Cisternal segments of the glossopharyngeal, vagus, and accessory nerves: detailed magnetic resonance imaging—demonstrated anatomy and neurovascular relationships

Clinical article

JENNIFER LINN, M.D.,1 BERNHARD MORIGGL, M.D.,2 FRIEDERIKE SCHWARZ,1 THOMAS P. NAIDICH, M.D., Ph.D.,3 URS D. SCHMID, M.D.,4 MARTIN WIESMANN, M.D.,1 HARTMUT BRUCKMANN, M.D.,4 AND INDRA YOUSRY, M.D.1

1Department of Neuroradiology, University Hospital Munich, Germany; 2Institute of Anatomy, Histology, and Embryology, Medical University Innsbruck, Austria; 3Department of Radiology, Section of Neuroradiology, Mount Sinai Medical Center, New York; and 4Neurosurgical Unit, Klinik Im Park, Zurich, Switzerland

Object. The aim of this study was to determine whether high-resolution MR imaging is suitable for identifying and differentiating among the nerve root bundles of the glossopharyngeal (cranial nerve [CN] IX), vagus (CN X), and accessory nerves (CN XI) as well as any adjacent vessels.

Methods. Twenty-five patients (50 sides) underwent MR imaging using the 3D constructive interference in steady-state (CISS) sequence, as well as noncontrast and contrast-enhanced 3D time-of-flight (TOF) MR angiography. Two individuals scored these studies by consensus to determine how well these sequences displayed the neurovascular contacts and nerve root bundles of CNs IX and X and the cranial and spinal roots of CN XI. Landmarks useful for identifying each lower CN were specifically sought.

Results. The 3D CISS sequence successfully depicted CNs IX and X in 100% of the sides. Nerve root bundles of the cranial segment of CN XI were identified in 88% of the sides and those of the spinal segment of CN XI were noted in 93% of the sides. Landmarks useful in identifying the lower CNs included the vagal trigone, the choroid plexus of the lateral recess, the glossopharyngeal and vagal meatus, the inferior petrosal sinus, and the vertebral artery. The combined use of 3D CISS and 3D TOF sequences demonstrated neurovascular contacts at the nerve root entry or exit zones in 19% of all nerves visualized.

Conclusions. The combined use of 3D CISS MR imaging and 3D TOF MR angiography (with or without contrast) successfully displays the detailed anatomy of the lower CNs and adjacent structures in vivo. These imaging sequences have the potential to aid the preoperative diagnosis of and the presurgical planning for pathology in this anatomical area. (DOI: 10.3171/2008.3.17472)

KEY WORDS • accessory nerve • glossopharyngeal nerve • magnetic resonance imaging • neurovascular relationship • vagus nerve

THE glossopharyngeal and vagus nerves and the cranial component of the accessory nerve are together designated the lower CN complex. The nuclei of these nerves are located in the medulla oblongata. The dorsal vagal nuclei form the bulging vagal trigone on the floor of the fourth ventricle.6 Cranial nerves IX, X, and XI arise from the medulla oblongata as a line of rootlets distributed along the posterior edge of the inferior olive in the postolivary sulcus. These rootlets coalesce to form nerve root bundles, which then traverse the lateral cerebellomedullary cistern. The bundles enter the jugular foramen close to each other through dural openings designated the glossopharyngeal meatus (for CN IX) and the vagal meatus (for CNs X and XI).27 A permanent dural septum separates the glossopharyngeal from the vagal meatus. Cranial nerve XI is traditionally considered to have both a cranial component (crCN XI) and a spinal root (spCN XI); however, the existence of a crCN XI is disputed, with different authors assigning the “traditional” crCN XI rootlets to either CN X or XI.17,40

Magnetic resonance imaging has been used successfully to visualize CNs and associated lesions within the basal cisterns.2,3,41,42,44–46 To our knowledge, however, only 1 imaging study has revealed the anatomy of the lower CN complex in detail.23 Pathological entities such as schwannomas1,4 and meningiomas5 can affect the cisternal portions of the lower CN complex. Compression of the REZ...
Magnetic resonance imaging–demonstrated anatomy of the cranial nerves

or RExZ by vessels or tumors can cause glossopharyngeal neuralgia.\textsuperscript{15,18,23} Surgically treating these lesions can cause iatrogenic lower CN pathology.\textsuperscript{22} Therefore, successfully displaying the anatomy of the caudal CN complex in vivo should help physicians to identify pathology, assess the extent of disease, formulate short differential diagnoses, and plan for successful surgical therapy for the pathology displayed.

Our specific aims in this study were to 1) determine whether high-resolution MR imaging of the lateral medullary cistern could reliably visualize and differentiate among the root bundles of CN IX, CN X, crCN XI, and spCN XI; 2) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; 3) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; 4) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; 5) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; 6) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; 7) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; 8) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI; and 9) discover the exact relationships among the root bundles of CN IX, CN X, crCN XI, and XI.

