Trigeminal Ganglion and its Divisions: Detailed Anatomic MR Imaging with Contrast-Enhanced 3D Constructive Interference in the Steady State Sequences

Indra Yousry, Bernhard Moriggl, Urs D. Schmid, Thomas P. Naidich, and Tarek A. Yousry

BACKGROUND AND PURPOSE: Visualization of the trigeminal system is important for imaging diagnosis but technically challenging. We assessed how well the trigeminal ganglion, its rootlets, and its branches (V1, V2, and V3) are depicted on three high-resolution pulse sequences.

METHODS: Twenty-two patients (44 sides) underwent nonenhanced 3D constructive interference in the steady state (CISS) MR imaging. Two of these patients and another 20 (44 sides) also underwent contrast-enhanced 3D CISS and contrast-enhanced 3D time-of-flight (TOF) MR angiographic (MRA) imaging. Appearances of the ganglion, sinus ganglii, ganglion lip, and sensory and motor rootlets in the Meckel cave were assessed.

RESULTS: The trigeminal ganglion was shown on enhanced 3D CISS images in all cases, on nonenhanced 3D CISS images in 77.3%, and on enhanced 3D TOF MRA images in 92.9%. Sinus ganglia and lips were demonstrated on 98% of enhanced 3D CISS images. Sensory rootlets were depicted with all 3D CISS sequences but no 3D TOF sequences. V1, V2, and V3 were displayed with all enhanced 3D TOF MRA sequences, 79.5–100% of enhanced 3D CISS sequences, and 0–50% of nonenhanced 3D CISS sequences.

CONCLUSION: The enhanced 3D CISS sequence was best for displaying the trigeminal ganglion, sinus ganglii, and sinus lips, whereas the enhanced 3D TOF sequence best displayed the emerging V1, V2, and V3 roots. The enhanced 3D CISS sequence was most useful. Complete MR imaging evaluation of the trigeminal ganglion and roots is best performed by using enhanced 3D CISS and enhanced 3D TOF MRA sequences.

The trigeminal (semilunar or gasserian) ganglion is situated along the anterior inferior lateral wall of the Meckel cave (1–4) (Fig 1). The ganglion presents a convex surface that merges with the anteroinferolateral dural wall of the sinus and a concave posteromedial surface (designated the sinus ganglii) that faces CSF in the Meckel cave (the trigeminal cistern) (3, 5, 6). The margins of the concave sinus ganglii are designated the ganglion lips (5, 6). Three major divisions (V1, V2, and V3) of the trigeminal nerve (cranial nerve [CN] V) arise from the convex face of the ganglion (1–4) (Fig 1). A group of small sensory rootlets, collectively designated the pars triangularis (5), emerge from the concave sinus ganglii to form the sensory root of CN V (2, 5, 7). The motor root of CN V courses along the medial aspect of the sensory fibers (8) and then passes inferior to the ganglion (9).

Previous authors have used contrast-enhanced T1-weighted MR imaging to evaluate the trigeminal ganglion (10) and nonenhanced 3D constructive interference in the steady state (3D CISS) MR images to evaluate the anatomy of the sensory and motor roots of the trigeminal nerve in the Meckel cave (11, 12). However, T1-weighted images do not display the fine detail of the ganglion and rootlets, while nonenhanced 3D CISS images inadequately display the trigeminal ganglion (13, 14). These findings suggested that contrast-enhanced 3D CISS sequences might depict the microanatomy of both the ganglion and the roots well. In the region of the Meckel cave, planning
The study group included 42 patients (21 men, 21 women; mean age, 52.5 years) who were to undergo MR study for a reason unrelated to our purpose (e.g., evaluation of supratentorial parenchymal hemorrhage, infarction, or tumor that did not affect the infratentorial compartment). The patients agreed to undergo imaging with extra cranial MRA sequences to confirm the presence of the trigeminal ganglion. The data sets from each CISS and TOF sequence were reconstructed in three orthogonal oblique planes oriented in relation to the cisternal course of the sensory root of CN V. All images were analyzed by two experienced neuroradiologists (I.Y., T.A.Y.) who had completed their training and who had 9 and 20 years of experience in neuroradiology and radiology, respectively. Images were analyzed and scored collaboratively.

