Aque duct al stenosis is a common cause of obstruc tive hydro cephalus, accounting for 10% of all adults with hydro cephalus.9,26 The most common treatment options—apart from removal of the occluding lesion—are either insertion of a ventriculoperitoneal or ventriculoatrial shunt, or ETV. Shunt placement is reported to have a success rate of 80%, but also a complication rate of 50% in 5 years due to infection, mechanical dysfunction, and overdrainage—all factors that lead to shunt failure.2,3 In comparison, ETV, which has become the treatment of choice for AS13 has a reported success rate of up to 90%, and seems to cause fewer complications.5,13,14,23,25 However, there are important sources of operative failure and serious complications during and/or after the procedure. Often the indication for ETV is difficult to determine due to indistinct imaging of the aqueductal region. Is there an occupying structure within or compressing the

Three-dimensional constructive interference in steady-state magnetic resonance imaging in obstructive hydrocephalus: relevance for endoscopic third ventriculostomy and clinical results

Clinical article

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Object. Endoscopic third ventriculostomy is the treatment of choice in patients with obstructive hydrocephalus caused by aqueductal stenosis. The authors examined the clinical course and results of surgical treatment for obstructive hydrocephalus with pre- and postoperative refined constructive interference in steady-state (CISS) MR imaging.

Methods. Forty patients with obstructive hydrocephalus underwent pre- and postoperative 3D-CISS imaging and clinical evaluation. Radiological findings were correlated with intraoperative observations of the thickness and transparency of the floor of the third ventricle and the patient’s postoperative clinical course.

Results. Three-dimensional CISS MR imaging provides precise visualization of the basal/posterior cerebral artery, its distance to the clivus, the diameter of the foramen of Monro, and the extension of and thickness of the floor of the third ventricle. In 71% of patients a flow void was detectable postoperatively on the ventriculostomy. In this group 81.5% had strong and 14.8% moderate clinical benefit, and 3.7% required secondary shunt placement. In the remaining 29% of the patients without a visible flow void, strong improvement was seen in 54.5%, moderate improvement in 18.2%, and stoma failure occurred in 27.3% (p = 0.094). Radiological measurements of the thickness of the third ventricle floor correlated with intraoperative findings (r = 0.35, p = 0.029). Comparison of outcomes showed a statistically significant tendency for a better outcome in patients with thin and easily perforated third ventricle floors (p = 0.04).

Conclusions. Endoscopic ventriculostomy in patients with obstructive hydrocephalus is safe and mostly successful, and 3D-CISS MR imaging seems to be a valuable diagnostic method for precisely identifying the anatomy of relevant structures. Furthermore, 3D-CISS MR imaging allows judgment of the thickness of the third ventricle floor and display of the ventriculostomy/flow void, which are predictive for intraoperative course and clinical outcome. (DOI: 10.3171/JNS/2008/109/11/0931)

Key Words • constructive interference in steady-state MR imaging • endoscopic third ventriculostomy • flow void • outcome • third ventricle

Abbreviations used in this paper: AS = aqueductal stenosis; BA = basilar artery; CISS = constructive interference in steady-state; CSF = cerebrospinal fluid; ETV = endoscopic third ventriculostomy; KPS = Karnofsky Performance Scale; SD = standard deviation.
aque duct, and is this structure flow-relevant? Furthermore, when ETV is indicated, the choice of endoscope can be influenced by knowledge of the precise diameter of the foramen of Monro and the size of the third ventricle. The shape and thickness of the floor of the third ventricle might influence the intraoperative course considerably as unfavorable conditions can aggravate the penetration and dilation of the stoma and have a potentially negative impact on its long-term patency. The precise preoperative location of the basil ar and posterior cerebral arteries in relation to the planned stoma, and their distance from the clivus and pons are important in minimizing the risk of intraoperative vessel damage. In addition, unnoticed secondary membranes such as the Liliequist membrane below the floor of the third ventricle can cause stoma failure by blocking CSF flow to the basal cisterns and Pacchioni granulations. Therefore, the identification of such membranes on preoperative imaging studies may influence the operative strategy. It must also be determined whether there are signs on postoperative images that predict long-term stoma patency and clinical course.

Due to the potential complications of ETV, a maximally precise and detailed imaging modality is needed to evaluate the operative indications and estimate the success of ETV.

