As radiologic imaging technology improves and more intricate details of the anatomy can be evaluated, images provide more precise diagnostic information and allow better localization of abnormalities. For example, standard T2-weighted magnetic resonance (MR) imaging sequences adequately depicted only the larger cranial nerves, whereas current steady-state free precession (SSFP) sequences are capable of depicting the cisternal segments of all 12 cranial nerves. SSFP sequences provide submillimetric spatial resolution and high contrast resolution between cerebrospinal fluid and solid structures, allowing the reconstruction of elegant multiplanar images that highlight the course of each nerve. These sequences have become a mainstay in the evaluation of the cerebellopontine angles and inner ear. Usually referred to by their trade names or acronyms (eg, constructive interference steady state, or CISS, and fast imaging employing steady-state acquisition, or FIESTA), SSFP sequences allow precise differentiation between branches of the facial and vestibulocochlear nerves, accurate detection of small masses in the cerebellopontine angles and internal auditory canals, and detailed evaluation of endolymph and perilymph within the inner ear. To take full advantage of these imaging sequences, radiologists must be familiar with the appearances of similar anatomic details of all 12 cranial nerves on SSFP MR images.

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Abbreviations: CSF = cerebrospinal fluid, SSFP = steady-state free precession

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Figures 1, 2. Olfactory nerve. (1) Axial (a) and coronal (b) 0.8-mm-thick SSFP MR images show the olfactory nerve (white arrow) within the CSF-filled olfactory groove and the optic nerve (black arrow in b) ringed by high-signal-intensity CSF within the dural sheath. (2) Coronal 1.0-mm-thick SSFP MR image shows the cisternal segment of the olfactory nerve (arrow), which is located inferior to and between the gyrus rectus (r) and the medial orbital gyrus (o).

Introduction
The anatomy of the cranial nerves is complex, and the evaluation of patients with cranial neuropathies requires an in-depth understanding of the normal course of these important structures. Whereas traditional magnetic resonance (MR) imaging sequences provide excellent soft-tissue resolution, they may lack the spatial resolution necessary to define smaller structures such as cranial nerves. Steady-state free precession (SSFP) sequences allow much higher spatial resolution and clearer depiction of tiny intracranial structures.

An SSFP sequence is any gradient-echo sequence in which a nonzero steady state develops between pulse repetitions for both the longitudinal and transverse relaxation values of the interrogated tissues. A small flip angle and short relaxation time are required for this to occur (1). The clinical utility of an SSFP sequence lies in its ability to generate a strong signal in tissues that have a high T2/T1 ratio, such as cerebrospinal fluid (CSF) and fat. SSFP sequences are particularly useful for visualizing the cisternal segments of cranial nerves because they provide excellent contrast resolution between CSF and nerves, as well as high spatial resolution with submillimetric section thicknesses (2). Another advantage is that the total acquisition time with SSFP sequences is shorter than that with traditional MR imaging pulse sequences, helping to reduce CSF pulsation artifact (3). The disadvantages of SSFP imaging include reduced contrast resolution between different soft tissues. In addition, global landmarks may be poorly depicted because of the submillimetric section thicknesses. Thus, SSFP sequences play a supplemental role alongside traditional sequences in MR imaging of the cranial nerves.

The article describes the normal appearances of the cisternal segments of the 12 cranial nerves, emphasizing the radiologic and anatomic landmarks that demarcate the expected locations of these nerve segments and distinguish them from other small curvilinear structures, such as blood vessels. Common pitfalls that are associated with the use of SSFP pulse sequences to assess the cranial nerves are reviewed.

Cranial Nerve I: The Olfactory Nerve
Unlike most cranial nerves, the olfactory nerve consists of white-matter tracts and is not surrounded by Schwann cells. The neurosensory
cells for smell reside in the olfactory epithelium along the roof of the nasal cavity (4). The axons of these cells extend through the cribriform plate of the ethmoid bone into the olfactory bulb at the anterior end of the olfactory nerve. The nerve then courses posteriorly through the anterior cranial fossa in the olfactory groove (Fig 1). Posterior to the olfactory groove, the cisternal segment of the nerve runs below and between the gyrus rectus and the medial orbital gyrus (Fig 2). These secondary axons in the olfactory nerve eventually terminate in the inferomedial temporal lobe, uncus, and entorhinal cortex.

To avoid confusing the olfactory nerve with the gyrus rectus on axial images, it is important to remember that the olfactory nerve is situated deep in the olfactory groove, inferior to the gyrus rectus. Coronal images are easiest to interpret because the nerves are seen in cross section.