Anatomic Assessment of the Trigeminal Ganglion

The certainty of identifying the trigeminal ganglion was determined for each pulse sequence in each of the transverse, sagittal, and coronal planes and recorded on an arbitrary scale, where a score of 2 was identified with certainty, 1 was most probable identification, and 0 was not identified (17–20). The trigeminal ganglion has an anatomically well-known semilunar form (5, 6, 8, 15) and location (at the anterior, inferior, and posterior aspects of the Meckel cave) (6, 8, 10, 15, 21). Clear recognition of this typical structure was considered positive identification. If this structure was not visible, negative identification was recorded.

In all cases with contrast enhancement, the intensity of enhancement in the trigeminal ganglion was visually determined on 3D TOF MRA and 3D CISS images. The ganglion was identified with certainty when the enhancing ganglion was clearly distinguishable from the less prominently enhancing dura (corresponding to strong ganglial enhancement). Most probable identification was when the ganglion enhanced only slightly more than the moderate enhancement of the dura. Mild enhancement was when the ganglion could not be identified because of the lack of differential enhancement between the ganglion and the dura.

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Anatomic Assessment of the Sensory and Motor Rootlets in the Meckel Cave

The certainties of identifying the motor root and the sensory rootlets of the pars triangularis were independently assessed in the sagittal plane and scored as described earlier.

Anatomic Assessment of the Main Trigeminal Branches

The certainties of identifying the cranial and foraminal segments of the ophthalmic nerve (V1), the maxillary nerve (V2), and the mandibular nerve (V3) were independently determined in each of the transverse, sagittal, and coronal planes and recorded by using the same arbitrary scale as described earlier.

Results

Identification and Dimensions of the Trigeminal Ganglion

Overall and for each one of the three orthogonal planes, the contrast-enhanced 3D CISS sequence was superior to the nonenhanced 3D CISS sequence or the contrast-enhanced 3D TOF sequence in depicting the trigeminal ganglion (Figs 2–5) (Table 1). The most useful sequence was the sagittal contrast-enhanced 3D CISS sequence, with which 100% of the ganglia were identified and 79.5% were scored 2. The two contrast-enhanced sequences showed the ganglion better than the nonenhanced 3D CISS sequence. The thickness of the ganglion was determined less often by using the nonenhanced 3D CISS sequence (n = 26, 59.1%) compared with the enhanced 3D CISS (n = 43, 97.8%) and 3D TOF (n = 39, 92.9%) sequences (Table 2). The trigeminal ganglion was usually 2 mm thick; less commonly, 1 mm; and rarely, 3 mm.

Identification of Upper and Lower Ganglion Lips and Sinus Ganglia

Identification of these structures was positive when all three elements were identified: the upper and lower lips of the ganglion and the sinus ganglion. The upper and lower lips of the ganglion and the sinus ganglion were best demonstrated by using the contrast-enhanced 3D CISS sequence (98%) (Figs 3 and 4, Table 3). The contrast-enhanced 3D TOF sequence (78.5%) was slightly superior to the nonenhanced 3D CISS sequence (77.3%) overall (Figs 2 and 5), but the percentage of positive identifications (score of 2) was higher with the nonenhanced 3D CISS sequence than with the 3D TOF sequence.

Identification of Sensory and Motor Rootlets

The sensory fibers emerging from the trigeminal ganglion were identified with certainty (score of 2) in all nonenhanced and the contrast-enhanced 3D CISS images (Figs 2–4). The motor root was depicted with certainty and differentiated from the sensory fibers in all cases on nonenhanced and enhanced 3D CISS images. However, the sensory and motor roots were not identified (score of 0) on any 3D TOF MRA image in any plane (Fig 5).

Identification of the Ophthalmic, Maxillary, and Mandibular Nerves

The course of V1 in the lateral wall of the cavernous sinus and in the superior orbital fissure was best identified with the contrast-enhanced 3D TOF sequence (100% in each imaging plane) (Fig 5, Table 4). V1 was well depicted on contrast-enhanced 3D CISS images (100% in the transverse plane, 91–97.7% in the other planes). Nonenhanced 3D CISS images did not display V1 adequately.

The course of V2 at the inferior border of the cavernous sinus and inside foramen rotundum was identified best by using the contrast-enhanced 3D TOF sequence (100% in the transverse and sagittal planes, 97.6% in the coronal plane) (Fig 5). V2 was well depicted on contrast-enhanced 3D CISS images in 84.1–93.2% (Figs 3 and 4). V2 was not adequately displayed by using the nonenhanced 3D CISS sequence (Fig 2).