Magnetic resonance imaging is the most sensitive modality for diagnosing obstructive hydrocephalus. However, conventional spin echo/fast spin echo MR imaging pulse sequences often leave room for interpretation due to low spatial resolution or even failure to delineate fine structures such as the aqueduct or arachnoidal membranes. In recent years, 3D-CISS MR imaging has gained increasing importance in displaying the course of neural structures and vessels within the cerebrospinal space of the basal cisterns in any desired plane. Furthermore, this gradient-echo imaging technique is sensitive to flow. We prospectively analyzed pre- and postoperative imaging studies and the clinical course of 40 consecutive patients with obstructive hydrocephalus caused by AS who underwent ETV. The aim of this study was to investigate the ability of 3D-CISS MR imaging to show relevant anatomical structures in the area of the third ventricle, and to detect relationships between characteristic marks on 3D CISS images as flow-void signals within the aqueduct and ventriculostomy, and the intraoperative course or clinical outcome.

Methods

All patients admitted between 2002 and 2005 to the Department of Neurosurgery, University Hospital Munich-Grosshadern, Germany, who suffered from obstructive hydrocephalus caused by AS who underwent ETV were enrolled in this study. The patients were clinically evaluated pre- and postoperatively (outcome at discharge from hospital, and after 3, 9, and 12 months) by using KPS scores. An improvement in KPS score of ≥ 20 points within 3 months postoperatively was defined as strong clinical improvement, < 20 points as moderate improvement, and failure was defined as a stagnant or worsened KPS score and the need for a secondary operation (shunt surgery or repeated ETV). Furthermore, clinical hydrocephalus symptoms were subdivided into 5 main qualitative categories: visual disturbance, mental disturbance (assessed with the Mini-Mental State Examination), urinary incontinence, gait disturbance, and headache combined with nausea and/or vomiting.

All patients underwent conventional spin echo/fast spin echo sequences (T1-weighted spin echo sequence, T2-weighted fast spin echo sequence, 3-mm slice thickness) and 3D-CISS imaging with a 1.5-T system (Magnetom Vision, Siemens) in the regular quadrature head coil. The 3D-CISS sequence is a heavily T2-weighted, 3D Fourier transformation MR technique, and is essentially a gradient-echo–based sequence. The images were reconstructed in the transverse, sagittal, and coronal planes with a slice thickness of 0.66 mm. Further technical data: TR = 12.3 msec; TE = 5.9 msec; 33.0-mm slab thickness; 0.66-mm effective section thickness; flip angle 70°; field of view 230 mm; number of partitions 50; pixel size 0.56 × 0.45 mm; scan time 6 minutes and 18 seconds.

A rigid fiberscope (Gaab universal neuroendoscopy system, Karl Storz GmbH and Co.) was inserted into the lateral ventricle. If no other location was suggested according to the preoperative 3D-CISS images, ventriculostomy was usually done halfway between the infundibular recess and mammillary bodies at the midline just behind the dorsum sellae. After blunt perforation with a monopolor probe without coagulation or a Fogarty catheter (3 Fr or 4 Fr) enlargement of the stoma by inflating the balloon of the catheter was achieved. If the third ventricle floor was thick and resistant, the initial perforation was achieved with a sharp instrument after bipolar coagulation. The number and duration of dilatory manipulations was noted in all patients. All ventriculostomies were performed by only 1 neurosurgeon to prevent diverging results. The aim of ventriculostomy—and concomitantly the number of dilations needed—was clearly defined. First, a sufficient stoma with clear endoscopic signs of flow was achieved as breath-synchronously flapping margins of the stoma. Second, inspection of the interpeduncular cistern for detection and perforation of additional thin membranes caudally located to the floor of the third ventricle (such as the Liliequist membrane), as recommended in the literature. Finally, the borders of the ventriculostomy were coagulated to prevent reclosure. The complete endoscopic procedure was recorded on video for later off-line analysis.

