Detailed anatomy of the motor and sensory roots of the trigeminal nerve and their neurovascular relationships: a magnetic resonance imaging study

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Object. The trigeminal nerve conducts both sensory and motor impulses. Separate superior and inferior motor roots typically emerge from the pons just anterosuperomedial to the entry point of the sensory root, but to date these two motor roots have not been adequately displayed on magnetic resonance (MR) images. The specific aims of this study, therefore, were to identify the superior and inferior motor roots, to describe their exact relationship to the sensory root, and to assess the neurovascular relationships among all three roots of the trigeminal nerve.

Methods. Thirty-three patients and seven cadaveric specimens (80 sides) were studied using three-dimensional (3D) Fourier transform constructive interference in steady-state (CISS) imaging. The 33 patients were also studied by obtaining complementary time-of-flight (TOF) MR angiography sequences with and without contrast enhancement.

At least one motor root was identified in all sides examined: in 51.2% of the sides a single motor root, in 37.5% two motor roots, and in 11.2% three motor roots. The superior cerebellar artery (SCA) and the anterior inferior cerebellar artery (AICA) contacted the sensory root in 45.5% of patients and 42.9% of specimens. The SCA often contacted the superior motor root (48.5% of patients and 50% of specimens) and less frequently the inferior motor root (26.5% of patients and 20% of specimens).

Conclusions. Three-dimensional CISS and complementary 3D TOF MR angiography sequences reliably display sensory, superior motor, and inferior motor roots of the trigeminal nerve and their relationships to the SCA and AICA.

Key Words • trigeminal nerve • magnetic resonance imaging • neurovascular contact • magnetic resonance angiography • anatomical study

The trigeminal nerve forms from both motor and sensory roots. Typically, one or more small motor roots emerge from the pons anterosuperomedial to the entry point of the large sensory root17,18,27 (Fig. 1). When motor roots are multiple, the most cephalic motor root may be designated the superior motor root, whereas the remaining ones may be collectively designated inferior motor roots. In a large number of studies the sensory root of the trigeminal nerve has been visualized by performing MR imaging.3,14,22,25,28 In contrast, few imaging studies have shown the motor roots of the trigeminal nerve,10,11,21 and those that have only identified one motor root.14 Because afferent fibers of this nerve may course within the inferior motor root,17,19,20,30,31 visualization of inferior motor roots and their neurovascular contacts might prove to be important in patients suffering from trigeminal neuralgia. Neurovascular contacts can be displayed with the same MR imaging sequences used to depict the course and neurovascular contacts of the trochlear nerve,26 the abducent nerve,33 and the rootlets of the hypoglossal nerve.15 These sequences include the 3D Fourier transform CISS sequence and the 3D TOF MR angiography sequence.

The aims of the present study, therefore, were to identify the superior and inferior motor roots of the trigeminal nerve, describe their exact relationship to the sensory root, and assess the neurovascular relationships of all three components of the trigeminal nerve by using a 3D CISS sequence and a complementary TOF sequence, with and without contrast enhancement.

Clinical Material and Methods

Patient and Specimen Populations

In this study we examined 33 neurologically healthy pa-
tients (17 men and 16 women ranging in age from 26–74 years [mean 51.8 years]) and seven cadaveric specimens (age range at death 60–79 years [mean 68.6 years]) obtained at autopsy within the first 10 hours after death from indi

tected with any trigeminal nerve root). Right: Anterior view of a specimen obtained from a man who was 77 years old at death. The sensory roots (large white arrows) are easily identified bilaterally. The left side of the specimen (right side of panel) shows a single superior motor root (short white arrow) and two inferior motor roots (long white arrows). The superior motor roots lie adjacent to each other in a superomedial position. An SCA branch (white arrowhead) contacts the superomedial motor root, which has been slightly elevated to provide better visualization. On the opposite side (left side of panel) one superior motor root (short white arrow) and one inferior motor root (long white arrow) are shown. The superior motor root lies close to an SCA branch (black arrow) but has no contact with it. MeC = Meckel cave.