Cranial Nerve II: The Optic Nerve

Like the olfactory nerve, the optic nerve is a white-matter tract without surrounding Schwann cells. It includes four anatomic segments: retinal, orbital, canalicular, and cisternal (Fig 3). The retinal segment leaves the ocular globe through the lamina cribrosa sclerae (the optic foramen of the sclera). The orbital segment, which is surrounded by a dural sheath containing CSF, travels through the center of the fat-filled orbit (4). The canalicular segment is the portion that lies in the optic canal, below the ophthalmic artery. This segment of the nerve is frequently overlooked on radiologic images, so it should be specifically sought when imaging for vision loss. Finally, the cisternal segment of the nerve can be visualized in the suprasellar cistern, where the nerve leads to the optic chiasm. The anterior cerebral artery passes over the superolateral aspect of the cisternal segment of the nerve.

Key anatomic landmarks in the suprasellar cistern include the infundibulum (stalk) of the pituitary gland, the anterior cerebral artery, and, posterior to the chiasm, the mamillary bodies (Fig 4). The optic nerve terminates at the optic chiasm, where the two nerves meet, decussate, and form the optic tracts. The optic tracts travel around the

Figures 3, 4.  Optic nerve. (3) Axial oblique 0.8-mm-thick SSFP MR image shows three of four segments of the optic nerve: the retinal (black arrow), orbital (black arrowheads), and canalicular (white arrowhead) segments. The infundibulum of the pituitary gland (white arrow) also is seen. The fourth (cisternal) segment of the optic nerve would be visible on more superior images. (4) Axial MR image obtained with a T2-weighted fast spin-echo sequence and a section thickness of 3 mm provides better depiction of global anatomic relationships than do images obtained with SSFP sequences. The cisternal segment of the optic nerve (white arrow) leads to the chiasm, which resembles the Greek letter χ in this plane. The optic tract (white arrowheads) leads backward from the chiasm to the thalamus. Important anatomic landmarks include the mamillary bodies (black arrowhead) and the anterior cerebral artery (black arrow).
The oculomotor nerve then enters the orbit and is the most superior of the nerves in this set. It runs along the lateral wall of the cavernous sinus and posterior cerebral arteries, which makes it the nerve travels between the superior cerebellar peduncles, after which most axons enter the lateral geniculate body of the thalamus, loop around the inferior horns of the lateral ventricles (Meyer loop), and enter the visual cortex in the occipital lobe. These anatomic segments can be readily identified and precisely distinguished from adjacent disease on SSFP images (Fig 5).

Because a single image obtained with an SSFP sequence usually depicts only a short segment of the optic nerve, thick-section reconstruction of SSFP acquisitions may be needed to allow examination of the entire length of the nerve on a single image. Standard T2-weighted images also are useful for this purpose (Fig 4).

Cranial Nerve III: The Oculomotor Nerve

The oculomotor nerve originates from nuclei deep to the superior colliculus, ventral to the cerebral aqueduct, and inferior to the pineal gland. The nerve then travels across the midbrain from posterior to anterior. The oculomotor nerve root emerges into the interpeduncular cistern, and this root entry zone in the cistern is a good way to identify the oculomotor nerve on axial SSFP MR images (Fig 6). In the preopticine cistern, the nerve travels between the superior cerebellar and posterior cerebral arteries, which makes it easy to identify on coronal SSFP images (Fig 7). The cavernous segment of the oculomotor nerve runs along the lateral wall of the cavernous sinus and is the most superior of the nerves in this sinus. The oculomotor nerve then enters the orbit through the superior orbital fissure, before splitting into superior and inferior divisions lateral to the optic nerve. Knowledge of this anatomy may be helpful for identifying the precise location of a nerve abnormality (Fig 8).

Cranial Nerve IV: The Trochlear Nerve

The trochlear nerve is the only nerve with a root entry zone arising from the dorsal (posterior) brainstem. After exiting the pons, the trochlear nerve curves forward over the superior cerebellar peduncle, then runs alongside the oculomotor nerve between the posterior cerebral and superior cerebellar arteries (4). The trochlear nerve then pierces the dura to enter the cisterna basalis between the free and attached borders of the cerebellar tentorium.

After completing its cisternal course, the trochlear nerve runs through the lateral cavernous sinus just below the oculomotor nerve and enters the orbit through the superior orbital fissure to innervate the superior oblique muscle. The nerve is named for the trochlea, the fibrous pulley through which the tendon of the superior oblique muscle passes.

The cisternal segment of this tiny nerve is most easily identifiable posterolateral to the brainstem (Fig 9). Along part of its intracranial course, the trochlear nerve lies between dural layers, where it is difficult to visualize on radiologic images. Particular attention should be given to the anterior aspect of the tentorium in patients in whom the presence of isolated trochlear nerve palsy is suspected.
Figure 8. Oculomotor nerve compression in an 82-year-old woman with ptosis of the right eye. Axial 0.8-mm-thick SSFP MR image shows displacement and compression of the right oculomotor nerve in the root entry zone (long arrow) by the distal basilar artery (short arrow). The left oculomotor nerve (arrowhead), in comparison, appears normal.

