A Pictorial Review of Cranial Nerves Imaging Anatomy and Pathology: Part 1—Anatomy

Ashwini Kulkarni, MD, Atefeh Geimadi, MD, Ahmed Sobieh, MD, Mohamed Qayati, MD, Ahmed Abbassy, MD, and Aly Abayazeed, MD

After participating in this educational activity, the radiologist should be better able to identify normal cranial nerve anatomy on high-resolution MRI and describe the origin, course, and anatomic relationships of cranial nerves.

Category: Neuroradiology
Subcategory: Brain
Modality: MRI

Key Words: Cranial Nerves, Brain, Head and Neck, Adult

The anatomy of cranial nerves is complex and its knowledge is a crucial first step in identifying nerve-related pathology. This article provides a comprehensive pictorial overview of cranial nerves using high-resolution steady-state free precession MRI sequences (SSFP).

Imaging

MRI is the best imaging modality for the study of cranial nerves. Traditional MRI provides excellent soft tissue resolution, but it lacks the spatial resolution necessary for imaging small intracranial structures. Steady-state free precession MRI (SSFP) sequences offer much higher spatial resolution for imaging of tiny intracranial structures such as cranial nerves.\(^1,2\)

An SSFP sequence is a type of gradient-echo (GRE) sequence that is able to generate strong signals for structures that have an inherent high T2/T1 ratio such as the cerebrospinal fluid (CSF) and fat.\(^3\) This is particularly important for visualization of cisternal regions of cranial nerves due to its submillimetric spatial resolution and its ability to accentuate the contrast resolution of dark cranial nerves against a background of bright CSF signal and the venous plexus.\(^2\) These regions include the cerebellopontine angle, cavernous sinus (CS), basilar plexus behind the clivus, jugular foramen, and hypoglossal canal. Another advantage of SSFP sequences is shorter acquisition time in comparison to traditional MRI imaging pulse sequences, which in turn help to reduce CSF pulsation artifact.

MRI with targeted cranial nerve protocol is suitable for imaging of cranial nerves using high-resolution fluid-sensitive steady-state free precession (SSFP) sequences with optimal spatial and contrast resolution delineating the cranial nerves.

Cranial Nerve Anatomy

There are 12 pairs of cranial nerves\(^1,2\) and a thirteenth cranial nerve, which is sparsely discussed in the medical literature, namely, terminal nerve (cranial nerve 0, anatomically closely approximated to olfactory nerve, but functionally distinct from it).\(^4\) Cranial nerves can provide afferent, efferent, or both innervation and have input from gray matter nuclei organized in the brain stem and cortex. Understanding
Cranial nerve nuclear anatomy within the brain stem is essential for determining the neuroanatomic substrates of neurologic signs and symptoms. Figure 1 demonstrates the approximate locations of important cranial nerve nuclei on high-resolution T1 sequences. Given the limited information on terminal nerves in the clinical literature, the current discussion is focused on CN I to CN XII.

**Cranial nerves can provide afferent, efferent, or both innervation and have input from gray matter nuclei organized in the brain stem and cortex.**

**Olfactory Nerve (CN I)**

The olfactory nerve is the first and the most rostral of cranial nerves and is responsible for the sense of smell. It is one of the two cranial nerves that consist of white matter tracts without being surrounded by Schwann cells. The neurosensory cells for smell reside in the olfactory epithelium along the roof of the nasal cavity. The olfactory filiae are axons of these cells extending through the cribiform plate of the ethmoid bone to terminate in the olfactory bulb within the second-order neurons. The olfactory tract arising from the bulb courses between the gyrus rectus medially and the orbital gyrus laterally. The secondary axons terminate in the inferomedial temporal lobe, parahippocampal gyrus, and entorhinal cortex (Figure 2). On imaging, the olfactory bulb can be best seen on coronal T1 and T2-weighted images, underneath the olfactory sulcus along its anterior end, with the olfactory tract originating from it coursing posteriorly along the base of the frontal lobe in the olfactory sulci. The olfactory tract, however, is often not visualized on imaging due to its small size.3

