial, both of which supply skin over the temporal and buccal regions of the face, respectively.

Infraorbital nerve

This is the very large terminal branch of the maxillary nerve, which runs first in the inferior orbital fissure, then in the inferior orbital groove and canal to emerge on the face through the infraorbital foramen (Figure 9). This foramen is approximately 10 mm from the inferior orbital margin formed by the maxillary bone. This nerve provides sensory innervation to a large area of the face from the upper lip to the lower eyelid. Specific palpebral branches supply the skin and conjunctiva of the lower eyelid.

Figure 8  A view of the lateral wall of the orbit with the bony roof and all the orbital contents removed. This allows visualization of parasympathetic nerves coursing in a superior direction from the inferior orbital fissure on the bony orbit floor toward the lacrimal gland. These carry parasympathetic secretomotor postganglionic innervation to the lacrimal gland.

Figure 9  An anterior view of the orbit on a dry skull. Foramina, or openings in the bone, can be seen. The superior orbital fissure is found at the orbital apex. The inferior orbital fissure is found on the orbital floor. The optic foramen is found on the superior-medial wall.

Motor Nerves

The Oculomotor Nerve or Cranial Nerve III

The oculomotor nerve provides motor innervation to the levator palpebrae superioris, the superior, medial and inferior rectus muscles, and the inferior oblique muscle. All these muscles insert directly onto the globe and move the eye within the orbit. In addition, as discussed in the section on autonomic innervation, the oculomotor nerve carries the parasympathetic preganglionic axons that synapses in the ciliary ganglion, and whose postganglionic axons innervate the pupillary sphincter and ciliary muscles of the eye.

The oculomotor neurons within the brainstem that give rise to the oculomotor nerve have a complex organization. The oculomotor nucleus is found at the level of the mesencephalon, ventral to the cerebral aqueduct. It extends from the posterior floor of the fourth ventricle to the trochlear nucleus. Generally, the oculomotor nucleus contains a midline dorsal nucleus and two lateral nuclei. Using a variety of tract-tracing techniques, it has been shown that the oculomotor nucleus is organized in a muscle-specific manner, with specific groups of neurons innervating single extraocular muscles. In addition, the muscles can receive ipsilateral, contralateral, or bilateral innervation. Each superior rectus muscle is innervated by contralateral oculomotor neurons located medially within the paired lateral nuclei. Each medial rectus is innervated by ipsilateral oculomotor neurons found in the inferior-most part of the paired lateral nuclei. Each inferior rectus muscle is innervated by ipsilateral oculomotor neurons located in the superior-most part of each of the paired lateral nuclei. The inferior oblique is innervated ipsilaterally by neurons located in the middle and lateral portion of the paired...
lateral nuclei. Only the levator palpebrae superioris muscle receives bilateral innervation from the single dorsal caudal nucleus located in the midline. All the nerve fibers from these various topographically organized nuclei join together within the brainstem, and after running through the red nucleus and cerebral peduncle, exit the brainstem on its ventral surface in the interpeduncular fossa. In their cisternal location, they pass between the posterior cerebral and superior cerebellar arteries, and course anteriorly, deep to the posterior communicating artery. The intracranial course is on average 25 mm long before the nerves enter into the dural border of the lateral cavernous sinus at the level of the posterior clinoid process (Figure 10). The oculomotor nerve enters the orbit through the superior orbital fissure, where it divides into a superior and an inferior division and enters the tendinous annulus (Figure 3). The diameter of the oculomotor nerve, as it enters the superior orbital fissure, is on average 2.1 mm, while the superior and the inferior divisions are 1.6 and 1.9 mm in diameter, respectively. The superior division innervates the superior rectus and levator palpebrae superioris muscles; the nerve enters the conal surface of the superior rectus muscle (Figure 11), and nerve fibers continue to the levator by either piercing through the superior rectus muscle or passing on its lateral border. The inferior division innervates the medial rectus, the inferior rectus, and the inferior oblique muscles. To reach these muscles, the inferior division of the oculomotor nerve runs medially and inferiorly, dividing into three branches (Figure 12). One branch enters the medial rectus muscle and the second branch enters the inferior rectus muscle, both on their conal surfaces; a third branch courses anteriorly along the lateral border of the inferior rectus muscle and pierces the inferior oblique at the point where it crosses the inferior rectus muscle. All the oculomotor nerve branches enter the muscles between the middle and posterior 1/3 of each muscle. In the majority of cases, the branch to the inferior oblique gives rise to nerves that carry parasympathetic axons to the ciliary ganglion. This is discussed in the section on autonomic nervous system.