Magnetic Resonance Imaging Procedures

All studies were performed using a 1.5-tesla MR imaging system (Magnetom Vision; Siemens, Erlangen, Germany) equipped with the regular quadrature head coil. A 3D CISS sequence and a 3D TOF sequence were obtained before and 3 minutes after administration of a Gd-chelate contrast agent (0.1 mmol/kg Gd-DTPA). The precise sequence parameters have been published previously.36 The specimens were studied as intact cadaver heads, free from other dissected parts.

Image Analysis Procedures

The data set from each 3D CISS sequence was recon-structed in three orthogonal planes to follow the anatomical course of each root of the trigeminal nerve. For better rade-

ability, these planes have been designated transverse, coro-

nal, and sagittal. In this paper, therefore, the term transverse

signifies the horizontal plane that runs parallel to the course of the trigeminal root, whereas the term coronal signifies the coronal plane oriented perpendicular to the course of the tri-
geminal root. All images were analyzed by two observers.36 To avoid possible misidentification of tiny motor roots as vessels, and vice versa, all structures identified as motor roots on the 3D CISS images were compared with corresponding structures on plain and contrast-enhanced 3D TOF images. Nonenhancing structures were identified as nerves. Enhancing structures were identified as vessels and then subclassified as arteries or veins by tracing them back to their parent vessels.36

Anatomical Assessment of Motor and Sensory Roots

Using a 3D CISS sequence, we determined the following data for each side. 1) The reliability of identifying the sensory root, superior motor root, and inferior motor root was determined in the transverse, sagittal, and coronal planes and recorded on an arbitrary scale as a positive identification (score of 2), a most probable identification (score of 1), or not identified (score of 0).33,36 Any single motor root was classified as a superior motor root. All additional motor

FIG. 1. Photographs showing anatomical specimens cut in the sagittal (left) and coronal (right) planes aligned along the cisternal course of the trigeminal nerve. Left: Left lateral aspect of a specimen obtained from a woman who was 74 years old at death. This plane depicts only a small portion of the sensory root near its point of entry (large black arrow). A loop of the SCA (white arrowhead) contacts the superior motor root (white arrow). The inferior motor root (small black arrow) emerges immediately superomedial to the sensory root. The black arrowhead indicates a branch of the SCA (not in con-
tact with any trigeminal nerve root). Right: Anterior view of a specimen obtained from a man who was 77 years old at death. The sensory roots (large white arrows) are easily identified bilaterally. The left side of the specimen (right side of panel) shows a single superior motor root (short white arrow) and two inferior motor roots (long white arrows). The inferi-
or motor roots lie adjacent to each other in a superomedial position. An SCA branch (white arrowhead) contacts the su-

ceptor motor root, which has been slightly elevated to provide better visualization. On the opposite side (left side of panel) one superior motor root (short white arrow) and one inferior motor root (long white arrow) are shown. The superior motor root lies close to an SCA branch (black arrow) but has no contact with it. MeC = Meckel cave.
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Fig. 2. Three-dimensional CISS image obtained in a 57-year-old man, demonstrating the sagittal plane along the motor roots. One inferior (long arrow) and one superior (short arrow) motor root are visualized. The cisternal course of the inferior motor root, from its origin to its apparent junction with the sensory root (SeR), is shorter than the cisternal course of the superior motor root. A vein (V) is in contact with the superior surface of the superior motor root.

Specimens: 3D CISS Sequence. Specimens cannot display a TOF MR angiography effect and thus any neurovascular contacts with the trigeminal nerve roots were evaluated only by viewing the 3D CISS sequences. Arteries could still be differentiated from veins by an analysis of their drainage patterns.

Results

Identification of Sensory Roots

In each of the three orthogonal planes the sensory roots of the fifth cranial nerve and their complete cisternal courses were identified on all 66 sides in the patients and on all 14 sides in the specimens (100%) (Figs. 2–4).