An experienced neuroradiologist (G.S.A.) blinded to the clinical and intraoperative course of the patients evaluated all the MR images using the 3D tool of a workstation (Magic View, Siemens). The following findings were evaluated: 1) diameter of the foramen of Monro; 2) extension of the third ventricle pre- and postoperatively in the axial and sagittal planes; 3) distance of the clivus to the BA and distance of the clivus to P1 in mm; 4) third ventricle floor thickness in front of the BA in mm; 5) the presence or absence of a flow void in the cerebral aqueduct prior to the ETV; and 6) the presence or absence of a flow void in the ventriculostomy after ETV. The distances between structures and the thickness of the third ventricle floor were measured using the maximum image magnification of 3D-CISS MR imaging to reach optimal.
accuracy. Because spatial resolution was limited by the given pixel size as well as susceptibility to artifacts and CSF pulsation that might have influenced the accuracy of measurements, we separated the measured thickness of the third ventricle floor into 2 groups with diameters ≤ 0.66 mm or > 0.66 mm.

The radiological findings were correlated with intraoperative course concerning consistency of the floor of the third ventricle and number and duration of dilatory manipulations using a 3-point scale: I, thin and translucent floor of third ventricle with an uncomplicated perforation performed with a blunt instrument (≤ 10 dilatory manipulations) and wide dilatory effect of balloon inflation; II, thin, not translucent floor, and > 10 dilatory manipulations with Fogarty catheter; and III, thick, opaque third ventricle floor, sharp instrument necessary for perforation, > 30 dilatory manipulations, and small ventriculostomy.

Statistical analysis was performed using SigmaStat 2.0 Statistical Software. For comparisons between groups the t-test or chi-square test was used. For evaluation of correlations, the Spearman rank-order test was performed. Results are presented as means ± SDs. Differences were considered statistically significant at a probability value < 0.05.

Results

Patient Population

Forty patients were enrolled (22 female and 18 male patients) with a mean age of 44.3 ± 19.9 years (range 10 months–77 years). The mean duration of follow-up was 13.4 ± 9.2 months.

There were no deaths or permanent neurological deficits. Five patients (12.5%) suffered transient complications including 2 cases of bacterial ventriculitis/meningitis, 2 cases of aseptic meningitis, and in 1 patient a chronic subdural hematoma developed 1 month after ETV and had to be evacuated. The success rate with strong improvement (KPS score increase of ≥ 20 points) was 75% (30 patients). In 6 patients (15%) only a moderate improvement (increase in KPS score < 20 points) could be seen. Failure of ETV occurred in 4 patients (10%) with a mean time to failure of 10.3 ± 14.2 months, which made a secondary operation necessary (shunt placement in 3 cases and 1 repeated ETV). The overall rate of postoperative shunt independence was 90%. Table 1 shows the incidence of preoperative symptoms and their postoperative status.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Summary of clinical symptoms and postoperative clinical improvement of each category</th>
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</thead>
<tbody>
<tr>
<td>Symptom</td>
<td>No. of Patients (%)</td>
</tr>
<tr>
<td>visual problems</td>
<td>11 (27.5)</td>
</tr>
<tr>
<td>mental disorder*</td>
<td>20 (50)</td>
</tr>
<tr>
<td>incontinence</td>
<td>16 (40)</td>
</tr>
<tr>
<td>gait problems</td>
<td>22 (55)</td>
</tr>
<tr>
<td>headache/nausea/vomiting</td>
<td>17 (42.5)</td>
</tr>
</tbody>
</table>

* Measured with the Mini-Mental State Examination.

Preoperative 3D-CISS MR Imaging

All 40 patients underwent CISS imaging preoperatively, and 38 patients underwent successful postoperative CISS imaging. In 2 patients the postoperative 3D-CISS sequences could not be evaluated due to motion artifacts.

Aqueductal stenosis was caused by a membrane (primary AS) in 28 patients (70%), and by a space-occupying lesion (secondary AS) in 12 patients (30%). Of all 28 patients with primary AS the obstructive membrane in the aqueduct was clearly identified by 3D-CISS MR imaging in 25 patients (89%) (Fig. 1), and in the remaining 3 patients a strong suspicion of an occluding membrane in combination with other signs such as missing flow void and prestenotic dilation allowed the diagnosis.

In 36 patients (90%) the flow-void signal in the aqueduct as a sign of stenosis was absent on preoperative 3D-CISS imaging. In 26 (72.2%) of these patients strong improvement was observed postoperatively, and in 7 (19.4%) only a minor improvement occurred. Three patients’ (8.3%) symptoms worsened and required secondary shunt surgery (in 2 patients) or repeated ETV (1 patient).