**Optic Nerve (CN II)**

The optic nerve is an extension of the central nervous system and is responsible for the sense of vision. It consists of white matter tracts not surrounded by Schwann cells and is divided into four anatomic segments: retinal (or intraocular, shortest segment as it emerges through the scleral opening), orbital (longest segment), canalicular (passing through the optic canal along with ophthalmic artery), and cisternal (or prechiasmatic segment, just before the optic chiasm within the suprasellar cistern). The retinal segment leaves the globe through the lamina cribrosa sclerae. The orbital segment is surrounded by a dural sheath containing CSF. The canalicular segment lies in the optic canal. The cisternal segment passes in the suprasellar cistern, where the nerve joins the contralateral optic nerve to form the optic chiasm. From the optic chiasm, the optic tract courses posteriorly along the cerebral peduncles and synapses at the lateral geniculate nuclei. From the lateral geniculate body, the optic radiation terminates in the primary visual cortex in the occipital lobe (Figure 2).6

Understanding cranial nerve nuclear anatomy within the brain stem is essential for determining the neuroanatomic substrates of neurological signs and symptoms.

**Oculomotor Nerve (CN III)**

The oculomotor nerve is responsible for motor supply to all extraocular muscles except lateral rectus (VI) and superior oblique (IV) muscles. It provides parasympathetic supply to ciliary and pupillary constrictor muscles. It originates from nuclei deep to the superior colliculus posteriorly and then travels across the midbrain and emerges into the interpeduncular cistern/perimesencephalic...
The nerve then traverses through the lateral wall of the CS as the most superior of the nerves in the CS. The nerve then enters the orbit through the superior orbital fissure before splitting into superior and inferior divisions lateral to the optic nerve.\(^1,2\)

The Edinger-Westphal nucleus is a small parasympathetic motor nucleus in the midbrain and one of the two nuclei for the oculomotor nerve. The parasympathetic fibers synapse in the ciliary ganglion and postganglionic fibers continue to the globe via the short ciliary nerves to innervate the constrictor pupillae muscle and ciliary body. Therefore, it is important in the functioning of the pupillary light and accommodation reflexes (Figure 3).

**Figure 1.** The major cranial nerve nuclei. Coronal (A) and sagittal (B) three-dimensional T1-weighted images. Edinger-Westphal nucleus (blue), oculomotor nucleus (orange), trochlear nucleus (light blue), trigeminal motor nucleus (red), trigeminal sensory nucleus (magenta), abducens nucleus (violet), facial motor nucleus (yellow), cochlear and vestibular nuclei (blue triangle), hypoglossal nucleus (gray), and vagus motor nucleus (green). Not depicted are the four distinct nuclei, which provide inputs to glossopharyngeal nerve, residing in the medulla oblongata, behind the inferior olivary nucleus, namely, efferent: nucleus ambiguus, inferior salivary nucleus; and afferent: solitary nucleus and sensitive trigeminal nucleus.

**Figure 2.** Coronal SSFP images demonstrate the normal appearance of the olfactory bulbs in the olfactory groove in the anterior aspect of olfactory sulcus (A, solid arrows) and the different segments (intraorbital, canalicular, prechiasmatic, and chiasmatic) of the optic nerve (B, solid arrows). The optic tract is depicted with dotted arrows.

**Trochlear Nerve (CN IV)**

The trochlear nerve supplies motor innervation to superior oblique muscles. Trochlear nuclei are paired nuclei located in the paramedian midbrain, ventral to the cerebral aqueduct, and caudal to the oculomotor nuclear complex at the level of inferior colliculus. It is the only cranial nerve with a root entry zone that is arising from the dorsal brainstem. Its fiber courses dorsally and decussates dorsal to the periaqueductal gray matter before exiting the brainstem. The nerve then rounds the superior cerebellar peduncle in the ambient cistern, eventually along with the oculomotor nerve (CN III); it passes between the posterior cerebral and superior cerebellar arteries. It then runs along the free margin of the tentorium and
enters the CS inferior to CN III and superior to the ophthalmic division (V1) of trigeminal nerve. After passing through the CS, the trochlear nerve enters the orbit through the superior orbital fissure to supply motor innervation to superior oblique muscles1,2,7 (Figure 4).