Methods

Patient Characteristics

The study group included 25 patients (11 men and 14 women, with a mean age of 58.3 years [range 29–81 years]) who had undergone contrast-enhanced MR imaging for reasons unrelated to the infratentorial compartment and who agreed to undergo additional 3D CISS MR imaging, noncontrast 3D TOF MR angiography, and contrast-enhanced 3D TOF MR angiography pulse sequences. None of these patients had clinical abnormalities known to affect the lower CN complex or any other pathology affecting the infratentorial compartment. Imaging studies from 3 additional patients were also included to illustrate the clinical relevance of the MR imaging pulse sequences in evaluating the pathology of the lower CNs.

The study was approved by the review board of the department and conformed to the Declaration of Helsinki. Before beginning the study, all patients gave written informed consent to participate.

Magnetic Resonance Imaging Procedures

Data were obtained on a 1.5-T unit (Magnetom Vision [17 patients] or Symphony [8 patients], Siemens) with a standard quadrature head coil by using 3D CISS MR imaging, noncontrast 3D TOF MR angiography, and contrast-enhanced 3D TOF MR angiography (starting 3 minutes after contrast administration) to display fine anatomical detail. The following pulse sequence was used in the 3D CISS MR imaging: TR = 12.25 msec, TE = 5.90 msec, flip angle = 70\(^\circ\), FOV = 180 × 180 mm (read × phase encode), slab thickness = 70.0 mm, number of 3D partitions = 106, number of slabs = 1, pixel size = 0.35 × 0.69 mm, effective slice thickness = 0.66 mm, number of acquisitions = 1, and scan time = 11.4 minutes. The following pulse sequence was used in the 3D TOF MR angiography studies before and 3 minutes after the administration of Gd-DTPA (0.1 mmol/kg): TR = 31 msec, TE = 7 msec, flip angle = 20\(^\circ\), FOV = 200 × 200 mm, slab thickness = 50 mm, matrix = 512 × 224, number of 3D partitions = 50, number of slabs = 1, pixel size = 0.78 × 0.39, effective slice thickness = 1 mm, number of acquisitions = 1, and scan time = 5 minutes 49 seconds.

Image Analysis Procedures

The 3D data sets were analyzed using the multiplanar reconstruction function of the standard PACS workstation (Magic View VE42, Siemens Medical Solutions) to identify and display the CNs in 3 planes: 1) a transverse plane, parallel to the cisternal courses of CNs IX, X, and XI; 2) a sagittal-oblique plane, precisely aligned from posteromedial to anterolateral along the anatomical course of each nerve root bundle identified (referred to as the “sagittal plane” in the following text); and 3) a coronal plane, parallel to the dorsal edge of the brainstem.

Two experienced neuroradiologists collaboratively analyzed the data sets from each sequence, and the results were decided by consensus. The left and right sides of each patient were evaluated independently.

Anatomical Assessment of the Cisternal Segments of CNs IX, X, and XI: 3D CISS Sequence.

For each of the 3 planes used, we recorded whether the nerve root bundles of CNs IX and X, the crCN XI, and the spCN XI could be identified and differentiated with certainty (score of 2), most probably (score of 1), or not at all (score of 0). The number of nerve root bundles identified was recorded for each CN separately. Specific attention was directed toward identifying and distinguishing between the nerve root bundles of CN X and the traditional crCN XI. Root bundles were classified as crCN XI when MR imaging showed that the roots exited the brainstem caudal to the superior third of the olive and did not join the main vagal trunks. Because the spinal portion of CN XI is the only nerve to pass through the foramen magnum,\textsuperscript{30} nerve root bundles here were classified as belonging to the spinal component of CN XI root bundles when MR imaging showed that they entered the posterior fossa through the foramen magnum and passed into the same dural meatus as CN X.\textsuperscript{31}

For each nerve root bundle identified, the length of the bundle’s cisternal segment was measured in the transverse and sagittal planes from its PE from the brainstem to the point at which the nerve root bundle entered the corresponding dural meatus. The PE of the nerve was defined as the point at which the specific root bundle was first separable from the brainstem.

The distance from CN IX to the vestibulocochlear (CN VIII) and facial nerves (CN VII) was determined at 2 sites. At the PE, the interneural distances were determined by extending perpendicular lines from the PE of CN VII and the PE of CN VIII to CN IX (Fig. 1). At the dural meatus, the interneural distances were determined by tracing a perpendicular line from CN IX to VII and to VIII at the points at which they entered the IAM.

The distance from CN IX to X was similarly determined in the sagittal plane at the nerves’ PEs by extending a perpendicular line from the PE of CN IX to the uppermost nerve root bundle of CN X (Fig. 1) and at the dural meatus by tracing a perpendicular line from CN IX to X at the entrance of CN IX into the glossopharyngeal meatus.
Neurovascular Relationships: Combined Use of 3D CISS MR Imaging and 3D TOF MR Angiography. Neurovascular contact was defined as the absence of any detectable layer of CSF between the CN and the adjacent vessel. If the 3D CISS MR images showed a vessel in contact with the CN, we identified the vessel by tracing it backward to its parent vessel and comparing it with corresponding structures depicted on the 3D TOF MR angiograms. Vessels could be identified as arteries by tracing them back to their parent artery. Vessels were defined as veins if 1) they appeared hyperintense on contrast-enhanced, and not hyperintense on noncontrast, 3D TOF MR angiograms, and/or 2) they could be traced forward to a larger vein. If there was direct contact between the nerve and vessel, we measured the distance between the PE of the nerve from the brainstem and the point of contact with the vessel.