The course of the oculomotor nerve is easily seen using standard magnetic resonance imaging (MRI) techniques, both intracranially and intraorbitally.

The Trochlear Nerve or Cranial Nerve IV

The trochlear nerve provides innervation to one skeletal muscle only, the superior oblique. The motor neurons that form the trochlear nerve are located in the trochlear

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**Figure 10** Superior view of the floor of the cranium. The orbital contents can be seen anteriorly. Four of the five cranial nerves can be seen. On the medial wall of the middle cranial fossa, the three divisions of the trigeminal nerve can be seen coursing from the anterior border of the trigeminal ganglion. The ophthalmic division can be seen coursing in the direction of the orbit. The oculomotor nerve can be seen crossing superior to the sella turcica of the sphenoid bone (which houses the pituitary gland in the hypophyseal fossa). The abducens nerve can be seen diving through the dura and coursing on the medial side of the trigeminal ganglion. The large foramen seen at the bottom of the photograph is the foramen magnum, where the spinal cord joins the medulla oblongata of the brain. The optic nerve can also be seen as it enters the optic canal.

**Figure 11** A deep dissection of the orbit from the superior view of the orbit. The optic nerve can be seen exiting the globe. The two divisions of the oculomotor nerve are dissected. The superior division is seen entering the superior rectuslevator palpebrae superioris muscles. The inferior division dives deep to the optic nerve on its way to innervate the medial and inferior rectus, and inferior oblique muscles. (Forceps is holding the cut proximal end of the oculomotor nerve.)
nucleus, which is located at the caudal end of the oculomotor nucleus at the level of the inferior colliculus. The nerve fibers run dorsally and slightly caudally, decussate (cross the midline), and emerge on the dorsal surface of the brainstem caudal to the inferior colliculus. This means that each trochlear nucleus innervates the contralateral superior oblique muscle within the orbit. However, a number of studies in various species unequivocally demonstrate that up to 5% of the superior oblique muscle innervation originates in the ipsilateral trochlear nucleus; this means that there is a small bilateral component to the innervation of the superior oblique muscle.

The course of the trochlear nerve is long, with an intracranial course of 60 mm. It also has the smallest cross-sectional diameter, averaging between 0.75 and 1 mm. The trochlear nerve courses on the lateral side of the midbrain running anteriorly to enter the cavernous sinus. Prior to entering the sinus wall, in 90% of specimens examined, the trochlear nerve is associated with the superior cerebellar artery, which usually runs superior to the nerve. Upon entering the cavernous sinus, the oculomotor nerve is medial and superior to the trochlear nerve and, more anteriorly, the oculomotor nerve ends up inferior and lateral to the trochlear nerve. The ophthalmic division of the trigeminal nerve consistently runs inferior to the trochlear nerve. Interestingly, in over 25% of trochlear nerves examined, there were nerves interconnecting V1 and trochlear nerves, presumably carrying general sensory information from the superior oblique muscle. The mean length of the intracavernous portion of the trochlear nerve is 26.8 mm.

The trochlear nerve enters the orbit through the superior orbital fissure in its most superior-lateral part, entering superior to the tendinous annulus (Figure 3). In this location its diameter is approximately 1.18 mm. Within the orbit, the trochlear nerve runs anteriorly and medially, with only periosteum separating the nerve from the sphenoid bone. The trochlear nerve terminates within the posterior half of the superior oblique muscle (Figure 13); in 76% of the orbits it ends in the medial aspect of the muscle and in the remaining 24% it ends in the superior aspect of the muscle. Generally, the total length of the trochlear nerve in the orbit is approximately 25 mm. Nerve branches first enter the muscle 17.25 mm from the muscle origin. Branches continue to dive into the muscle surface for an additional 7 mm.

Due to its small diameter, the trochlear nerve is difficult to image consistently using normal T1-weighted MRI, although T2-weighted fast spin-echo or T2-weighted...
three-dimensional sequences, such as 3D-CISS, were able to visualize the trochlear nerve in up to 95% of patients examined.