In 4 patients (10%) a flow void in the aqueduct was preoperatively identified by 3D-CISS MR imaging (Fig. 1). In 2 of these 4 patients a strong improvement was achieved after ETV. In 1 patient only a minor improvement occurred and 1 patient’s condition deteriorated 8 months postoperatively due to stoma failure (p = 0.861, chi-square test).

The borders of third ventricle and the mean diameter of the foramen of Monro (6.9 ± 3.3 mm) could be exactly visualized on 3D-CISS imaging. In all patients the course of the BA, both P1 segments, and the border of the clivus were clearly identified and the distances precisely measured (Table 2; Fig. 2). The thickness of the third ventricle floor at the site of perforation as measured on 3D-CISS MR imaging was a mean of 1.1 ± 0.3 mm (Table 2). In 35% of patients a membrane beneath the third ventricle floor was preoperatively detected on 3D-CISS imaging and was confirmed intraoperatively in all cases (Fig. 3).

Fig. 1. Representative 3D-CISS MR images. Left: Note presence of membrane and lack of flow void in the aqueduct (arrow) with prestenotic dilation. The floor of the third ventricle, BA tip, and their distance to clivus are clearly visualized. Right: Image obtained in a patient without stenosis and with aqueductal flow void.
Imaging and Intraoperative and Clinical Course

In 12 patients, Type I third ventricle floors were found intraoperatively. The measured thickness was a mean of 0.9 ± 0.3 mm in this group (Table 3). A flow-void sign within the floor of third ventricle was seen postoperatively in 11 (92%) of these 12 patients. In 75% the borders of the stoma could be identified on 3D-CISS MR imaging; no stoma failure was observed in this group. In 11 of these 12 patients strong improvement could be seen either immediately after ETV or within a 3-month follow-up period. In 1 patient only a moderate and delayed improvement was seen, although persistent urinary incontinence and lower-extremity weakness may have been due to multiple lumbar sacral neurinomas associated with neurofibromatosis Type I and not new symptoms of hydrocephalus.

In 23 patients, Type II third ventricle floors that required > 10 dilatory manipulations with a Fogarty catheter were found. In this group the mean value of the radiologically measured thickness was 1.1 ± 0.3 mm. In 78% the borders of the ventriculostomy could be determined radiographically and in 61% with positive flow-void signal. We observed 18 patients (78.3%) with strong and 3 patients (13%) with moderate improvement in this group. Two of the 23 patients (8.7%) deteriorated due to stoma failure and became shunt dependent.

In 5 cases the intraoperative course was complicated by the thickness (mean 1.3 ± 0 mm) and consistency of the floor of third ventricle corresponding to Type III. In 3 patients the postoperative 3D-CISS MR imaging could not reveal the ventriculostomy. In 1 of the 5 patients a strong improvement and in 2 patients a moderate improvement could be established. The other 2 patients suffered from stoma failure that required secondary surgery (1 ventriculoperitoneal shunt and 1 repeated ETV) (Table 3).

Radiological measurements of the third ventricle floor thickness on 3D-CISS MR imaging significantly correlated with intraoperative observations of thickness and transparency (r = 0.35, p = 0.029, Spearman rank order). Comparison of outcome between the 3 types of third ventricle floor thicknesses revealed a statistically significant difference toward a better outcome in patients with Type I (p = 0.04, chi-square test).

Altogether, the borders of the stoma could be verified on postoperative 3D-CISS MR imaging in 76% of patients. Furthermore, in 71.1% a positive flow-void signal due to increased flow velocity through the stoma was detectable confirming patency of the ventriculostomy (Figs. 3 and 4). Twenty-two (81.5%) of these 27 patients with a positive flow void in the ventriculostomy showed a strong clinical improvement, and 4 (14.8%) a moderate improvement after ETV. Only 1 stoma failure (3.7%) occurred.

Patients without a visible flow void had a trend toward a worse relief of symptoms or stoma failure (p = 0.094, chi-square test).

Comparing the diameter of the third ventricle in the axial and craniocaudal planes pre- and postoperatively on 3D-CISS MR imaging, there was no significant difference in the outcome of patients with a decrease in third ventricle diameter of > 15% of the presurgical diameter (p = 0.821). Furthermore, there was no significant difference in outcome between patients with preoperative heavily dilated third ventricle (axial or craniocaudal diameter of ≥ 20 mm) or moderately dilated third ventricle (< 20 mm; p = 0.68).