The precise neurovascular relationship was recorded at 3 sites: contact at the PE of the respective nerve root bundle, contact along the REZ and/or RExZ, and contact along the cisternal segment of the nerve distal to the REZ or RExZ.

The definitions of the REZ or RExZ of CNs vary in the literature.\footnote{5,19,21,28,39} In the context of the present study, we defined the REZ and RExZ, respectively, as the length of the nerve segment between the PE of the nerve from the brainstem and the point of transition from central to peripheral myelin. Histologically, the mean length of the central (glial) segment of the CN is 1.1 mm for the sensory root of CN IX, \( < 1 \) mm for the motor root of CN IX, \( \leq 2 \) mm for CN X, and \( \leq 0.1 \) mm for CN XI.\footnote{19}

**Landmarks for Identifying CNs IX, X, and XI.** We determined whether the vagal trigone, the choroid plexus of the lateral recess of the fourth ventricle, the dural entrances into the jugular foramen (glossopharyngeal and vagal meatus), and the inferior petrosal sinus could be used as landmarks for identifying the cisternal segments of CNs IX and X and the crCN XI. We also considered whether the VA could be used as a landmark for identifying the cisternal segment of the spCN XI. In each case, the certainty with which these structures could be identified by these landmarks was scored with the previously described system (Scores 0, 1, and 2) used to grade the nerve bundles themselves.

The dimensions of the glossopharyngeal and vagal meatus were measured in the transverse and coronal planes. The distance between the cranial margin of the

---

**Fig. 1.** Schematic illustrating measurements performed to determine distances between the CNs at their PEs and dural entrances. Distances between the respective nerves at their PEs were calculated by dropping perpendiculars from CN VII to IX (yellow arrow), from CN VIII to IX (blue arrow), and from CN IX to the uppermost CN X root bundle (white arrow). At their dural entrances distances were determined by drawing perpendiculars from CN IX to VII (light green arrow), from CN IX to VIII (dark green arrow), and from CN IX to the uppermost CN X root bundle (black arrow). Red line marks the entrance level into the glossopharyngeal meatus. 1 = CN IX; 2 = CN VII; 3 = CN VIII; 4 = CN X root bundles; 5 = crCN XI nerve root bundles; 6 = spCN XI; 7 = vagal meatus; 8 = glossopharyngeal meatus; 9 = IAM.
Magnetic resonance imaging–demonstrated anatomy of the cranial nerves

Results

All 3 MR sequences—3D CISS MR imaging and 3D TOF MR angiography with and without contrast—were obtained successfully and used for the evaluation of CNs IX and X and the crCN IX in all 25 of the study participants (100%). In 1 patient the quality of the caudal slices of the 3D CISS MR imaging sequence was markedly reduced by a motion artifact, and so the sequence was not used for analyzing the spCN XI.

Nerve Identification and Distances

Identification of Root Bundles. In the transverse plane the 3D CISS MR imaging sequence successfully displayed at least 1 nerve root bundle of CN IX and ≥ 1 nerve root bundle of CN X in all 50 sides (100%; Figs. 2 and 3). In the sagittal and coronal planes the 3D CISS MR imaging sequences revealed at least 1 nerve root bundle of CN IX in 92% of the sides and of CN X in 100% of the sides (Fig. 4 and Table 1). In all planes and sides, we detected only a single nerve root bundle of CN IX, but 1 or 2 nerve root bundles of CN X (average 1.7 nerve root bundles).

One to four nerve root bundles originating caudal to the superior third of the olive were identified in 88% of the sides (average 2 root bundles; Figs. 4–6). These root bundles did not join with each other or with a different CN in their cisternal course and were reliably differentiated from the main CN X root bundles in the 3 orthogonal planes. Therefore, these bundles were designated traditional crCN XI root bundles. Nerve root bundles that traversed the foramen magnum and the vagal meatus of the jugular foramen were identified in all 3 planes in 93.4% of the sides. These roots were considered to be spCN XI (Fig. 7 and Table 1).

Cisternal Length. Table 2 details the cisternal lengths of the nerve root bundles of CN IX, CN X, and crCN XI in the 2 imaging planes.

Distances to Neighboring Nerves. Table 3 lists the

glossopharyngeal meatus and the caudal margin of the IAM was recorded. The certainty with which a dural septum could be identified between the glossopharyngeal meatus and the vagal meatus was also noted.
Fig. 4. Sagittal (A and B) and coronal (C) 3D CISS MR images clearly depicting the nerve root bundles of CN IX (crossed white arrows), CN X (plain white arrows), and the crCN XI (black arrows).