The course of V3 in the foramen ovale was best identified by using the contrast-enhanced 3D TOF sequence (100% in each imaging plane), and it was
well depicted by using the contrast-enhanced 3D CISS sequence (100% in the coronal and sagittal planes, 79.5% in the transverse plane) (Fig 3). Non-enhanced 3D CISS images displayed V3 better than V2 or V1, but they were inadequate for consistent identification.

**Discussion**

The contrast-enhanced 3D CISS sequence depicted the trigeminal ganglion, the sinus ganglii and its lips, the sensory roots in the Meckel cave, and the motor root coursing along the floor of the Meckel cave well. For these structures, the contrast-enhanced 3D CISS sequence was superior to the nonenhanced 3D CISS and the contrast-enhanced 3D TOF sequences. The contrast-enhanced 3D CISS sequence also provided excellent depiction of the three main trigeminal branches (V1, V2, and V3), although the contrast-enhanced 3D TOF sequence was better for displaying these nerves.

**Meckel Cave and its Contents**

The Meckel cave is an enclosure formed by two layers of dura: an internal layer of dura propria and
an external layer of intracranial periosteum (3, 6, 22). The subarachnoid space extends upward from the prepontine cistern to form the trigeminal cistern in the cave (3, 5, 6). This cistern extends forward from the porus trigeminus to approximately the level of the midportion of the trigeminal ganglion (8).

The trigeminal ganglion is a thin crescent-shaped (semilunar) structure (5, 6) that lies at the anterior, inferior, and lateral aspects of the Meckel cave (6, 10, 21). The convex surface of the ganglion is directed toward the anteroinferolateral walls of the Meckel cave (5). The concave posterosomedical surface, designated the sinus ganglii, is directed posterosuperomedially toward the trigeminal cistern and the ostium of the Meckel cave (9). The margins of the sinus ganglii represent the lips of the ganglion (5, 22). The size of the ganglion varies widely (3, 6), ranging from 14 to 22 mm in length and from 4 to 5 mm in overall thickness (anteroposterior dimension) (5–7). However, after one accounts for its concave shape, the true thickness of the ganglion is 1.5–2 mm (5, 9). An envelope of dura propria and arachnoid encloses the ganglion (2, 3, 5, 6). The posterosomedical portion of the ganglion lies in the trigeminal cistern, but the convex anteroinferior surface of the ganglion is extremely adherent to the dura of the Meckel cave in its medial aspect and to the dura of the temporal fossa in its lateral aspect (2, 3, 5, 6, 22). Therefore, this portion lies outside the cistern.

The pars triangularis is the fan-shaped expansion of sensory rootlets that anastomose with each other and that extend posteriorly from the sinus ganglii (3–6, 9, 23). The motor root of CN V passes inferior to the trigeminal ganglion (9) and is adherent to the basal wall of the Meckel cave in its distal portion (6).

**MR Imaging**

Most previous studies of the trigeminal ganglion were performed using contrast-enhanced T1-weighted sequences (10, 24–26). For example, Downs et al (10) reported enhancement of the trigeminal ganglion in 100% of such studies. One report addressed the possibility of identifying the trigeminal ganglion with T2-weighted fast spin-echo and nonenhanced 3D CISS sequences (24), but other authors could not replicate the findings (13, 14). To our knowledge, no previous reports have addressed the true dimensions of the ganglion, its extension in the Meckel cave, the sinus ganglii and its lips, or the reliability of displaying the sensory and motor rootlets in the cave.

**3D CISS Sequences.**—The 3D CISS sequence is a high-spatial-resolution, refocused gradient-echo MR imaging sequence that is flow compensated. It can be performed with thin (0.66-mm) sections, and it can depict small structures surrounded by CSF with high contrast and high spatial resolution. Therefore, the sequence is useful for MR cisternography and has been successfully applied to visualize small cisternal structures, such as the trochlear nerve (18), the abducens nerve (17), and the rootlets of the hypoglossal nerve (17). In all of our patients, the intracisternal portions of the sensory and motor rootlets were well depicted and differentiated from each other with both nonenhanced and contrast-enhanced 3D CISS sequences.
The trigeminal ganglion, however, lies only partially within the trigeminal cistern. The convex anteroinferior surface of the ganglion is adherent to the dura of the Meckel cave and therefore lies outside the trigeminal cistern (2, 3, 5, 6, 22). For that reason, the 3D CISS sequences were not expected to display the ganglion well. The dura and the ganglion had similar signal intensities on nonenhanced CISS images (Fig 2); therefore, nonenhanced were also not expected to depict the ganglion well. However, Shigematsu et al (27) demonstrated that contrast-enhanced 3D CISS sequences show increased signal intensity that is directly proportional to the concentration of gadopentetate dimeglumine administered. Therefore, should the dura and the ganglion enhance to different degrees after the administration of contrast material, contrast-enhanced 3D CISS images should successfully distinguish the trigeminal ganglion from the adjacent dural wall of the Meckel cave and display the ganglion well. This postulate was confirmed. In our study, identification of the trigeminal ganglion (score of 2) improved from 15.9% on nonenhanced 3D CISS images to 92.9% on contrast-enhanced 3D CISS images (Figs 2–4, Table 1). Identification of the ganglion lips improved from 43.2% with the nonenhanced 3D CISS sequence to 95.5% with the contrast-enhanced 3D CISS sequence. The thickness of the ganglion lips improved from 43.2% with the nonenhanced 3D CISS sequence to 95.5% with the contrast-enhanced 3D CISS sequence.