Figure 9. Trochlear nerve. Axial 0.8-mm-thick SSFP MR image shows both trochlear nerves (arrows) where they emerge from the dorsal midbrain to cross the ambient cisterns. The characteristic course of the trochlear nerves allows their differentiation from the nearby superior cerebellar artery (arrowheads).
**Figure 10.** Trigeminal nerve. Axial 0.8-mm-thick SSFP MR image shows the sensory (arrowhead) and motor (large arrow) roots of the trigeminal nerve where they cross the prepontine cistern and enter the Meckel cave (small arrows).

**Figure 11.** Trigeminal nerve. Coronal 0.8-mm-thick SSFP MR image at the level of the Meckel cave shows the complex web of trigeminal nerve branches (arrows), which coalesce anteriorly to form the gasserian ganglion. The temporal horn of the lateral ventricle (arrowhead) is also shown.

**Figure 12.** Abducens nerve. Axial 0.8-mm-thick SSFP MR image at the level of the pontomedullary junction shows both abducens nerves (arrows) where they traverse the prepontine cistern. The bottom of the pons (p) and the top of the medulla (m) are visible in this section, and the cerebellopontine angle (CPA) and basilar artery (arrowhead) are important anatomic landmarks.

**Figure 13.** Abducens nerve. Axial 0.8-mm-thick SSFP MR image shows the abducens nerve where it enters the Dorello canal (arrow) along the posterior aspect of the clivus. Vascular landmarks include the basilar artery (black arrowhead) and the anterior inferior cerebellar artery (white arrowhead).
Cranial Nerve V: The Trigeminal Nerve

The trigeminal nerve is the largest cranial nerve. It is composed of a large sensory root that runs medial to a smaller motor root. The roots emerge from the lateral midpons and travel anteriorly through the prepontine cistern and the porus trigeminus to the Meckel (trigeminal) cave, a CSF-containing pouch in the middle cranial fossa (Fig 10). Because the trigeminal nerve is large and its course proceeds straight forward from the lateral pons, it is easy to recognize on most MR images.

In the Meckel cave, the nerve forms a meshlike web that can be visualized only with high-resolution imaging (Fig 11). Along the anterior aspect of the cavity, the trigeminal nerve forms the trigeminal (gasserian) ganglion before splitting into three subdivisions. The ophthalmic (V₁) and maxillary (V₂) divisions of the nerve move medially into the cavernous sinus and exit the skull through the superior orbital fissure and foramen rotundum, respectively. The mandibular division (V₃), which includes the motor branches, exits the skull inferiorly through the foramen ovale.

Cranial Nerve VI: The Abducens Nerve

The abducens nerve emerges from nuclei anterior to the fourth ventricle, then courses anteriorly through the pons to the pontomedullary junction and into the prepontine cistern (Fig 12). After crossing the prepontine cistern in a posterior-to-anterior direction, the abducens nerve runs vertically along the posterior aspect of the clivus, within a fibrous sheath called the Dorello canal (Fig 13). The nerve then continues over the medial petrous apex and through the medial cavernous sinus, entering the orbit through the superior orbital fissure to innervate the lateral rectus muscle.

It is important to note that the abducens nerve runs almost the entire length of the clivus. Radiologists should be vigilant for clivus and petrous apex abnormalities in the setting of abducens nerve palsy. Although the abducens nerve lies near the anterior inferior cerebellar artery and has a similar caliber, the two structures course in orthogonal directions and are thus easily distinguished (Fig 13).

Cranial Nerves VII and VIII: The Facial and Vestibulocochlear Nerves

The facial and vestibulocochlear nerves have similar cisternal and canalicular courses (Fig 14). They both emerge from the lateral aspect of the lower border of the pons and traverse the cerebellopontine angle cistern at an oblique angle. There, they may be in close proximity to the anterior inferior cerebellar artery. Next, the nerves cross the porus acusticus (an opening between the cerebellopontine angle cistern and the internal auditory canal; also known as the internal acoustic meatus) and traverse the length of the internal auditory canal. Radiologic images that precisely depict the relationship of the nerves to masses in the cerebellopontine angle can help in surgical planning (Fig 15).
Within the internal auditory canal, the vestibulocochlear nerve splits into three parts (cochlear, superior vestibular, and inferior vestibular). These three vestibulocochlear nerve branches, along with the facial nerve, have a characteristic appearance on sagittal oblique SSFP cross-sectional images (Fig 16). Images in that plane are most frequently used for the detection of cochlear nerve aplasia.

