Magnetic resonance cisternography for visualization of intracisternal fine structures

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Object. To assess its usefulness in demonstrating cisternal anatomy, the authors investigated magnetic resonance (MR) cisternography in which a heavily T₂-weighted turbo spin–echo method was used to visualize normal anatomical fine structures and lesions in the basal cisterns in 20 healthy volunteers and 43 patients. The authors applied peripheral pulse gating, which had been optimized to reduce artifacts in the cisterns attributable to cerebrospinal fluid (CSF) flow.

Methods. The detectability of each cranial nerve was determined in healthy volunteers. The first, second, and third nerves and the seventh–eighth nerve complex were clearly visualized in all participants; the fifth nerve was clearly seen in 80% and the sixth cranial nerve in 50%. The fourth nerve and the ninth through 12th nerves were difficult to identify individually, except in some volunteers.

To reduce artifacts caused by fast CSF flow, we determined the delays as a function of the time elapsed between two consecutive peaks of pulse wave in a peripheral pulse gate (P–P interval) at which there was reversal of flow direction to minimize the CSF flow–related artifact. Using peripheral pulse gating and a time delay of 30% of the R–R interval, the authors succeeded in minimizing the CSF flow–related artifacts.

Magnetic resonance cisternography appears to be very useful for demonstrating intracisternal fine anatomy and enhancing the contours of the juxtacisternal lesion. A minute amount of CSF interposed between lesions and normal structures such as nerves, vessels, or bone structures can be detected by means of this sequence. In patients with facial spasm, axial images and oblique coronal images obtained in a plane parallel to the seventh–eighth cranial nerve complex demonstrated vascular compression in all 13 patients. The MR cisternography finding of compression was confirmed in all nine patients who underwent microvascular decompression.

Conclusions. Magnetic resonance cisternography appears to show great promise for evaluation of patients with neurovascular compression or tumors in and around the basal cisterns; the procedure adds only a small amount of imaging time.

KEY WORDS • cranial nerve • cistern • cisternography • magnetic resonance imaging

EVALUATION of the subarachnoid cisterns made by performing computerized tomography (CT) scanning with contrast media or intrathecal gas cisternography has been popular in recent years. Advances in magnetic resonance (MR) imaging have permitted visualization of the cranial nerves and vascular structures in the subarachnoid cisterns. We investigated the use of a heavily T₂-weighted turbo spin–echo sequence with peripheral pulse gating (PPG) that focuses especially on the parasellar and cerebellopontine angle (CPA) cisterns. Peripheral pulse gating was used to reduce the artifact caused by cerebrospinal fluid (CSF) flow.

We discuss the origin of contrast resolution in the heavily T₂-weighted turbo spin–echo sequence, the imaging planes needed for evaluation of cranial nerves, and the optimization of PPG.

Clinical Material and Methods

We performed MR cisternography in 20 healthy volunteers; in 10 of these participants the study was focused on the parasellar region, and in the remaining 10, imaging was limited to the posterior fossa. In addition, we performed MR cisternography in selected patients admitted to our institution between February 1995 and October 1996. Of the 43 patients studied, 14 had tumors in the juxtasellar region (nine had pituitary adenoma, three had meningioma, one had Rathke’s cleft cyst, and one had cranioopharyngioma); nine had CPA lesions (seven had acoustic neuroma, one had jugular foramen neurinoma, and one had epidermoid tumor); three had meningiomas that originated from another site (one in the frontal base and two in the sphenoidal ridge); four had cerebral aneurysms; and 13 had facial spasms.