Trigeminal Nerve (CN V)

The trigeminal nerve is the largest cranial nerve and is composed of sensory and motor roots. It provides motor supply (V1) to muscles of mastication, anterior belly of digastric, mylohyoid, tensor tympani, and palatine muscles. It carries sensory information from the surface of forehead and nose (V1), cheek (V2), and jaw (V3), and the sinuses, meninges, and the external surface of tympanic membrane (TM).

The larger sensory root runs medially to a smaller motor root. The roots emerge from the lateral mid-pons and travel anteriorly through the prepontine cistern to enter the Meckel cave from which the nerve splits into three subdivisions. The ophthalmic (V1) and maxillary (V2) divisions pass in the lateral wall of the CS, inferior to the trochlear nerve (CN IV).

The ophthalmic division exits the skull via the superior orbital fissure (along with CN III, IV, and VI and the superior ophthalmic vein). The maxillary division exits the skull through the foramen rotundum, crosses the pterygopalatine fossa and then enters the orbit via the inferior orbital fissure, passes within the infraorbital canal, and reaches the face through the infraorbital foramen. The mandibular division (V3) exits the skull via the foramen ovale and passes in the infratemporal fossa, where it divides into several branches (meningeal branch, medial and lateral pterygoid nerves, mas- seteric nerve, deep temporal nerve, buccal nerve, auriculotemporal nerve, lingual nerve, and inferior alveolar nerve).1,2 The auriculotemporal branch communicates with the facial nerve within the parotid gland (Figure 3).

Abducens Nerve (CN VI)

The abducens nerve provides motor supply to lateral rectus muscle only. It originates from nuclei anterior to the fourth ventricle, then courses anteriorly through the pontomedullary junction into the prepontine cistern. It ascends near the posterior aspect of the clivus, passing through the Dorello canal, and enters the CS. It passes through the central portion of the CS as the only cranial nerve traveling through the substance of the CS. Finally, it enters the orbit via the superior orbital fissure to innervate the lateral rectus muscle (Figure 5).1,2

Facial Nerve (CN VII)

The facial nerve carries motor fibers to the muscles of facial expression via terminal motor branches and the stapedius muscle via the stapedius nerve. It carries parasympathetic fibers to the lacrimal glands via the greater superficial petrosal nerve, and the submandibular and sublingual glands. It carries taste sensation from the anterior two-thirds of tongue via the chorda tympani nerve. It also provides general sensation for the periauricular skin and external surface of the TM. The facial nerve has two roots in the brainstem—the larger motor root and the smaller sensory root (nervus intermedius). The nervus intermedius exits the lateral brainstem between the motor root of the facial nerve and the vestibulocochlear nerve, hence the name.

The facial nerve consists of the following segments: supranuclear, nucleus and tracts, cisternal segment, intratemporal segment, and peripheral segment. The nerve fibers within the pons create a loop surrounding the nucleus of the abducens nerve (CN VI), forming the facial colliculus along the posterior surface of the pons. It exits the lateral aspect of the lower border of the pons at the recess between the olive and the superior cerebellar peduncle. The cisternal segment of

Figure 3. Axial SSFP images demonstrate the normal appearance and course of the oculomotor nerve (A, solid arrows) and the trigeminal nerve (B, dotted arrows).