Discussion

The aim of this study was the prospective analysis
Three-dimensional CISS MR imaging in obstructive hydrocephalus

Three-dimensional CISS MR imaging identified space-occupying lesions in all patients with secondary stenosis and a membrane in the cerebral aqueduct in 89% of the patients with primary stenosis. A flow-void signal was usually absent in the cerebral aqueduct as sign of stenosis. Doll and colleagues\(^6\) reported good visualization of the cerebral aqueduct and diagnosis of the underlying obstruction on CISS MR imaging, better than by classical MR sequences. Our results are in accordance with those of Aleman et al.,\(^1\) who recommend CISS imaging with its excellent CSF-to-brain tissue contrast before performing ETV, thus allowing a detailed study of the architecture of ventricular system for preoperative anatomic evaluation. Corresponding with our results, a clear demonstration of thin membranes obstructing the aqueduct and detection of membranes within the ventricles and cisterns not observed in T2-weighted images and clearly displaying fenestration site in 67%, compared with none using conventional T2-weighted imaging, was observed in their study.\(^1\) In the present study, the borders of the stoma could be verified on postoperative 3D-CISS imaging in 76%. Furthermore, we found precise display of the borders of the foramen of Monro, which—especially in case of a small foramen—might become important in choosing an endoscope. In anatomical studies of nonhydrocephalic brains, the mean diameter of the foramen of Monro was 5.1 mm (range 2–8 mm) in the vertical and 2.9 mm (range 1–6 mm) in the sagittal plane;\(^19\) however, we found an average diameter of 6.9 mm. This difference between our findings and those of others might be the result of pressure-derived dilation in hydrocephalic brains. Schröder et al.\(^25\) observed a contusion of the fornix in a very narrow foramen of Monro due to a disproportion between the size of the foramen and that of the endoscope used. Fortunately, these lesions were not associated with any clinical seque-

**TABLE 3**

*Intraoperative course, thickness of floor of V3, number and duration of dilatory manipulations, and clinical outcome*

<table>
<thead>
<tr>
<th>Floor Type</th>
<th>No. of Patients</th>
<th>V3 Floor Thickness (mm)</th>
<th>No. of Dilations</th>
<th>Length of Perforation (min)</th>
<th>Clinical Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>12</td>
<td>0.9 ± 0.3</td>
<td>8.5 ± 1.3</td>
<td>6.3 ± 2.0</td>
<td>11 (92)</td>
</tr>
<tr>
<td>II</td>
<td>23</td>
<td>1.1 ± 0.3</td>
<td>18.7 ± 4.3</td>
<td>15.2 ± 5.6</td>
<td>18 (78)</td>
</tr>
<tr>
<td>III</td>
<td>5</td>
<td>1.3 ± 0</td>
<td>40.4 ± 6.3</td>
<td>30.2 ± 10.5</td>
<td>1 (20)</td>
</tr>
</tbody>
</table>

No. of Patients (%)

<table>
<thead>
<tr>
<th></th>
<th>Strong Improvement</th>
<th>Moderate Improvement</th>
<th>Stoma Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Patients (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>11 (92)</td>
<td>1 (8)</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>18 (78)</td>
<td>3 (13)</td>
<td>2 (9)</td>
</tr>
<tr>
<td>III</td>
<td>1 (20)</td>
<td>2 (40)</td>
<td>2 (40)</td>
</tr>
</tbody>
</table>

* Numbers are given as means ± SDs unless otherwise noted.
MR images obtained in a patient with a caudally enlarged third ventricle wall postoperatively (thick arrow), and receded third ventricle wall postoperatively (thin arrow). The preoperative image (left) accurately displays a thin third ventricle floor; the floor was confirmed intraoperatively to be thin and translucent (Type I).

lai, but to avoid this complication, he recommended the use of smaller endoscopes.