TABLE 1: Identification of nerve root bundles of CNs IX and X, the crCN XI, and the spCN XI in their cisternal course

<table>
<thead>
<tr>
<th>Region</th>
<th>Transverse</th>
<th>Sagittal</th>
<th>Coronal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 1 0</td>
<td>2 1 0</td>
<td>2 1 0</td>
</tr>
<tr>
<td>CN IX</td>
<td>39 (78)</td>
<td>8 (16)</td>
<td>4 (8)</td>
</tr>
<tr>
<td>CN X</td>
<td>44 (88)</td>
<td>6 (12)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>crCN XI</td>
<td>29 (58)</td>
<td>11 (22)</td>
<td>4 (8)</td>
</tr>
<tr>
<td>spCN XI†</td>
<td>42 (87.5)</td>
<td>3 (6.25)</td>
<td>3 (6.25)</td>
</tr>
</tbody>
</table>

* Values represent the number of sides (%). With regard to CNs IX and X and the crCN XI, 50 sides were analyzed; with regard to the spCN XI, only 48 sides were analyzed because of severe motion artifacts in the caudal slices in 1 patient. Scores: 2 = positive identification, 1 = highly probable identification, 0 = no identification.

† Sagittal plane was not evaluated.
distances between the nerve root bundles of CNs IX and X as well as the distances between the nerve bundles of CNs VII and IX, and VIII and IX at their PEs and their entrances into the dural meatus.

Anatomical Landmarks

Vagal Trigone. The vagal trigone was successfully identified at the floor of the fourth ventricle in all study participants (score of 2 on all sides; Fig. 8A).

Choroid Plexus of the Lateral Recess of the Fourth Ventricle. The 3D-CISS MR imaging sequence depicted the choroid plexus of the lateral recess of the fourth ventricle in 100% of the sides (score of 2 on all sides; Figs. 3 and 8B). In all cases the nerve root bundle of CN IX passed immediately anterior to and in contact with the choroid plexus, with no CSF demonstrated between the nerve bundle and the choroid plexus (Fig. 8B, right side of patient). In 9 sides (18%), CN IX appeared to be displaced anteriorly by the choroid plexus (Fig. 8B, left side of patient).

Glossopharyngeal Meatus. The dural meatus of CN IX (Figs. 3 and 9A) was visualized in all 3 imaging planes in 100% of cases (score of 2 in all cases; Table 4). The mean distance from the cranial margin of the glossopharyngeal meatus to the caudal margin of the IAM was 5.8 ± 0.86 mm (range 4–7.5 mm).

Vagal Meatus. The common dural meatus of CNs X and XI was identified on the 3D CISS MR imaging sequence in all 3 orthogonal planes in all cases (score of 2; Table 4 and Fig. 9B). In all sides a dural septum was detected between the glossopharyngeal and vagal meatus.

Inferior Petrosal Sinus. Contrast-enhanced 3D TOF...
MR angiograms revealed the entrance of the inferior petrosal sinus into the jugular foramen at the level of the entrance of CN IX into its meatus in all 3 orthogonal planes in all cases (Fig. 9C).

Vertebral Artery. The imaging studies always displayed a close relationship between the spCN XI and the point of entry of the VA into the dura mater at the level of the atlas (100% of cases; Figs. 10 and 11). The spCN XI always crossed the VA dorsomedially (see Neurovascular Relationships below).

**TABLE 3: Distances between the CNs at their PEs and dural entrances**

<table>
<thead>
<tr>
<th></th>
<th>CN VII–IX</th>
<th>CN VIII–IX</th>
<th>CN IX–X</th>
</tr>
</thead>
<tbody>
<tr>
<td>at PE†</td>
<td>2.98 ± 0.3 (2.6–3.6)</td>
<td>3.1 ± 0.5 (1.4–3.8)</td>
<td>2.5 ± 0.6 (1.4–4.6)</td>
</tr>
<tr>
<td>at dural entrance‡</td>
<td>5.5 ± 0.7 (4.5–6.9)</td>
<td>5.7 ± 0.9 (4.7–7)</td>
<td>NM</td>
</tr>
</tbody>
</table>

* Values represent the means ± SD (range) in millimeters. Abbreviation: NM = not measured.
† Measured by extending perpendicular lines from CN VII to IX, from CN VIII to IX, and from CN IX to the uppermost nerve root bundle of CN X at the PEs.
‡ Measured by extending perpendicular lines from CN IX to VII, from CN IX to VIII, and from CN IX to the uppermost nerve root bundle of CN X at the entrance into their dural meatus.
Neurovascular Relationships

The vessels identified as having a relationship to the cisternal segments of CNs IX and X and the crCN XI included branches of the AICA, PICA (Fig. 12), VA, and diverse veins (Table 5). The spCN XI showed neurovascular contacts with the VA and PICA. Direct contact of the VA with the spCN XI occurred at the PE of the VA into the dura at the atlas in 76% of cases; proximity of the artery and nerve was observed in the remaining 24% of cases. In all of these cases, the spCN XI passed immediately dorsomedial to the VA at the level of the vessel’s entry into the dura (Figs. 7, 8, and 10). Direct contact between the PICA and the spCN XI was identified in 31.6% of the sides. No neurovascular contact was found between CN IX, X, or XI and the basilar artery in this series.

Pathological Cases

**Glossopharyngeal Neuralgia: Neurovascular Contact.** In a 46-year-old woman with severe glossopharyngeal neuralgia, imaging studies demonstrated neurovascular compression of the left CN IX by the left VA (Fig. 13A and B). The patient became symptom free after interposition of a Teflon pad between the nerve and the vessel. Control imaging after surgery revealed a correct location of the Teflon spacer (Fig. 13C).