Magnetic Resonance Cisternography in Healthy Volunteers

Initially, we studied the ability of MR cisternography to depict normal anatomical structures in the cisterns in 20 healthy volunteers. All imaging was performed using a 1.5-tesla superconducting magnet (Philips Gyrosan...
ACS-NT, Best, The Netherlands) with a standard head coil. Magnetic resonance cisternography was performed in which a heavily T2-weighted turbo spin–echo sequence was used to display a reversed image with the following parameters (without PPG): TR 5800 msec, TE 220 msec, 200-mm field of view, 3-mm slice thickness with a 0.3-mm interslice gap, 284 × 512 pixel matrix, echo train length of 23, and four excitations (nose to ear to xiphoid). The time required for 13 images in one direction was 3 minutes and 48 seconds. We usually obtained axial and coronal images in each healthy volunteer; in some volunteers we also obtained oblique sagittal or oblique coronal images to demonstrate the entire course of some cranial nerves.

The parasellar region comprises important structures, which include the pituitary gland, pituitary stalk, first through sixth cranial nerves, internal carotid artery (ICA), and the anterior and middle cerebral arteries (ACA and MCA, respectively). Various lesions can develop in this region, and a clear understanding of the anatomical relationships in the cisterns is needed for more desirable surgical planning.

**Cerebrospinal Fluid Flow–Related Artifact on MR Cisternography Images**

We investigated the occurrence of artifacts on axial and coronal images in the cisterns in 10 volunteers (20 sides). We also used a phase-contrast technique to measure CSF flow in the CPA cistern (TR 22 msec, TE 14 msec, flip angle 10°, two excitations, 7-mm slice thickness, velocity encoding 3 cm/sec, retrospective gating) in some of the volunteers to ascertain the origin of the artifact (one participant) and to determine the phases of CSF flow during the cardiac cycle (eight participants). Results were used to determine the optimal timing of minimum CSF flow needed to reduce the artifacts.

**Results**

**Magnetic Resonance Cisternography in Healthy Volunteers**

We conducted a systematic analysis of the visualization of each of the cranial nerves to determine the percentage of detectability (Table 1). The optimal imaging plane and detectability rate for each cranial nerve are summarized in Table 1. Magnetic resonance cisternography clearly demonstrated cranial nerves as well as vascular structures in the same image (Fig. 1). On coronal images, the olfactory tract could be seen in cross section in the olfactory cistern in all volunteers (Fig. 2A). The olfactory tract was difficult to identify on axial images.

The optic nerve, chiasm, and tract and their relation-
ships to surrounding structures within the chiasmatic cistern were visualized in all healthy participants (Fig. 1). The optic nerve within the optic canal and orbit was outlined by a CSF sleeve of low signal intensity (Fig. 2B and C). In all 10 volunteers the optic nerves were demonstrated along their courses on oblique sagittal images. Within the optic canal, the optic nerve was identified by its outline of CSF in only five participants, regardless of whether axial or oblique views were used.

The oculomotor nerve travels in the interpeduncular cistern between its exit from the midbrain and its entry to the cavernous sinus. The oculomotor nerve runs almost parallel to the course of the optic nerve. Oblique sagittal images demonstrated the oculomotor and optic nerves in all volunteers (Fig. 2F).

The entry zone into the cavernous sinus is followed by a 6- to 8-mm-long dural and arachnoid pocket within the sinus. In this area, the oculomotor nerve is outlined by the CSF sleeve that is formed by the dural pocket (Fig. 2D and E); this was visualized on coronal images in all 10 volunteers and on axial images in six of them. The trochlear nerve is approximately 0.7 to 1.5 mm thick and is therefore difficult to distinguish from vascular components. In one volunteer the nerve was seen at its exit site; in another individual its course within the ambient cistern was demonstrated. The pituitary gland was well delineated from the adjacent cavernous sinus because of the low signal intensity caused by the venous plexus (Fig. 1C). The pituitary gland itself, however, was poorly visualized in two of the 10 volunteers. The pituitary stalk was visualized on both axial and coronal images in all participants.

On axial images of the posterior fossa, the trigeminal nerve was demonstrated along its course in the superior CPA cistern to Meckel’s cave in eight participants (Fig. 3A and B). The cisternal portion of the nerve was demonstrated along its entire course on oblique sagittal images. In the prepontine cistern the abducent nerve is approximately 1 to 1.8 mm thick. In five participants this nerve was demonstrated in the cistern; in four the nerve was visualized in Dorello’s canal (Fig. 3C and D).