On any single axial SSFP image, only two of the four nerves within the internal auditory canal typically are visible. If one of the nerves is seen to enter the modiolus of the cochlea, then the two visible nerves are the cochlear and inferior
vestibular nerves. If the central modiolus is not depicted on the image, the visible nerves are the facial and superior vestibular nerves. A filling defect within the membranous labyrinth on SSFP images may signal a nerve abnormality in a branch of the facial or vestibulocochlear nerve.

The facial nerve exits the internal auditory canal and enters the facial canal via the fallopian aqueduct on the anterior aspect of the Bill bar. After a complex course within the petrous bone, the facial nerve exits the skull base through the stylomastoid foramen and enters the substance of the parotid gland.

Cranial Nerve IX: The Glossopharyngeal Nerve

The glossopharyngeal nerve emerges from the lateral medulla into the lateral cerebellomedullary cistern, above the vagus nerve and at the level of the filling defect. In the lateral cerebellomedullary cistern, the glossopharyngeal nerve is closely associated with the flocculus of the cerebellum (Fig 17). The flocculus is a lobule of cerebellar tissue that is directly adjacent to the glossopharyngeal nerve, and it should not be mistaken for an abnormality.

From the lateral cerebellomedullary cistern, the nerve plunges into the jugular fossa and exits the skull through the jugular foramen. In the jugular foramen, the glossopharyngeal nerve is anterior to the vagus and accessory nerves and is surrounded by its own dural sheath (the glossopharyngeal canal).

Cranial Nerve X: The Vagus Nerve

The vagus nerve comprises two roots that emerge from the side of the medulla, from a groove called the posterolateral sulcus. Leaving the medulla, the nerve roots enter the lateral cerebellomedullary cistern in a position inferior to the glossopharyngeal nerve and run parallel to it through the cistern. Because of their parallel course, it may be difficult to distinguish between the glossopharyngeal and vagus nerves on axial SSFP images; coronal or oblique coronal views along the course of the nerves probably are best for that purpose (Fig 17).

After obliquely traversing the lateral cerebellomedullary cistern (Fig 18), the vagus nerve enters the jugular fossa and exits the skull through the jugular foramen, between the glossopharyngeal and accessory nerves. In the neck, the vagus nerve lies within the carotid sheath, behind and between the internal jugular vein and common carotid artery.
Cranial Nerve XI: The Accessory Nerve

The accessory nerve is composed of multiple cranial and spinal rootlets. The cranial rootlets emerge into the lateral cerebellomedullary cistern below the vagus nerve (Fig 19). The spinal rootlets emerge from upper cervical segments of the spinal cord (Fig 20).

After leaving the spinal cord, the spinal rootlets pass superiorly through the foramen magnum into the cisterna magna (ie, the posterior cerebellomedullary cistern), in a position posterior to
the vertebral artery, and join the cranial rootlets in the lateral cerebellomedullary cistern. The conjoined nerve fibers then leave the skull through the jugular foramen, posterior to the glossopharyngeal and vagus nerves.

Segmental spinal nerve roots at the C1 and C2 levels are distinguishable from accessory nerve rootlets at these levels because the spinal nerve roots are larger and extend to the neural foramina instead of continuing superiorly.

Cranial Nerve XII: The Hypoglossal Nerve

The hypoglossal nerve arises from nuclei in front of the fourth ventricle, within the medulla, and emerges as a series of rootlets extending from the ventrolateral sulcus of the medulla into the lateral cerebellomedullary cistern (Fig 21). The combined rootlets then cross the lateral cerebellomedullary cistern, where the nerve is surrounded anteriorly by the vertebral artery and posteriorly by the posterior inferior cerebellar artery (Fig 22). The hypoglossal nerve then exits the skull via the hypoglossal canal, which runs obliquely in the axial plane, at an angle of approximately 45° between the coronal and sagittal planes. After exiting the skull, the hypoglossal nerve runs medial to the glossohypharyngeal, vagus, and accessory nerves and deep to the digastric muscle, looping over the hyoid bone to innervate a large part of the tongue.

Conclusions

With the use of traditional MR imaging pulse sequences, it may be difficult to evaluate the cisternal segments of the cranial nerves, which are small in diameter and are located in close proximity to many other anatomic structures. SSFP sequences depict these nerve segments in greater detail and can provide important information about the relationship of the nerves to pathologic processes. To take full advantage of this information, radiologists must be familiar with the expected nerve anatomy and relevant anatomic landmarks.

References

Appearance of Normal Cranial Nerves on Steady-State Free Precession MR Images

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