---

**TABLE 4: Dimensions of the glossopharyngeal and vagal meatus in 50 sides*‡**

<table>
<thead>
<tr>
<th>Meatus</th>
<th>Width†</th>
<th>Height‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>glossopharyngeal</td>
<td>3.4 ± 0.9 (2–5.4)</td>
<td>2.4 ± 0.6 (1.2–4.1)</td>
</tr>
<tr>
<td>vagal</td>
<td>4.4 ± 0.9 (2.4–6.5)</td>
<td>3.6 ± 0.9 (1.9–6)</td>
</tr>
</tbody>
</table>

* Values represent the means ± SD (range) in millimeters.
† Assessed in the transverse planes.
‡ Assessed in the coronal planes.
Schwannoma of the spCN XI: Neurotumoral Contact. In a 30-year-old woman with known neurofibromatosis Type II, contrast-enhanced MR imaging demonstrated a tumor of the right CN XI at the craniocervical junction and a second small lesion in the right perimedullary cistern (Fig. 14). Three-dimensional CISS MR imaging showed neurotumoral contact between the large right craniocervical junction tumor and the right spCN XI. The smaller tumor originated from the right CN IX. Surgery revealed 2 schwannomas. A right-sided acoustic schwannoma, bilateral trigeminal schwannomas, and a right frontal convexity meningioma were also present.

Agenesis of CNs IX and X. A 6-month-old child presented with severe dysphagia and velopharyngeal insufficiency. Three-dimensional CISS MR imaging revealed bilateral agenesis of CNs IX and X (Fig. 15).

Discussion

The combined use of 3D CISS MR imaging and 3D TOF MR angiography (with or without contrast) permits reliable identification of the individual nerves and neurovascular relationships of the lower CN complex. These sequences depicted CNs IX and X in 100% of the sides in 25 patients, and the crCN XI and spCN XI in 88 and 93.4% of the sides, respectively. Neurovascular contacts were identified at the REZ or RExZ in 8 (CN XI), 22 (CN X), and 18% (crCN XI) of the sides.

Emergence and Course of the Lower CNs

The nuclei of the caudal CNs are located in the medulla oblongata. The dorsal vagal nuclei form the vagal trigone on the floor of the fourth ventricle. The rootlets...
of CNs IX and X and the crCN XI arise from the brainstem in the postolivary sulcus. Cranial nerve IX emerges from the medulla oblongata as 10–20 rootlets distributed along the upper third of the postolivary sulcus. These rootlets coalesce to form the cisternal segment of CN IX, with a nerve root diameter of 0.4–1.1 mm.

The rootlets of CN X also arise in the upper third of the postolivary sulcus but slightly caudal to CN IX. These rootlets emerge along a length of 2–5.5 mm, have diameters of 0.1–1.5 mm, and typically coalesce into 2 (upper and lower) nerve root bundles. The most rostral vagal fibers usually arise immediately adjacent to the rootlets of CN IX but can be separated from CN IX by as much as 2.0 mm.

Just caudal to the vagal bundle at the level of the inferior third of the olive, 6–16 additional delicate rootlets (diameter 0.1–1.0 mm) emerge from the medulla oblongata and coalesce into 4–5 nerve root bundles. These rootlets have traditionally been regarded as the crCN XI, because they are considered to join the spCN XI and travel with it briefly before they become part of CN X (the so-called pars vagalis) within the jugular foramen. The spCN XI arises as 6–7 rootlets emerging from the cervical spinal cord segments C1–6 in line with the paraolivary sulcus of the medulla. The spCN XI ascends vertically into the spinal canal, traverses the foramen magnum, and passes to the jugular foramen. The final spinal nerve root has a mean diameter of ~1.0 mm.

It is unclear whether the cranial rootlets of CN XI are best considered to be rootlets of the vagus or accessory nerve. Lang has pointed out that the cranial rootlets of CN XI cannot be securely separated from rootlets of the vagus nerve. He has shown that these rootlets have their origin in the caudal part of the nucleus ambiguus and the dorsal nucleus of the vagus nerve, and therefore are functionally vagal rootlets. Lachmann et al. have found no connection between “the cranial CN XI rootlets” and the spCN XI, so they considered these rootlets to be the “caudal posterior medullary rootlets of the vagus nerve.” However, other authors have shown that these caudal rootlets do intermingle with the spCN XI. Working in embalmed human cadavers, Wiles et al. have shown that distinct rootlets emerge from the postolivary sulcus caudal to, and separate from, the main trunk of the vagus nerve and then join the spCN XI. They considered these rootlets to be cranial CN XI rootlets.