The facial and acoustic nerves traveling in the inferior CPA cistern were identified as two distinct bundles of nerves in all volunteers (Fig. 4A). In the internal acoustic meatus the vestibulocochlear nerve divided into two bundles, which were identified bilaterally in three volunteers and unilaterally in three. On oblique coronal images, there was excellent visualization of the seventh and eighth cranial nerves as they passed through the CPA cistern toward the internal acoustic meatus in all volunteers (Fig. 4B). Furthermore, on oblique sagittal images obtained in a plane perpendicular to the seventh and eighth cranial nerves, three distinct branches (the cochlear nerve and the superior and inferior vestibular nerves) were demonstrated in four participants (Fig. 4D).

Vascular components around the seventh–eighth cranial nerve complex showed high signal intensity on MR cisternography and were well visualized in relation to the nerve complex. Because every cranial nerve that passes through the lateral cerebellomedullary and inferior CPA cisterns toward the jugular foramen (that is, the ninth–11th cranial nerves) is thin and dispersed in a fan shape, they were difficult to

Fig. 2. Magnetic resonance cisternograms obtained without PPG at the level of the olfactory tract, and optic and oculomotor nerves. A: Coronal image showing both olfactory tracts outlined by CSF (arrows). B and C: Axial image and oblique sagittal image obtained in a plane parallel to the right optic nerve showing the nerve outlined by a CSF sleeve (arrows) as well as the optic canal. Note that the nerve is slightly angled within the canal. D-F: Axial (D) and coronal (E) images and an oblique sagittal (F) image obtained in a plane parallel to the right oculomotor nerve (arrows). The oculomotor nerves are seen in tangent on the coronal image. Arrowheads (E) indicate the artifacts caused by CSF flow, which are usually identified in the narrow site of the cisterns.
identify along their entire course in most volunteers (Fig. 4C). The ninth and 10th nerves were seen on axial images, but they were difficult to identify individually because of their close apposition to each other.

**Origin of the CSF Flow–Related Artifact**

We investigated the occurrence of artifacts on axial and coronal images in the cisterns in 10 volunteers (20 sides). Axial images in all individuals showed an artifact around the basilar artery within the interpeduncular and prepontine cisterns. On images of 12 sides (60%) the artifact displayed higher signal intensity than the cranial nerves, and on all images the cistern appeared to be relatively narrow. A similar artifact was observed around the fifth cranial nerve (Fig. 5A) within the superior CPA cistern in all healthy participants. The artifact was observed at the medial aspect of the fifth cranial nerve, and the medial artifact was more prominent than the lateral artifact in 65% of the sides studied. Because of the presence of these artifacts, the fifth nerve was poorly visualized in 20% of sides. In the CPA cistern, the artifact was observed only on the ventral aspect of the nerve in 60% of sides and on both the ventral and dorsal aspect in 25%, making it difficult to distinguish nerve from vessel. On coronal images of the parasellar region, the artifact was conspicuous around the ICA bilaterally (Fig. 2E), precluding depiction of structures within the cistern.

On MR cisternography images obtained in these volunteers, artifacts appeared in the narrowed portion of the cisterns, indicating that the artifacts were a result of high-velocity signal loss induced by CSF flow. To study this, we used a phase-contrast technique in volunteers to measure CSF flow in the CPA cistern to ascertain the origin of the artifact (one participant) and to determine the phases of CSF flow during the cardiac cycle (eight participants).

Investigation of the relationship between maximum CSF-flow velocity and signal intensity at fixed locations within the prepontine cistern and the superior CPA cistern revealed a negative correlation (Fig. 6); these artifacts appeared in areas of high-velocity signal loss.