Identification of Motor Roots

In the patients, MR imaging depicted 108 motor roots (54 on the right side and 54 on the left side) on 66 sides. These motor roots were single on 32 sides (48.5%), dual on 26 sides (39.4%), and triple on eight sides (12.1%) (Figs. 2 and 3). The motor roots were classified as superior on 66 sides (61.1%) (all single motor roots) and inferior on 42 sides (38.9%) (all motor roots that were neither single nor superior). Superior motor roots were identified (score of 1 and 2) in 98.5% of the sides in the transverse and sagittal planes and in 97% of the sides in the coronal plane. Inferior motor roots were detected (score of 1 and 2) in 100% of the sides in the transverse and cisternal planes and in 92.9% of the sides in the sagittal plane.

In specimens, MR imaging displayed 20 motor roots on 14 sides. These motor roots were single on nine sides (64.3%), dual on four sides (28.6%) (Fig. 4), and triple on one side (7.1%). Of these 20 motor roots, 14 (70%) were classified as superior and six (30%) as inferior. When iden-
Motor Roots. The SCA was the only artery in which we observed points of contact with motor roots. The nerves that were affected exhibited no distortion.

In patients, the SCA contacted the superior motor root at 35 sites on 32 (48.5%) of the 66 sides analyzed. Points of contact were located at the point of emergence in seven (20%) of the 35 sites, at the REZ in two sites (6%), and at the distal cisternal segment in 26 sites (74%). In specimens, the SCA contacted the superior motor root at nine sites in seven (50%) of the 14 sides analyzed (Fig. 4). Points of contact were located at the point of emergence in one site (11%) and at the distal cisternal segment in eight sites (89%).

Veins contacted the superior motor root at 19 sites on 18 (27.3%) of the 66 sides observed in patients (Fig. 2) and at six sites on five (35.7%) of the 14 sides in specimens.

In patients, the SCA contacted the inferior motor root at 10 sites on nine (26.5%) of the 34 sides analyzed. Four (40%) of these contacts were located at the point of emergence and six (60%) at the distal cisternal segment. In specimens, the SCA contacted the inferior motor root on only one (20%) of the five sides examined, along the distal segment of the root. In patients, veins contacted the inferior motor root at one site each on nine (26.5%) of the 34 sides. In specimens, veins were not observed to contact the inferior motor root.

Sensory Root. In patients, the sensory root of the fifth cranial nerve was contacted by the anterior inferior cerebellar artery (4.5% of sides), the SCA (45.5% of sides), and diverse veins (54.5% of sides). The root was not distorted or grooved in any instance. Seven (17.1%) of the 41 arterial contact points lay at the point of emergence, 24 (58.5%) at the REZ and 10 (24.4%) at the distal cisternal segment. In specimens, eight SCA points of contact were identified on six (42.9%) of the 14 sides. One of the eight contact points was found at the point of emergence (12.5%), four at the REZ (50%), and three at the distal cisternal segment (37.5%). There were 48 points of contact between veins and the sensory root on 36 (54.5%) of 66 sides in patients and 10 points of contact on seven (50%) of the 14 sides in specimens.

Discussion

Using the 3D CISS and 3D TOF sequences, we reliably identified and described neurovascular contacts with the sensory root, the superior motor root (Fig. 4), and the inferior motor root of the trigeminal nerve. In all instances, these sequences depicted the sensory root and at least one motor root (Figs. 2–4). In 11% of the sides, they depicted two separate inferior motor roots (Fig. 3). To our knowledge, this is the first MR imaging study in which all three roots of the trigeminal nerve have been successfully visualized.

The Motor Root

Lang17,18 and Saunders and Sachs27 defined two “radices motoriae,” a primary superior and a secondary inferior motor root, with numerous connections between both of these and the sensory root (Fig. 1). The superior root, with its dis-
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tinct position and relative isolation from the main sensory root, represents the classic origin of the motor root. The two separate groups of motor rootlets join together to form a single root within approximately 1 cm of the pons. Because of their intermediate position between the sensory root and the superior motor root, the inferior group of motor rootlets has also been called “fibrae intermediae” or “accessory fibers.”