Magnetic Resonance Imaging of CNs IX, X, and XI

**Nerve Identification.** The small distances between the origins of CNs IX, X, and XI at the brainstem and the small diameters of these rootlets make it particularly difficult to identify and separate them on MR imaging. The diameters of the glossopharyngeal, vagal, and cranial accessory rootlets vary from 0.1 to 1.5 mm. These thin rootlets then coalesce into the thicker nerve root bundles and roots. Given that the 3D CISS sequence in our study pro-

---

**Fig. 12.** Neurovascular contact in a symptom-free patient. Axial (A) and coronal (C) 3D CISS MR image revealing broad-based contact between the right CN X (black arrows) and the right PICA (white arrows). Neurovascular contact is also present at the PE (asterisk) of CNX. Noncontrast TOF MR angiograms (B and D) showing a flow void within the vessel, identifying it as an artery (white arrows).
vided slice thicknesses of 0.6 mm, the depiction of structures much smaller than 0.6 mm is impossible; therefore, single rootlets with a diameter smaller than 0.6 mm could not be depicted by using this sequence and would escape detection. Despite this technical limitation, we identified 1 nerve root bundle of CN IX in 100% of the sides, 1 or 2 nerve root bundles of CN X in 100% of sides, and 1–4 nerve root bundles originating caudal to the upper third of the postolivary sulcus and not joining the main vagal trunks in 88% of the sides (considered the traditional crCN XI bundles).

All root bundles identified caudal to the vagal trunks were followed through the lateral medullary cistern from their PEs at the brainstem to their entrance into the dural meatus. As Rhoton31 has noted, CN XI is often indistinguishable from CN X at the dural orifice of the jugular foramen. For that reason, we primarily used the PEs of these nerves from the brainstem to classify the visualized nerve root bundles as main vagal nerve root bundles or as traditional “cranial accessory rootlets.” Root bundles that exited the brainstem caudal to the superior third of the olive and did not join the 1 or 2 main vagal trunks were classified as traditional “cranial accessory root bundles” (see Methods). However, we could not visualize the distant courses of these roots to determine whether they actually joined the vagus or the accessory nerve within the jugular foramen, to identify them more specifically.

**Cisternal Length.** In this study, the cisternal lengths of all nerve root bundles could be identified on the 3D CISS sequences. The mean cisternal length of CNs IX or X in the transverse plane was 15.3 mm. This finding accords well with anatomical data in the literature, in which cisternal lengths have been reported to vary from 15.27 to 15.65 mm22 for CN IX and from 15.3 to 15.6 mm for CN X.22 The mean cisternal length of the traditional root bundles of the crCN XI in the transverse plane was 17 ± 2.3 mm, a value that accords reasonably with anatomical measurements of the average length of the uppermost rootlets (16.42 mm) and the middle rootlets (18.7 mm).22

### TABLE 5: Neurovascular relationships of CNs IX and X and the crCN XI

<table>
<thead>
<tr>
<th>Region</th>
<th>AICA</th>
<th>PICA</th>
<th>VA</th>
<th>Veins</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CN IX (50 sides)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no. of nerves (%)</td>
<td>12 (24)</td>
<td>5 (10)</td>
<td>0 (0)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>contacts/nerve</td>
<td>12/0</td>
<td>8/3</td>
<td>0/0</td>
<td>2/0</td>
</tr>
<tr>
<td>PE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>REZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>distal to REZ or RExZ†</td>
<td>12</td>
<td>4</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>no. of contacts over long distances</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>CN X (50 sides)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no. of nerves (%)</td>
<td>2 (4)</td>
<td>10 (20)</td>
<td>1 (2)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>contacts/nerve</td>
<td>3/1</td>
<td>13/3</td>
<td>1/0</td>
<td>2/0</td>
</tr>
<tr>
<td>PE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>REZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>distal to the REZ or RExZ†</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>no. of contacts over long distances</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>crCN XI (44 sides)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no. of nerves (%)</td>
<td>1 (2.3)</td>
<td>13 (29.5)</td>
<td>1 (2.3)</td>
<td>3 (6.8)</td>
</tr>
<tr>
<td>contacts/nerve</td>
<td>1/0</td>
<td>14/1</td>
<td>1/0</td>
<td>3/0</td>
</tr>
<tr>
<td>PE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>REZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>distal to the REZ or RExZ†</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>no. of contacts over long distances</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>spCN XI (38 sides)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>no. of nerves (%)</td>
<td>0 (0)</td>
<td>12 (31.6)</td>
<td>29 (76)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>contacts/nerve</td>
<td>0/0</td>
<td>13/1</td>
<td>32/3</td>
<td>0/0</td>
</tr>
<tr>
<td>PE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>REZ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>distal to the REZ or RExZ†</td>
<td>0</td>
<td>13</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>no. of contacts over long distances</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Values represent the number of all contacts/number of nerves with 2 contacts with the respective vessels.
† The REZ was 1.1 mm along the nerve for the sensory root of CN IX, < 1 mm for the motor root of CN IX, ≤ 2 mm for CN X (mean 1.3 mm), and ≤ 0.1 mm for CN XI.
Distances. Cranial nerve IX arises between CN VIII cranially and CN X caudally. Systematic evaluation of the distance between these nerves and CN IX showed that the mean distance between CNs IX and VIII at their PEs was 3.1 mm, and the mean distance between CNs IX and X at their PEs was 2.5 mm. These measurements accord well with anatomical dissection data. The mean distance between CNs VII and IX, and VIII and IX at their dural entrances measured 5.5–5.7 mm. We could find no reference values for these meatal measurements in anatomical cadaver studies.

Because CN VII consistently arises from the brainstem 2–3 mm from CN IX, knowledge of the constancy of these relationships may assist the neurosurgeon in preoperative planning and intraoperative decision making with regard to the facial nerve or lower cranial nerve complex.