Observation of the flow-time activity curve pattern, obtained using the phase-contrast technique in eight volunteers, indicated that the phase at which the CSF flow became zero and converted to a caudocranial direction...
corresponded to approximately 30% of the time elapsed between two consecutive peaks of pulse wave of peripheral pulse gate (P–P interval) (Fig. 7). Compared with the flow in the craniocaudal direction, the flow in the caudo-cranial direction was slower, with phase-reversal timing. When the time delay was set at 30% of the R–R interval using PPG in an attempt to reduce the high-velocity signal loss, the artifacts on the MR cisternography images decreased substantially.

We compared axial MR cisternography images acquired with or without PPG in healthy participants (five volunteers). On images obtained without PPG, at the level of the trigeminal nerve, the nerve was visualized in two of five volunteers. Images acquired with PPG showed a decreased artifact in one volunteer and a reduction in the extent of the artifact around the basilar artery in three (Fig. 5B), with improved visualization of the trigeminal nerve. Use of PPG failed to reduce the artifact in volunteers in whom the prepontine cistern was very narrow and the basilar artery was tortuous and close to the trigeminal nerve. However, use of PPG permitted better delineation of the nerve and vessels in the seventh–eighth cranial nerve complex.

Magnetic Resonance Cisternography Findings

Magnetic resonance cisternography images obtained in patients with pituitary adenomas, particularly in those with suprasellar extension (nine patients), demonstrated the relationship of the tumor to the optic nerve and optic chiasm, to the pituitary stalk, and to vascular components such as the ICA and ACA (Fig. 8A and B).

In a patient with craniopharyngioma (Fig. 8C), the space between the tuberculum sellae and chiasm was easily identified. It is very useful to determine the appearance of the chiasm, such as a prefixed or postfixed chiasm, and MR cisternography is also able to detect the direction of tumor extension (such as entering into the prechiasmatic cistern or interpeduncular cistern, or being limited to the intrasellar region).

In a patient who harbored a frontal base meningioma (Fig. 9), the surrounding structures were easily identified, and there was a CSF sleeve of low signal intensity between the tumor and the severely compressed frontal base. This peritumoral low signal intensity suggested the presence of an intervening layer of CSF. At surgery, it was easy to dissect the lesion away from the adjacent frontal base cortex. In all 12 patients who had tumors (six with meningioma, one with craniopharyngioma, and five with neurinoma) and demonstrated a peritumoral CSF sleeve, no adhesions were found at surgery and all tumors were easily dissected, suggesting that visualization of the peritumoral CSF sleeve excluded the presence of firm adhesions.

In a patient with a tumor of the CPA, MR cisternography accurately depicted the relationship of the tumor to the seventh and eighth cranial nerves as well as to surrounding vascular and brainstem structures. Magnetic resonance cisternography also identified a portion of the tumor within the internal acoustic meatus (Fig. 10).
case of a relatively large sized CPA tumor, it is difficult to identify surrounding fine structures. However, in the upper or lower pole of the lesion, MR cisternography images can provide details on changes in surrounding structures such as a stretched pyramidal vein, upward displacement of the trigeminal nerve, medial displacement of the abducent nerve and the basilar artery, and caudal displacement of the ninth and 10th cranial nerves; the vertebral arteries were recognized in some cases. Therefore, with severe compression of the nerves, the border of the lesion could not be identified.

Axial images and oblique coronal images parallel to the seventh and eighth cranial nerve complex clearly demonstrated vascular compression against the complex (Fig. 11) in all 13 patients with facial spasm. Nine of the 13 patients underwent microvascular decompression; the MR cisternography finding of vascular compression was confirmed in all nine patients. Magnetic resonance cisternography was repeated after microvascular decompression in six patients, and successful decompression was confirmed in all six.

In all four patients with cerebral aneurysm, the aneurysm and surrounding structures were clearly demonstrated (Fig. 12), and the perforating branches adjacent to the aneurysm were also clearly identified.

Discussion

Previously, to detect a fine structure in the cisterns, we used metrizamide-enhanced CT scanning, air-CT scanning, conventional MR imaging, and MR cisternography. Metrizamide sodium or air was used as a contrast material and introduced into the subarachnoid spaces, but these methods were invasive. Magnetic resonance imaging and MR angiography provide information on lesions with nerves or vascular structures viewed separately. In contrast, MR cisternography is a noninvasive technique using in vivo CSF as a contrast material, which travels by itself into the subarachnoid spaces.