Note.—Data are the numbers of nerves (percentage).

<table>
<thead>
<tr>
<th>Study and Plane</th>
<th>V3*</th>
<th>V2†</th>
<th>V1‡</th>
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<tbody>
<tr>
<td>Nonenhanced 3D CISS (44 sides)</td>
<td>2 (4.5)</td>
<td>0 (0)</td>
<td>42 (95.5)</td>
</tr>
<tr>
<td>Transverse</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>44 (100)</td>
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<tr>
<td>Sagittal</td>
<td>7 (15.9)</td>
<td>11 (25)</td>
<td>24 (54.5)</td>
</tr>
<tr>
<td>Coronal</td>
<td>6 (13.6)</td>
<td>15 (34.1)</td>
<td>23 (52.3)</td>
</tr>
<tr>
<td>Enhanced 3D CISS (44 sides)</td>
<td>25 (59.1)</td>
<td>9 (20.5)</td>
<td>9 (20.5)</td>
</tr>
<tr>
<td>Transverse</td>
<td>18 (41)</td>
<td>22 (50)</td>
<td>4 (9.1)</td>
</tr>
<tr>
<td>Sagittal</td>
<td>24 (54.5)</td>
<td>17 (38.6)</td>
<td>3 (6.8)</td>
</tr>
<tr>
<td>Coronal</td>
<td>11 (25)</td>
<td>24 (54.5)</td>
<td>7 (15.9)</td>
</tr>
<tr>
<td>Enhanced 3D TOF (42 sides)</td>
<td>26 (59.1)</td>
<td>9 (20.5)</td>
<td>9 (20.5)</td>
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<tr>
<td>Transverse</td>
<td>18 (41)</td>
<td>22 (50)</td>
<td>4 (9.1)</td>
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<tr>
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<td>11 (25)</td>
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<td>7 (15.9)</td>
</tr>
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</table>

**TABLE 4: MR imaging identification of the mandibular, maxillary, and ophthalmic nerves**

Note.—Data are the numbers of nerves (percentage).

*Inside foramen ovale.

†At the inferior border of the cavernous sinus and inside the foramen rotundum.

‡Inside the lateral wall of the cavernous sinus and the superior orbital fissure.

We deliberately used the 3D TOF sequence instead of conventional T1-weighted spin-echo or fast (turbo) spin-echo sequences because the 3D TOF sequence allowed for thin (1-mm) sections for ready reconstruction along the oblique planes needed to follow the course of the nerves and for improved contrast enhancement achieved by saturating the background soft tissue. Nevertheless, the 3D TOF sequence depicted the ganglion lips with certainty in only 9.5% of sides (vs. 95.5% for contrast-enhanced 3D CISS images), and the images failed to depict the sensory and motor rootlets in the trigeminal cistern (Fig 5, Table 3).

**Contrast Enhancement of the Trigeminal Ganglion.—** Reports about the contrast enhancement of the trigeminal ganglion are discordant. Downs et al (10) reported enhancement of the trigeminal ganglion on all coronal T1-weighted spin-echo MR images. Williams et al (26) found enhancement in 4% of cases and stated that the ganglial enhancement that Downs et al reported might represent enhancement of a pericavernous venous plexus engulfing the ganglion. This pericavernous venous plexus is a well-described feature that Rhoton reported (8). It converges on the cavernous sinus, with the lateral edge of its posterior wall lying just medial to the ostium of the Meckel cave and medial to the upper third of the trigeminal ganglion but not situated in the Meckel cave (8). Furthermore, we found no description of a venous plexus in the Meckel cave or directly surrounding the dural sheath of the ganglion in any previous anatomic report.