**The Abducens Nerve or Cranial Nerve VI**

The abducens nerve provides motor innervation to only one extraocular muscle in humans, the ipsilateral lateral rectus muscle. While CNVI innervates the retrobulbar muscle in animals such as rats and rabbits, nonhuman primates and humans do not have a retrobulbar muscle. The motor nucleus for the abducens nerve lies inferior to the floor of the fourth ventricle. Nerve fibers leave the nucleus and run anteriorly, laterally, and caudally through the pons, emerging in the medullary–pontine sulcus, a groove between the medulla and the pons. In this location the nerve is intracisternal, deep to the pons. The nerve is in close proximity to the anterior inferior cerebellar artery, and in approximately 80% of dissected human cadavers, the artery is inferior to the nerve. The nerve courses over the lateral edge of the dorsum sellae, pierces the dura of the clivus, runs in a canal formed by the petrophenoidal ligament superiorly and a bony ridge in the petrous ridge of the temporal bone (Dorello's canal), and passes through the inferior petrosal sinus as it courses anteriorly, lateral to the petrous part of the temporal bone. It crosses superior to the petrous ridge and deep to the petrophenoidal ligament, lateral to the bend of the internal carotid artery. Unlike CNIII, CNIV, and CNV1, the abducens nerve does not sit within the wall of the cavernous sinus; it floats free within the cavernous sinus, where it is medial to the trigeminal ganglion (Figure 10). The total length of the intracranial abducens nerve is on average 53 mm in adults.

The abducens nerve enters the orbit through the superior orbital fissure within the tendinous annulus (Figure 3). In this location its mean diameter is 1.54 mm, and it is found lateral to both branches of the oculomotor nerve and inferior to the nasociliary nerve and the superior branch of CNIII. It rapidly gains the medial surface of the lateral rectus muscle, splits into three to four branches, and enters the muscle within the posterior 1/3 of its length (Figure 14). The intracanal length of the abducens nerve is about 5 mm.

In contrast to the trochlear nerve, the abducens nerve, from its exit at the brainstem to its entry into the lateral rectus muscle, can be visualized using MRI.

**Autonomic Nervous System Contributions to Orbital Innervation**

The autonomic nervous system is ubiquitously located throughout the body and is responsible for controlling involuntary structures, including smooth muscle, the conducting cells of the heart, and glandular secretion. The autonomic nervous system is divided into two systems: the sympathetic and the parasympathetic nervous systems. As a rule, these two parts of the autonomic nervous system have opposing functions. Simplistically speaking, the sympathetic nervous system helps the body respond to stress, such as increasing blood flow to the muscles in preparation for activity. The parasympathetic nervous system, in general, actively promotes normal bodily functions at rest, such as increasing blood flow to the intestines and aiding in peristalsis.

The main anatomical differences of the two parts of the autonomic nervous system are based on the location of the preganglionic neuronal cell bodies and what nerves conduct their axons to the periphery. Each autonomic circuit consists of a two-neuron chain. In general, the sympathetic nervous system has short preganglionic nerves and long postganglionic nerves. The opposite is true of the parasympathetic nervous system, where the preganglionic nerves are long and the postganglionic nerves are short. The preganglionic sympathetic neuronal cell bodies are located in the thoracic and upper lumbar regions of the spinal cord, while the preganglionic parasympathetic neuronal cell bodies are located in specific brainstem nuclei as well as in lower sacral levels of the spinal cord.
Parasympathetic Innervation in the Orbit

As is typical of parasympathetic innervation, the nerve fibers originate in specific brainstem nuclei. The axonal paths of these parasympathetic nerves within the orbit are extremely complex. Four of the twelve cranial nerves have parasympathetic components (CNIII, CNVII, CNIX, and CNX). Of these, both the oculomotor (CNIII) and facial (CNVII) nerves send parasympathetic innervation into the orbit. The preganglionic neuronal cell bodies are located in brain nuclei, while the postganglionic cell bodies are located in peripherally located ganglia.