In 1994, El Gammal and Brooks introduced the use of inverted images of a heavily T2-weighted fast spin–echo pulse sequence as MR cisternography. In a separate article we present a preliminary report of MR cisternography in which a heavily T2-weighted fast spin–echo pulse sequence was used. Contrast resolution plays an important role in the demonstration of cranial nerves within the cranial cisterns. A heavily T2-weighted fast spin–echo pulse sequence with long repeat and echo times provides excellent contrast resolution and emphasizes the CSF signal. Typical T1 values for CSF range from 2105 to 3800 msec and T2 values range from 1519 to 2640 msec. To shorten the examination time, we limit the imaging area to

Fig. 8. Axial (A) and coronal (B) MR cisternograms obtained with PPG in a 61-year-old woman with a pituitary macroadenoma demonstrating tumor between the ICAs pressing on the optic chiasm. Magnetic resonance cisternogram (C) obtained with PPG in a 37-year-old woman with a craniopharyngioma. The space between the tuberculum sellae and chiasm is easily identified.

Fig. 9. Axial (A), coronal (B), and oblique sagittal (C) MR cisternograms obtained with PPG in a 45-year-old woman with a frontal base meningioma. The tumor is shown surrounded by a CSF sleeve (black arrowheads). The tumor is pushing down the left side of the optic chiasm and the left ICA is involved by the tumor (B). At surgery, the tumor was easily dissected from the surrounding structures. White arrowheads indicate the oculomotor nerve.
smaller regions. We used a 5800-msec TR, which is sufficiently long for good contrast resolution. We also used an echo train length of 23 (echo spacing 18.3 msec) and a scan duration of approximately 3 minutes and 48 seconds. When imaging brain matter, use of a relatively long echo train length results in a poor signal-to-noise ratio. However, because of the long $T_2$ value of CSF, a long echo train length produces a minimal signal-to-noise reduction. With PPG, the length of the repeat time is determined by the cardiac cycle and, therefore, is changed by the cardiac cycle in each case.

**Magnetic Resonance Cisternography in Healthy Volunteers**

The optic nerves and chiasm were best demonstrated on axial images, which provided good visualization of the cavernous portion of the ICA, anterior communicating artery, pituitary stalk, and other surrounding structures. Oblique sagittal images obtained in a plane parallel to each optic nerve provided excellent visualization of lesions in the more distal optic nerve. The oculomotor nerve was observed in the interpeduncular cistern on axial and oblique sagittal images. The fifth, seventh, and eighth cranial nerves were well demonstrated on both axial and oblique sagittal images obtained in a plane parallel to each nerve. The entire course of the fifth, seventh, and eighth cranial nerves could be observed within the cranial cisterns using a combination of axial and oblique images. Oblique images obtained in planes parallel to the fifth cranial nerve and the seventh–eighth cranial nerve complex were very useful for visualization of the root entry/exit zones of the nerves along the brainstem.

The optic pathway and oculomotor nerves in the basal cisterns were clearly demonstrated in all healthy volunteers on MR cisternography. The distal optic pathway was well demonstrated except for the portion within the optic chiasm.
canal; this was detected in only 50% of volunteers. This was probably due to misregistration of slice selection for the optic canals. Standard axial or oblique images obtained along the distal optic nerves are not parallel to the nerve within the canal because the nerve angles slightly as it courses through the canal and can only be well visualized on images obtained in a plane parallel to the optic canal portion of the nerve. The contour of the pituitary gland was blurred on coronal images in 20% of volunteers, perhaps because of the artifact from the cavernous sinus, which shows wide individual variability. Flow characteristics within the cavernous sinus can be variable, resulting in an assortment of flow-related artifacts and obscuring visualization of the cranial nerves within the sinus. Because MR cisternography could be used to visualize the fifth cranial nerve in 80% of volunteers and the seventh–eighth cranial nerve complex in 100% suggests that this technique would be very useful in patients with suspected cranial nerve lesions such as trigeminal neuralgia and facial spasm. The ninth and 10th cranial nerves were visualized in 30% of the volunteers. Unfortunately, the 12th cranial nerve was difficult to identify.