Identification of Motor Roots by Using MR Imaging. In this study, we could identify at least one motor root on all sides. We found a single motor root on 51.3%, two motor roots on 37.5%, and three motor roots on 11.3% of sides (Figs. 2–4). On all sides in which there were multiple motor roots, one motor root always lay superior to the others. Therefore, we elected to follow the definition of Lang and Saunders and Sachs and called all motor roots that arose in the intermediate position between the sensory root and the most superior motor root, the “inferior” motor root.

Cisternal Length of the Motor Roots. The length of the cisternal segment of the motor roots has not been described in previous anatomical or MR imaging studies. The cisternal segment of the inferior motor root appears shorter than that of the superior motor root because the former root joins the sensory root closer to its point of emergence from the pons (Fig. 2).

Emergence and Course of Motor Roots

As previously described, superior and inferior motor roots most often emerge superomedial and less often directly superior or superolateral to the sensory root6 (Figs. 3 and 4). In the present study, the superior motor root emerged from the pons 0 to 4 mm superior to the sensory root (mean 1.8 mm, Figs. 2–4), which accords well with the range of 0.2 to 5.5 mm reported in the anatomical literature.6,10,16,17,19,27 The inferior motor root emerged at 0 to 2 mm from the sensory root (mean 0.9 mm; Figs. 2–4). No interval or hiatus could be discerned between the points of emergence of the sensory root and the inferior motor root in 25% of instances (Figs. 3 and 4). Interestingly, anatomical studies typically demonstrate that the inferior motor root arises in contact with the inferior rostral aspect of the sensory root.27 Only in rare instances is a narrow (~0.3-mm) hiatus described.27 This discordance could be related to the loss of CSF in the isolated head specimens with the consequent collapse of the hiatus in this study.6,15

Technical Factor

No MR images of the inferior motor root have been reported previously, probably because of the root’s small cross-sectional area. The mean diameter of the superior motor root is only 1 mm (range 0.6–2.7 mm).16 The diameter of the inferior motor root usually is even smaller (Fig. 2).27 Visualizing small structures requires special sequences in which pixel sizes are less than or equal to the diameter of the structure to be visualized.2 Otherwise partial volume effects preclude the reliable depiction of the desired structure.3 Previous studies, in which 3D CISS sequences were used with 0.6 × 0.45–mm pixels and an effective slice thickness of 1 mm, identified the primary (superior) motor root successfully but not the inferior motor root.10 The present study, in which a 3D CISS sequence was used with an effective slice thickness of 0.66 mm and a 0.35 × 0.69–mm pixel, successfully displayed both the superior and the inferior motor roots of the trigeminal nerve. When preoperative planning depends on detecting the exact position and pathological changes of each component of the trigeminal nerve, such fine detail can be important (Figs. 5 and 6).

Neurovascular Relationships

On 3D CISS images, both arteries and veins are visualized as structures of low signal intensity coursing through the high signal that represents CSF. Arteries can usually be differentiated from veins by identifying drainage patterns. This strategy and the experience gained through previous investigations enabled us to depict neurovascular contacts reliably in specimens. In living patients, use of MR angiographic sequences before and after intravenous injection of contrast agent improved the visualization and identification of small arteries and veins.5,34,36

Root Entrance and Exit Zones. Compression syndromes only result when the neurovascular contact occurs at, or very near to, the REZ and REZ.Z24,26 for this reason special attention must be paid to neurovascular contacts at these zones. Defining the REZ of the sensory root as its proximal 6 mm (see Clinical Material and Methods), we found arterial contacts on 40% of the sides, 8.8% of which were located at the precise point of entrance into the pons. These findings are consistent with the 3 to 35% incidence at the point of entrance reported in anatomical studies7,9 and the 5 to 28% in-
Vascular contacts along the motor roots have not been investigated previously. Defining the RExZ of the motor root as its proximal 1.5 mm, we found arterial contacts at the RExZ of superior motor roots on 12.5% of the sides (Fig. 4). Most often, this contact lay precisely at the point of emergence. Arterial contacts at the RExZ of the inferior motor roots were found on 8.3% of the sides. Considering any contacts along the full lengths of the roots, we found that the motor roots had a larger number of neurovascular contacts than the sensory root. Limiting ourselves to the REZ, however, we found that the sensory root had a higher incidence of contacts because the sensory REZ is longer than the motor RExZ. Our success in detecting neurovascular contacts along the REZ and RExZ illustrates the sensitivity of our methods; however, the detection of these contacts in patients with no signs of neuralgia provides evidence that images of neurovascular contacts have a low specificity for the prediction of clinical symptomatology.