Parasympathetic innervation within the oculomotor nerve

The accessory oculomotor nucleus is the site of origin of the preganglionic nerve fibers that enter the orbit with the oculomotor nerve. This nucleus is located both rostral and dorsal to the oculomotor nucleus. Its nerve fibers run into and travel along with the superior aspect of the ipsilateral oculomotor nerve. Within the orbit, these preganglionic parasympathetic nerve fibers run with the inferior division of the oculomotor nerve, and eventually extend nerve branches to the ciliary ganglion. The ciliary ganglion is located on the lateral side of the optic nerve close to the orbital apex. It is between 1 and 3 mm in diameter. In approximately 8% of the orbits, the ciliary ganglion is located directly on either the inferior division of the oculomotor nerve or the nerve to the inferior oblique muscle. In addition, many authors have described accessory ciliary ganglia as well as scattered ganglion cell neurons within the ciliary nerves themselves. We use the term ciliary ganglion to encompass all three of these ganglion locations.

Within the ciliary ganglion are postganglionic neuronal cell bodies that receive synapses from the preganglionic nerve fibers. The postganglionic nerve fibers, for the most part, travel within the short ciliary nerves and enter the sclera on the temporal side of the globe. These nerves innervate the ciliary muscles and iris sphincter muscles; roughly 95% go to the ciliary muscles and 5% innervate the sphincter muscles. Thus, this parasympathetic innervation is responsible for pupil constriction in response to light as well as for accommodation needed for near vision.

It should also be noted that experimental evidence demonstrates that intraocular parasympathetic projections also can arise from the pterygopalatine ganglion. These fibers arrive in the orbit by either (1) joining the retro-orbital plexus and then traveling anteriorly to the globe with the ciliary artery, long ciliary nerve, short ciliary nerve, and/or within the optic nerve sheath, or (2) they travel retrogradely with the ethmoidal or infra-cholesterol nerves and join the long ciliary nerves to enter the globe.

An additional source of parasympathetic innervation to the globe itself is supported by the fact that removal of the ciliary ganglion only reduces the cholinergic nerve fibers within the cornea, iris, and choroid by 60%.

Parasympathetic innervation to the lacrimal gland

The brainstem neurons, which every basic anatomy textbook describes as giving rise to the parasympathetic secretomotor nerve fibers of the lacrimal gland, are found within the ventral subgroup of neurons in the superior salivatory nucleus located between the root of the facial nerve and the superior olive nuclei. The preganglionic parasympathetic secretomotor fibers exit the brainstem within the intermediate root of the facial nerve. The intermediate root joins the motor root of the facial nerve and exits the cranium through the internal acoustic meatus. Within the temporal bone, the parasympathetic fibers exit the facial nerve at the geniculum and leave the temporal bone as the greater petrosal nerve. This nerve courses anteriorly, crosses the middle cranial fossa, and enters the pterygoid canal where it is joined by the deep petrosal nerve, which brings sympathetic nerve fibers that ascended from the superior cervical ganglion by running on the internal carotid artery. These two nerve branches unite and form the nerve of the pterygoid canal (formerly called the vidian nerve). The nerve of the pterygoid canal courses to the pterygopalatine ganglion, which is associated with V2 within the pterygopalatine fossa. Here in the pterygopalatine ganglion, the preganglionic parasympathetic nerve fibers synapse with neurons that will form the postganglionic nerve fibers. These secretomotor fibers have been described as coursing with the zygomatic nerve, which runs on the floor and lateral wall of the orbit. Eventually, a nerve root anastomosis with the lacrimal nerve forms and carries the postganglionic secretomotor fibers that originated in CNVII to the lacrimal gland. A number of scientists question this pathway, as it is extremely complex and the anastomosis between the zygomatic and lacrimal nerve is often nonexistent. In addition, section of the connecting ramus between the zygomatic and lacrimal nerves does not reduce lacrimation.

Recent studies using modern tract-tracing techniques have demonstrated that, in fact, there is a direct pathway from the pterygopalatine ganglion to the lacrimal gland via a retro-orbital autonomic plexus. In humans and in the nonhuman primates, 5–10 rami can be traced directly from the pterygopalatine ganglion to the retro-orbital nerve plexus, and rami from this plexus are easily traced directly to the lacrimal gland. In other studies, nerve rami were followed that passed directly from the pterygopalatine ganglion to the lacrimal gland. These studies demonstrate that, contrary to current dogma, pterygopalatine
postganglionic parasympathetic efferents course to the lacrimal gland without using branches of the maxillary (zygomatic branch) nerve as a route.