Cerebrospinal Fluid Flow–Related Artifact on MR Cisternography Images

Using MR cisternography in the area surrounding the trigeminal nerve, the preopticine and upper CPA cisterns have the same signal intensity as that of the brainstem. Artifacts observed in the narrow regions of the cisterns were likely due to increased CSF flow velocity and resulting high-velocity signal loss and/or turbulence. Bradley and Waluch2 showed that the mechanism of high-velocity signal loss is caused by protons that are exposed to the initial 90° pulse flowing completely out of the section during the interpulse interval, before exposure to the 180° pulse. Protons that flow into the section during the interpulse interval have not been affected by the 90° excitation pulse; therefore, no signal is emitted. Additional loss of signal is due to CSF turbulence in the cistern. Turbulence can arise in the narrow region of the cisterns, particularly adjacent to irregular surfaces, cranial nerves, vascular branches, and choroid plexus. It is difficult to reduce the artifacts because of the wide variability of the anatomical structures. To reduce the high-velocity signal loss, we determined the delay as a function of the P–P interval at which there was reversal of flow direction. Using PPG and a time delay of 30% of the P–P interval, we were able to reduce the CSF flow–related artifacts. Another way to reduce the artifacts caused by CSF flow is to use volume acquisition. However, when using volume acquisition, imaging time exceeds 10 minutes for imaging in one direction. To shorten the examination time by using volume acquisition, the echo train length needs to be increased. However, a downside of increasing the echo train length is a possible blurring artifact that may jeopardize edge detail. In contrast, MR cisternography (with PPG and a delay time of 30% of the P–P interval) requires only an average of 4.5 minutes for imaging in one direction, and satisfactory resolution of the image can be obtained. Even using PPG, however, we could not resolve the artifact that was caused by turbulence.

Clinical Feasibility of Using MR Cisternography in Patients

Magnetic resonance cisternography appears to be very useful for demonstrating cisternal anatomy and enhancing the contours of a juxtacisternal lesion. A minute amount of CSF interposed between lesions and normal structures, such as nerves, vessels, or bone structures, can be detected by using this sequence. The disadvantage of this sequence is less contrast between brain matter and lesions within the brain. In assisting the physician in diagnosing facial spasm caused by neurovascular compression, MR cisternography appears to have an accuracy rate equal to either MR angiography or gradient-echo imaging. However, MR cisternography was not reliable in identifying vessels in three of nine patients with facial spasm who underwent surgery; thus, MR angiography remains a necessary tool for use in these patients. After neurovascular decompression, the Teflon prosthesis was visualized on MR...
Cisternography as a tiny structure with high signal intensity; this appears to be useful in evaluating patients after surgery, particularly if there are recurrent symptoms.

**Peritumoral CSF Sleeve**

In all six patients with meningiomas and in four of seven patients with acoustic neurinomas, MR cisternography showed a peritumoral CSF sleeve of low signal intensity. At surgery, all of these tumors were easily dissected from the brainstem or other adjacent structures, indicating that the presence of the peritumoral CSF sleeve is useful for surgical planning. In some patients with larger tumors and greater mass effect on the brainstem, no peritumoral CSF sleeve was seen. This may be explained by a lack of CSF between the tumor and surrounding structures, a CSF sleeve that is too thin to be demonstrated, or a partial volume effect.

**Conclusions**

Noninvasive MR cisternography is an excellent modality for demonstration of cisternal fine anatomy. It shows great promise for evaluation of patients who have neurovascular compression or tumors around the basal and CPA cisterns. Imaging can be accomplished in a relatively short time.

In addition, MR cisternography, when performed with PPG and a delay time of 30% of the P–P interval, is a useful guide for better surgical planning.

**References**