Figure 4. Axial SSFP showing the right-sided CN IV, trochlear nerve arising from the dorsal midbrain (white arrow), after decussating dorsal to periaqueductal grey matter before exiting the midbrain.
Cerebellopontine Angle Cistern

The nerve crosses the cerebellopontine angle cistern at an oblique angle (in close proximity to the vestibulocochlear nerve) to enter the porus acusticus of the internal auditory canal (IAC) and traverse the length of the canal (Figures 6 and 7). It is located in the anterosuperior quadrant of the IAC.

The intratemporal segment of the nerve has three segments: labyrinthine, tympanic, and mastoid. The shorter labyrinthine segment passes from the fundus of the IAC to end within the geniculate ganglion giving the greater superficial petrosal nerve as its first branch. The proximal tympanic segment passes along the medial wall of the anterior epitympanic recess. The distal tympanic segment lies within the pyramidal eminence posteriorly within the middle ear cavity. The mastoid segment passes lateral to the jugular foramen giving two branches, the stapedius nerve and the chorda tympani. The nerve then exits the skull at the stylomastoid foramen and enters the parotid gland where it divides into its terminal branches: temporal, zygomatic, buccal, mandibular, and cervical branches.

Glossopharyngeal Nerve (CN IX)

The glossopharyngeal nerve provides motor supply to the stylopharyngeus muscle—parasympathetic to the parotid gland and visceral sensory to the carotid body. It gives a taste sensation to the posterior one-third of the tongue. It gives general sensation to the posterior one-third of the tongue and internal surface of the TM. It arises from the lateral aspect of the medulla and passes within the lateral cerebellomedullary cistern, where it is closely related to the flocculus of the cerebellum. It exits the skull through the pars nervosa of the

Vestibulocochlear Nerve (CN VIII)

The vestibulocochlear nerve is a purely sensory nerve and functions as a sense of hearing (cochlear) and balance (vestibular). It has the same cisternal and canalicular course as the facial nerve where it arises from the lateral aspect of the lower border of the pons and passes through the cerebellopontine angle cistern at an oblique angle to enter the porus acusticus of the IAC and traverse the length of the canal. Within the IAC, it divides into three parts (cochlear, superior vestibular, and inferior vestibular). The cochlear branch courses inferior to CN VII; the superior and inferior vestibular nerves are posterior in the IAC (Figures 5 and 7).

The cochlear nerve carries sensory information from bipolar neurons within the spiral ganglion of modiolus of cochlea and the vestibular nerve provides sensory information from bipolar neurons in the vestibular (Scarpa) ganglion. Scarpa’s ganglia can enhance physiologically due to a surrounding venous plexus and mimic a vestibular schwannoma. Correlation with high-resolution SSFP sequences can aid detection of a nodular lesion, which is typically seen with a schwannoma. The cochlear and vestibular components join in the IAC.

Glossopharyngeal Nerve (CN IX)

The glossopharyngeal nerve provides motor supply to the stylopharyngeus muscle—parasympathetic to the parotid gland and visceral sensory to the carotid body. It gives a taste sensation to the posterior one-third of the tongue. It gives general sensation to the posterior one-third of the tongue and internal surface of the TM. It arises from the lateral aspect of the medulla and passes within the lateral cerebellomedullary cistern, where it is closely related to the flocculus of the cerebellum. It exits the skull through the pars nervosa of the

Figure 5. Axial SSFP images demonstrate the normal appearance and course of the abducens nerves (A, solid arrows) and the left cochlear and inferior-vestibular nerves (B, dotted arrows).

Figure 6. Axial SSFP images demonstrate the normal appearance and course of the facial nerves (A, solid arrows), the glossopharyngeal nerve (B, dotted arrows). In the axial plane, these may overlap the vagus nerve and may be difficult to delineate separately.
It is the longest cranial nerve and arises laterally from the medullary posterolateral sulcus between the glossopharyngeal and accessory nerves. It then crosses the lateral cerebellomedullary cistern at an oblique angle inferior and parallel to the glossopharyngeal nerve. It then enters the jugular fossa and leaves the skull through the pars vascularis of the jugular foramen.