Function and Clinical Relevance of the Inferior Motor Root

The function of inferior motor roots has been the subject of considerable speculation. May and Horsley suggested that afferent fibers to the mesencephalic nucleus course within the motor root. Although most accessory rootlets are small motor filaments that join the superior motor root distally, some inferior fibers seem to be sensory fibers that enter the sensory root instead. Thus, afferent fibers were identified within motor roots in 12 to 20% of cases and may constitute an accessory sensory group. This concept is supported by the observation that touch sensation may be preserved after total sectioning of the sensory root at the pons. The presence of afferent sensory fibers within the inferior motor root may be significant in patients with trigeminal neuralgia who continue to experience pain following MVD of the classic sensory root of the trigeminal nerve (Fig. 5).

In patients with trigeminal neuralgia, MR imaging can provide precise preoperative data on the number, sites, and nature of any neurovascular contacts, thereby aiding surgical planning. Images of neurovascular contact along the motor root, but not the sensory root, for example, may lead to detailed inspection of these roots at surgery and consideration of performing MVD of the motor root. Failure to demonstrate any neurovascular contact should raise concern about the cause of the trigeminal neuralgia and should elicit an especially detailed evaluation of other potential causes of the symptoms. In the final analysis, however, trigeminal neuralgia remains a clinical diagnosis. Imaging data are not sufficient to preclude MVD in a patient with typical trigeminal neuralgia.

Conclusions

The 3D CISS MR sequence can be used reliably to identify individual components of the motor root of the trigeminal nerve and display their exact relationships to each other, the sensory root, and adjacent vessels. In nine (11.3%) of 80 sides examined, MR images displayed two components of the inferior motor root, a pattern known from anatomical studies but not previously depicted by neuroimaging. By combining 3D CISS and 3D TOF sequences obtained before and after intravenous administration of Gd-DTPA, MR imaging can successfully display neurovascular contacts with the sensory and motor roots at their points of emergence, along their REZs and RExZs, and along their peripheral cistern segments. In this study we detected a higher incidence of artery contacts with superior motor root than with inferior motor roots and a slightly higher incidence of artery contact with motor roots than with the sensory root. Because afferent sensory fibers may course within the inferior motor root in up to 20% of cases, evaluation of patients with trigeminal neuralgia should include assessment of neurovascular conflicts with both the sensory and the inferior motor root of the trigeminal nerve. The 3D CISS and 3D TOF sequences now make that evalu-
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Fig. 6. Neuroimages obtained in a 20-year-old woman with a large right lateral pontine cavernoma who presented with dysesthesia of the second and third trigeminal branches on the right side. **Left:** A T₂-weighted spin-echo image obtained in the transverse plane, revealing a large pontine cavernoma with intrallesional hematoma (short white arrows) that protrudes into the sensory root of the fifth cranial nerve on the right side (long white arrow). The motor and sensory roots cannot be differentiated from each other. A developmental venous anomaly is noted (black arrow). The sensory root on the left side is indicated by a white arrowhead. **Right:** Three-dimensional CISS image obtained in the coronal plane. The cavernoma (short white arrow) can be clearly identified within the sensory component (long black arrow) of the trigeminal nerve. The inferior (black arrowhead) and superior (short black arrow) motor roots are visualized. The inferior motor root is in direct contact with the superior surface of the sensory root but is not affected by the cavernoma. A thin component of the sensory root is found between the cavernoma and the inferior motor root (long white arrow). The superior motor root is not affected by the cavernoma. The cavernoma was completely resected from the sensory root with preservation of sensory and motor trigeminal function. The **white arrowhead** indicates a branch of the SCA.

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