Anatomical Landmarks

Structural relationships and landmarks identified in this study may assist with imaging and intraoperative identification of the lower CN roots. These landmarks include the vagal trigone (Fig. 8A), the choroid plexus of the lateral recess of the fourth ventricle (Fig. 8B), the meatus of the glossopharyngeal and vagus nerves, the inferior petrosal sinus (Fig. 9), and the vertebral artery at the point at which it pierces the dura at C-1 (Fig. 10).

Vagal Trigone. In 3D CISS images, the vagal trigone is consistently (100% of cases) displayed as a distinct bulge formed in the caudal portion of the floor of the fourth ventricle by the dorsal motor nucleus of the vagus nerve. Given that CN X exits the brainstem at this level, the vagal trigone may serve as an imaging landmark for CN X (Fig. 8A).

Choroid Plexus. Anatomical studies have shown that the choroid plexus of the fourth ventricle’s lateral recess may help to identify the cisternal segment of CN IX. In the present study we noted that CN IX always courses anterior to the choroid plexus of the lateral recess and always has direct contact with the plexus in vivo; thus, the choroid plexus serves as a valuable landmark for the depiction and identification of CN IX. In 18% of the sides in this study we even noted anterior displacement of the nerve by the plexus. Although we confirmed that contact between CN IX and the choroid plexus is a normal finding and that anterior displacement of CN IX by the plexus may also be a typical finding, glossopharyngeal neuralgia has been reported to result from a compromised cisternal segment of CN IX by an exuberant choroid plexus.

Glossopharyngeal and Vagal Meatus. The dural cover of the neural portion of the jugular foramen has 2 characteristic perforations: the glossopharyngeal meatus cranially and the vagal meatus caudally, separated by a fibrous crest (dural septum). Cranial nerve IX enters the jugular foramen through the glossopharyngeal meatus, whereas CN X, the crCN XI and the spCN XI enter the jugular foramen via the vagal meatus. Anatomical cadaver studies have shown that the glossopharyngeal meatus may serve as a landmark for identifying CN IX in the subarachnoid space. Rhoton has noted that the correct identification of the specific nerves may be easiest in the area just proximal to the dural septum, because the close origin of these nerves from the brainstem and the arachnoidal adhesions between them in the lateral medullary cistern make it difficult to identify them elsewhere.
Fig. 14. Three-dimensional CISS MR images demonstrating schwannomas of CN IX and the spCN XI in a 30-year-old woman with neurofibromatosis Type II and a right frontal convexity meningioma (not shown). A and B: A small tumor at the right cranio-cervical junction (open arrow), which contacts the right spCN XI (arrowheads). At surgery, this lesion proved to be schwannoma deriving from the spCN XI. C and D: The smaller tumor arising from the right CN IX (black arrow) proved to be a schwannoma at surgery. E: Thin white arrow (also in panel C) indicates CN X. The patient also had an additional right acoustic schwannoma (thick solid white arrow) easily distinguishable from CN IX (D) and CN X.

Fig. 15. Three-dimensional CISS MR images obtained in a 6-month-old child who had presented with severe dysphagia and velopharyngeal insufficiency, revealing bilateral agenesis of the CNs IX and X. Arrows mark the glossopharyngeal meatus (A) and vagal meatus (B). Cranial nerves IX and X are not discernible in their respective meatus, whereas CN VIII can easily be identified within the IAM (C, arrows).
In the present study, 3D CISS MR images consistently revealed the glossopharyngeal and vagal meatus and the intervening dural septum in all 3 orthogonal planes. Thus, MR imaging has proved to be a valuable tool for identifying and distinguishing these structures and the related nerves in vivo.

In accord with anatomic studies we found that the glossopharyngeal meatus is funnel-shaped, narrows distally, and resembles a “small internal auditory canal” (Figs. 3 and 9), whereas the vagal meatus is round to elliptical and approximately twice as wide as the glossopharyngeal meatus.32 We also found that the mean width of the glossopharyngeal meatus was 3.4 ± 0.9 mm (height 2.4 ± 0.6 mm), whereas the mean width of the vagal meatus was 4.4 ± 0.9 mm (height 3.6 ± 0.9 mm). The differences in size and shape help to distinguish the glossopharyngeal meatus from the vagal meatus, and therefore CN IX from CN X and CN XI.

In this study the mean distance from the glossopharyngeal meatus to the inferior lip of the internal auditory canal was 5.8 ± 0.9 mm. This finding accords well with the distance of 2.5–6.5 mm reported in anatomic dissection studies.19 This intermeatal distance could help to identify the glossopharyngeal meatus in the coronal and sagittal planes.

**Inferior Petrosal Sinus.** The inferior petrosal sinus courses on the intracranial surface of the petroclival fissure before it enters the petrosal part of the jugular foramen. Anatomical cadaver studies have shown that the inferior petrosal sinus empties into the medial aspect of the jugular bulb between the glossopharyngeal nerve anteriorly and the vagus nerve posteriorly.31 On MR imaging, we reliably identified the entrance of the inferior petrosal sinus into the jugular foramen at the level of the glossopharyngeal meatus. Thus, we propose this venous structure as a valuable landmark for the identification of CN IX.