The nerve then descends the neck within the carotid sheath between the internal jugular vein and the internal carotid artery. Within the thorax, the right vagus nerve passes anterior to the origin of the right subclavian artery (SCA) and then descends along the right side of the trachea deep to the azygos vein. Then it passes posteriorly to the root of the right lung. The left vagus nerve courses between the left subclavian and left common carotid arteries behind the left brachiocephalic vein in the left side of the mediastinum anterior to the aortic arch and then passes behind the root of the left lung. Both nerves enter the jugular foramen where it is surrounded by its own dural sheath and lies anterior to the vagus and accessory nerves in the pars vascularis. Extracranially, it descends posterior to the internal carotid artery, and then superficial to the stylopharyngeus muscle and the inferior aspect of the palatine tonsil. Finally, it crosses deep to the hyoglossus muscle to end at the back of the tongue providing taste sensation to its posterior third.

The tympanic branch (Jacobson nerve), which arises from inferior sensory ganglion in jugular foramen, carries sensation from the middle ear and parasympathetic to parotid gland via the lesser petrosal nerve and otic ganglion. It forms a tympanic plexus on the cochlear promontory, which is related to glomus tympanicum paraganglioma10,11 (Figure 6).

**Vagus Nerve (CN X)**

The vagus nerve provides motor supply to the pharynx and the larynx. It gives parasympathetic and visceral sensory supply to the pharynx, larynx, thoracic, and abdominal viscera. It provides a general sensation from a small area around the external ear.

**Figure 7.** Oblique sagittal SSFP images demonstrate the arrangement of the facial, vestibular, superior, and inferior vestibular nerves within the IAC. A fifth nerve (nervus intermedius) that runs in the IAC is too small to be visualized.

**Figure 8.** Vagus nerve (CN X), arising from the lateral medulla (arrow), posterior to CN IX. Often in the axial plane, CN IX and CN X cannot be separately resolved and can be better delineated using oblique axial or coronal reformats.

**Figure 9.** Cranial rootlets of spinal accessory nerve (CN XI) (white oval) arising from the cervicomедullary junction.

It is the longest cranial nerve and arises laterally from the medullary posterolateral sulcus between the glossopharyngeal and accessory nerves. It then crosses the lateral cerebellomedullary cistern at an oblique angle inferior and parallel to the glossopharyngeal nerve. It then enters the jugular fossa and leaves the skull through the pars vascularis of the jugular foramen.

The nerve then descends the neck within the carotid sheath between the internal jugular vein and the internal carotid artery. Within the thorax, the right vagus nerve passes anterior to the origin of the right subclavian artery (SCA) and then descends along the right side of the trachea deep to the azygos vein. Then it passes posteriorly to the root of the right lung. The left vagus nerve courses between the left subclavian and left common carotid arteries behind the left brachiocephalic vein in the left side of the mediastinum anterior to the aortic arch and then passes behind the root of the left lung. Both nerves enter the
abdomen through the esophageal hiatus and continue as the anterior and posterior vagal trunks respectively.

The branch of the recurrent laryngeal nerve, on the right, arises at the cervicothoracic junction, and passes posteriorly around the SCA. On the left, it recurs in the mediastinum, and passes posteriorly under the aorta to the aortopulmonary window. They travel in the tracheoesophageal groove posteriorly to thyroid lobe and enter the larynx at cricothyroid join level. It supplies motor function to all laryngeal muscles except the cricothyroid muscle. It also provides sensory information to the mucosa of infra-glottis.