The ganglion enhanced more than the adjacent dura in 92.9% of sides on contrast-enhanced 3D TOF imaging, and all sides on contrast-enhanced 3D CISS imaging (Figs 3–5). These findings support the hypothesis that the trigeminal ganglion does enhance.
appreciably, as Downs and co-workers originally suggested (10).

**Ophthalmic, Maxillary, and Mandibular Nerves**

**Anatomy.**—V1 courses anteriorly in the lateral wall of the cavernous sinus (2, 8, 13). It enters the orbit through the superior orbital fissure (21), a bony hiatus 20 mm long by 6 mm wide that contains an anterior extension of the cavernous sinus (28). The major portion of V2 courses below the line of junction of the medial and lateral walls of the cavernous sinus (8). It exits the skull through the foramen rotundum (21), a narrow canal approximately 4 mm long and 3 mm wide (6). V3 courses inferiorly to exit the skull through the foramen ovale, an ostium 7 mm long by 4 mm wide (5, 21).

**MR Imaging of V1, V2, and V3.**—Previous MR imaging studies involved a systematic identification of the three major trigeminal branches with nonenhanced and contrast-enhanced T1-weighted sequences (1, 24, 26, 29), nonenhanced T2-weighted fast spin-echo sequences (24), and nonenhanced 3D CISS sequences (24). In studies of contrast enhanced T1-weighted sequences, V2 and V3 were visualized in the foramina ovale and rotundum in up to 93% of cases, but the authors did not report on visualization of V1 (14, 26). To our knowledge, we are first to assess the cranial segments of all three major branches of CN V by using contrast-enhanced 3D CISS and 3D TOF images, which successfully depicted V1, V2, and V3 on 84.1–93.2% and 97.6–100% of the images, respectively (Figs 3–5, Table 4).

The improvement in visualizing the foraminal and cranial segments of V1, V2, and V3 most likely resulted from enhancement of the perineural venous plexus that surrounds each nerve within the foramen. Because the nerves do not enhance, they are displayed as linear structures of low signal intensity within the high signal intensity, enhancing venous plexus (14, 17, 26, 30).

In most cases, contrast-enhanced 3D TOF MR images successfully depicted V1 in the lateral wall of the cavernous sinus and the superior orbital fissure, V2 along the inferior border of the cavernous sinus and in foramen rotundum, and V3 in the foramen ovale (Fig 5). Compared with nonenhanced 3D CISS sequences, the enhanced 3D CISS sequence dramatically improved the identification of V1, V2, and V3 in all three planes (Figs 2–4). Overall, the enhanced T1-weighted 3D TOF sequence was superior to the enhanced 3D CISS sequence and appeared to be the most suitable sequence for depicting the main trigeminal branches (Table 4).

**Study Limitations**

We did not have a true reference standard. This could have been achieved by imaging the specimens in whom cryomicrotomic sections were later obtained. The role of contrast enhancement, however, could not have been evaluated in that group. Another approach would have been to evaluate patients undergoing surgery for the Meckel cave and to compare the MR images with in vivo photographs and surgical descriptions. Because we excluded patients with disease of CN V, this approach was also not possible. We tried to circumvent this problem by comparing our imaging results with the classic anatomic descriptions of this well-studied structure and with the cryomicrotomic sections we obtained. Nevertheless, the absence of a direct criterion standard is a drawback of our study, as in many other anatomic imaging studies (14, 26).

**Conclusion**

Contrast-enhanced 3D CISS images exquisitely displayed the trigeminal ganglion, the sinus ganglii, and the sinus lips. The motor root of CN V was clearly distinguishable from the sensory rootlets of the pars triangularis in the Meckel cave. Enhanced 3D CISS images also depicted the trigeminal branches V1 (91–100%), V2 (84–93%), and V3 (80–100%) but not as well as enhanced 3D TOF images (97.6–100% for all divisions). Therefore, the contrast-enhanced 3D CISS sequences appeared to be the most appropriate sequence for evaluating the trigeminal ganglion, whereas contrast-enhanced 3D TOF sequences were most appropriate for depicting the cranial and foraminal segments of V1, V2 and V3. Complete MR imaging evaluation of the trigeminal ganglion and roots is best performed using both contrast-enhanced 3D CISS and contrast-enhanced 3D TOF MRA sequences.

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