**Vertebral Artery.** We consistently observed a close relationship between the dural entrance of the VA and the spCN XI, with the spCN XI passing immediately dorsomedial to the VA. A general relationship between the vessel and the nerve root has been described in several anatomical cadaver studies19,22,25 and in an imaging study by Edal et al.7 To our knowledge, the present study is the first in which this constant relationship has been analyzed in detail and the VA at its dural entrance has been proposed as an explicit landmark for the identification of the spCN XI on cranial MR imaging.

**Neurovascular Relationships**

Vascular compression can occur at any point along a CN; however, only compression at vulnerable sites along the cisternal segment of the nerve is widely believed to cause neurovascular compression syndromes.5,9,21,24 The precise locations of and nomenclature for these vulnerable sites has been debated in the literature.5,9,21,24 For the purposes of this study, we designated the central portion of the cisternal segment of the nerve, where the myelin is derived from oligodendroglial cells, as the REZ or RExZ and considered it to be the portion of the nerve vulnerable to neurovascular compression. As defined, the REZ or RExZ extends from the nerve’s point of entry into or exit from the brainstem to the point of transition from central (derived from oligodendroglia) to peripheral myelin (derived from Schwann cells).

The length of the REZ or RExZ varies from nerve to nerve. Histologically, the mean length of the central (glial) segment of the CN is 1.1 mm for the sensory root of CN IX, <1 mm for the motor root of CN IX, up to 2 mm for CN X (average 1.3 mm), and up to 0.1 mm for CN XI.5,9,19 Thus, for this study and in accordance with the literature, we considered the REZ or RExZ to be within 1 mm of the PEs for CNs IX and XI but within 2 mm of the PE for CN X.21

Based on this definition, we identified neurovascular contacts at the REZ or RExZ of CNs IX, X, and XI in 19% of all nerves investigated (Fig. 12). Specifically, we identified neurovascular contacts at the REZ/RExZ of CN IX in 8% of all sides, of CN X in 22% of all sides, and of the crCN XI in 18% of all sides. In accordance with anatomic reports, vessels noted to have contact with CNs IX, X, and XI were the PICA, AICA, VA, and various veins.19,20,23 We did not detect contact between the REZ or RExZ of the CNs and the basilar artery.19,20,23

**Clinical Relevance**

A number of syndromes are thought to result from the contact of vessels with the REZ or RExZ of specific CNs.8,10,11,14,16,24,33,38,43 It is suggested that at least some cases of glossopharyngeal neuralgia are caused by vessels compressing the sensory root of the CN IX. The vessel most frequently implicated in glossopharyngeal neuralgia has been the PICA.8,11,38 However, Jannetta10 has reported on 2 cases of glossopharyngeal neuralgia caused by compression of the nerve by the VA (Fig. 13). Neurovascular contact has also been proposed to cause essential hypertension (CN X)44,33,24 and spasmodic torticollis (CN XI).37

None of the study participants manifested any symptoms of CN abnormality. This high incidence of clinically normal neurovascular contacts accords well with studies on essential hypertension that show neurovascular contact in 12–53% of healthy control groups.33,34 Neurovascular contacts at the lower CNs, therefore, have low specificity for predicting clinical symptomatology, as is the case for neurovascular contacts at CN V.46

Figures 13–15 illustrate the clinical application of MR imaging studies for the diagnosis and surgical management of lower CN pathology, such as neural compression by intrinsic and extrinsic neurinomas and neurovascular contact.36,47 Interestingly, in the case of glossopharyngeal neuralgia presented in Fig. 13, the contact between nerve and vessel was considerably distal to the REZ or RExZ. Nonetheless, the patient did benefit from decompression surgery. These observations confirm the widely held clinical conviction that physicians should not rely on imaging alone for making therapeutic decisions about neurovascular compression syndromes. The presence and localization of neurovascular contacts should be evaluated only in the context of a specific clinical presentation.
Conclusions

This study demonstrates that in vivo MR imaging with 3D CISS and 3D TOF sequences (with or without contrast) successfully visualizes and reveals differentiation among the cisternal segments of CNs IX and X and the cranial and spinal roots of CN XI. Our data provide detailed information regarding the lengths of the cisternal segments of the lower CNs, the distances between nerve root bundles, the distances between their dural meatus, and the neurovascular relationships of the lower CN complex. We also showed landmarks useful for identifying the specific CNs with the aid of preoperative imaging and intraoperative inspection. A detailed depiction of patient anatomy—and individual anatomical variation—should assist the surgeon in proper preoperative planning and intraoperative decision making, potentially leading to improved outcome with decreased perioperative morbidity and death.48

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References

21. Lang J: [Neuroanatomy of the optic, trigeminal, facial, glossopharyngeal, vagus, accessory and hypoglossal nerves (author’s transl).] Arch Otorhinolaryngol 231:1–69, 1981 (Ger)
compression of the cranial nerves IX and X root-entry zone. Invest Radiol 34:774–780, 1999

Accepted March 25, 2008.
Please include this information when citing this paper: published online January 30, 2009; DOI: 10.3171/2008.3.JNS17472.
Address correspondence to: Jennifer Linn, M.D., Department of Neuroradiology, Klinikum Grosshadern, Marchioninistrasse 15, D-81377 Munich, Germany. email: linn@nrad.de.