**Sympathetic Innervation in the Orbit**

The sympathetic innervation of the body is extremely ubiquitous. It has long been understood that preganglionic sympathetic neuronal cell bodies are located in the intermediolateral portion of the spinal cord at the thoracic and upper lumbar levels. The sympathetic nerve fibers exit the spinal cord in the ventral root and branch off as white rami communicans to join the sympathetic chain running on the lateral sides of the vertebral bodies. First-order central sympathetic fibers arise from the posterolateral hypothalamus and descend to terminate in the intermediolateral cell column of the spinal cord at the level of C8–T2. Second-order preganglionic pupillomotor fibers exit the spinal cord at the level of T1 and ascend in the cervical sympathetic chain which is found on the lateral sides of the cervical vertebrae. The fibers synapse in the superior cervical ganglion at the level of the bifurcation of the common carotid artery. After the postganglionic fibers leave the superior cervical ganglion, the pupillomotor fibers ascend along the internal carotid artery and enter the cavernous sinus. Some axons leave the carotid plexus to join the abducens nerve (CNVI) in the cavernous sinus and enter the orbit through the superior orbital fissure along with the ophthalmic branch of the trigeminal nerve (V1). These axons course toward the globe in the long ciliary nerves, which innervate the iris dilator and superior and inferior tarsal muscles within the upper and lower eyelids, respectively. In addition, these sympathetic nerves control the diameter of all vasculature.

The standard view that the only route of entry of sympathetic nerve fibers into the orbit is the ophthalmic artery, a branch of the internal carotid artery that enters the orbit through the orbital foramen, has been challenged in recent years. A large proportion of the sympathetic innervation does enter the orbit hitchhiking on the ophthalmic artery and traveling along its branches within the orbit. However, with the use of specific enzymatic labeling methods, the sympathetic nerve routes within the orbit have turned out to be much more numerous and complex than previously described in standard anatomy textbooks. Sympathetic nerves now are known to enter the orbit by a significant number of other routes, including the first and second divisions of the trigeminal nerve (the ophthalmic and maxillary nerves) as they enter the orbit through the superior orbital fissure. All branches of the ophthalmic division of the trigeminal nerve within the orbit contain sympathetic nerve fibers. Sympathetic nerves from these sensory branches of the trigeminal nerve join and travel within the extraocular motor nerves in the posterior orbit. The smooth muscles that open the eyelid and the superior and inferior tarsal muscles receive their sympathetic innervation from terminal branches of the lacrimal nerves and the infratrochlear branch of the nasociliary nerve. Sympathetic nerve fibers from the nasociliary nerve also run directly through the ciliary ganglion without synapsing and travel distally toward the sclera in long ciliary nerves. Sympathetic innervation also has been seen in the short ciliary nerves by some authors, although there appears to be some variability in this pathway. Within the sclera, the sympathetic nerves reach the iris dilator muscle, the ciliary body, and the trabecular meshwork anteriorly. Injury to these nerves anywhere along their pathway results in Horner's syndrome, which refers to a constellation of signs produced when sympathetic innervation to the eye is interrupted. This results in moderate ptosis due to denervation of the superior tarsal muscle, slight elevation of the lower lid due to denervation of the inferior tarsal muscle, a muscle analogous to the superior tarsal muscle in the upper lid, as well as miosis and dilation lag, that is, pupillary dilation is slowed in the affected pupil.

The zygomatic branch of the maxillary division of the trigeminal nerve carries sympathetic nerve fibers; thus, sympathetic innervation is carried to the lacrimal gland within both the zygomatic and lacrimal nerves. This innervation not only controls vascular diameter, but also directly innervates the secretory acini within the gland. In addition, sympathetic nerve fibers have been demonstrated to enter the orbit within the optic nerve, trochlear nerve, and abducens nerve, again contrary to what has been believed historically.

In summary, the postganglionic sympathetic fibers appear to be distributed to and course in all cranial nerves entering the orbit, as well as within more distal branches. While a large number enter the orbit with the ophthalmic artery as traditionally described, the ophthalmic division of the trigeminal nerve provides a major route for entry of sympathetic fibers into the human orbit.

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*See also:* Congenital Cranial Dysinnervation Disorders; Extraocular Muscles: Extraocular Muscle Anatomy; Extraocular Muscles: Extraocular Muscle Involvement in Disease; Extraocular Muscles: Functional Assessment in the Clinic; Eyelid Anatomy and the Pathophysiology of Blinking; Imaging of the Orbit.
Further Reading