The auricular branch (Arnold nerve) carries sensation from the external surface of the TM, external auditory canal, and external ear. It is the source of glomus jugulotympanicum paraganglioma from the nonchromaffin paraganglion cells. It is also responsible for the referred otalgia through the vagus nerve (CN X), in the case of laryngeal pathology. On imaging, CN IX and X are often difficult to distinguish in the axial plane and may overlap each other; in those scenarios, axial oblique or coronal oblique images may be useful (Figure 8).10

Accessory Nerve (CN XI)

The accessory nerve provides motor supply to sternocleidomastoid and trapezius muscles. It has cranial and spinal roots. The cranial roots arise from the side of the medulla and then course through the lateral cerebellomedullary cistern below the vagus nerve. The spinal roots arise from the upper part of the cervical cord, and then course superiorly through the foramen magnum to join the cranial roots in the lateral cerebellomedullary cistern. The nerve then exits the skull through the jugular foramen pars vascularis. Extracranially, the nerve courses between the internal carotid artery and the internal jugular vein. The cranial fibers of the nerve join the vagus nerve whereas the spinal fibers (joined by branches of the cervical nerves) pass superficially to the internal jugular vein to supply the sternocleidomastoid and trapezius muscles.7 On imaging, the rootlets are occasionally visualized arising laterally from the cervicomедullary junction, however, not consistently visualized due to their small size and pulsation artifact in this region from the vertebral arteries (Figure 9).10

Hypoglossal Nerve (CN XII)

The hypoglossal nerve provides motor supply to intrinsic and extrinsic tongue muscles except the palatoglossus muscle, which is supplied by the pharyngeal branch of vagus nerve (CN X). It is an entirely motor nerve that arises from nuclei located within the dorsal medulla in front of the fourth ventricle. The nerve exits the medulla through the ventrolateral sulcus to traverse the lateral cerebellomedullary cistern in close proximity with the vertebral artery. It exits through the hypoglossal canal and passes within the carotid space medial to the glossohygeyneal, vagus, and accessory nerves, deep to the digastic muscle, looping over the hyoid bone to supply the intrinsic and extrinsic muscles of the tongue (Figure 10).12

Conclusion

Understanding the normal anatomy and course of cranial nerves is the first step in identifying pathology. The combination of traditional MRI with SSFP sequence has greatly improved the imaging of small intracranial structures, especially cranial nerves. Steady-state sequences are fast GRE sequences with very high signal-to-noise and contrast-to-noise ratio. In addition, the fast acquisitions make steady-state sequences advantageous in reducing the effects of CSF pulsation artifacts.

Acknowledgment

The authors thank Sathish Kumar Dundadappada, MD, Prachi Dubey, MBBS, MPH, and Amy Juliano, MD, for assistance with the article.

References

1. The best MRI sequence for evaluating the cranial nerves is
   A. SWI.
   B. T2.
   C. FLAIR.
   D. thin-section multiplanar SSFP

2. The two cranial nerves that are not surrounded by Schwann cells are
   A. III and I.
   B. IV and II.
   C. I and II.
   D. III and IV.

3. The only cranial nerve that arises from the posterior surface of the brain stem is CN
   A. III.
   B. IV.
   C. V.
   D. VI.

4. All of the following nerves traverse through the lateral wall of the CS except CN
   A. III.
   B. IV.
   C. V1.
   D. V2.
   E. V3.

5. All of the following nerves traverse through the superior orbital fissure except CN
   A. III.
   B. IV.
   C. V1.
   D. V2.

6. After exiting the brain stem, the abducens nerve traverses through
   A. Meckel’s cave.
   B. the Dorello canal.
   C. the IAC.
   D. the foramen rotundum.

7. In the IAC, the facial nerves are located
   A. anterosuperior.
   B. anteroinferior.
   C. posterosuperior.
   D. posteroinferior.

8. Which one of the following cranial nerves enters the orbit via superior orbital fissure?
   A. V2
   B. VIII-cochlear
   C. VIII-vestibular
   D. VI

9. The cranial nerve that traverses the pars nervosa of the jugular foramen is CN
   A. IX.
   B. X.
   C. XI.
   D. XII.

10. Which one of the following cranial nerves traverses most medially within the carotid space?
    A. IX
    B. X
    C. XI
    D. XII