Third Ventricle Floor Thickness on 3D-CISS MR Imaging and the Intraoperative Course

A further requirement on preoperative MR imaging is the precise display of the size of the third ventricle, which should be >5 mm in width to place the tip of the endoscope without damaging surrounding structures. Rohde et al. described the use of preoperative MR imaging in examining anatomical anomalies in patients with hydrocephalus who underwent ETV due to the fact that most anatomic variants have the potential to increase the operative risk. All anatomical anomalies had been detectable on preoperative MR imaging with the exception of a thickened third ventricle floor. We have found that 3D-CISS imaging allows a precise preoperative judgment of the shape and thickness of the third ventricle floor. Although the floor thickness was measured with high-resolution 3D-CISS MR imaging, the spatial resolution was limited to measuring distances < 0.66 mm due to the pixel size. Furthermore, we are aware that limited pixel size and susceptibility to artifacts and CSF pulsation might have influenced the accuracy of our measurements. In the future, the more common use of the 3-T MR imaging unit in preoperative MR imaging with a probably higher spatial resolution might further improve the accuracy of these measurements. We therefore separated the measured thickness of the third ventricle floor into 2 groups with diameters ≤ 0.66 mm or > 0.66 mm. Radiological measurements significantly correlated with intraoperative findings concerning the consistency of the third ventricle floor (thickness and transparency). Additionally, the intraoperative evaluation of third ventricle thickness and transparency (Types I–III) allowed prediction of outcome and the necessity for a repeated operation (p = 0.04). A thicker floor was not only significantly associated with a prolonged intraoperative course, including more difficulties in perforating the floor and dilating the ventriculosotomy, but also worse outcomes and a higher risk of stoma failure and repeated operation. Presumably a stronger correlation was not found due to the relatively low number of patients with Type III third ventricle floors. In contrast, no stoma failures were seen in patients with intraoperatively observed Type I third ventricle floors. In 11 of these 12 patients, a strong clinical improvement was achieved and in all patients the stoma patency was radiologically confirmed by a flow-void sign postoperatively.

Three-Dimensional CISS MR Imaging of Vascular Anatomy

In the present study, 3D-CISS MR imaging allowed very precise identification of the course of the BA and its distance to the clivus and both P1 segments in all cases. The spatial relations of these structures to the borders of the third ventricle, a possible prominent position of the tip of the BA into the third ventricle, and the exact distance of the arteries to the clivus and to the pons are indispensable information for ETV planning. Our findings are in accordance with those of Doll et al., who reported on the clear visualization of the position of the third ventricle floor and its relationship to the tip of the BA on CISS MR imaging. Burtscher et al. conducted a preoperative evaluation of the individual intraventricular and vascular anatomy at the floor of the third ventricle in 9 patients with AS based on virtual endoscopy images. These authors found that preoperative virtual display of the position of the BA, the posterior cerebral arteries, and the posterior communicating arteries in their relationship to the mammillary bodies and the clivus can intraoperatively assist in finding a safe location for ETV. The main reason for severe complications is misplacement of the fenestration, which may lead to injury of the basilar or posterior cerebral arteries. Therefore, a sufficient distance of the tip of the BA to the clivus is preoperatively required. In our experience, 3D-CISS MR imaging allowed precise and reliable preoperative planning of stoma location, helping especially in cases of the parasagittal position of tip of the BA. In these cases, we planned to make the stoma immediately behind the clivus, but on the contralateral side, allowing us to avoid the most feared and potentially life-threatening rupture of the BA or posterior cerebral arteries, or venous bleeding in our patients. Krombach and associates assessed the utility of virtual endoscopy combined with intraoperative stereotactic neuronavigation. Anatomical landmarks for endoscopic access such as the choroid plexus, fornix, mammillary bodies, foramen of Monro, the lateral wall of the third ventricle, and the BA were clearly shown preoperatively and achieved good concordance to observations of the real endoscopy. However, the floor of the third ventricle and the septum pellucidum could not be detected accurately. Especially in cases of a thick and consistent floor of the third ventricle, it may be impossible to visualize the BA through the floor, which could be associated with an increased intraoperative

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of Patients (%)</th>
<th>Visible</th>
<th>Not Visible</th>
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<tbody>
<tr>
<td>strong improvement</td>
<td>30 (75)</td>
<td>22 (81.5)</td>
<td>6 (54.5)</td>
</tr>
<tr>
<td>moderate improvement</td>
<td>6 (15)</td>
<td>4 (14.8)</td>
<td>2 (18.2)</td>
</tr>
<tr>
<td>stoma failure</td>
<td>4 (10)</td>
<td>1 (3.7)</td>
<td>3 (27.3)</td>
</tr>
</tbody>
</table>
Three-dimensional CISS MR imaging in obstructive hydrocephalus

risk. We have found that 3D-CISS MR imaging allows exact judgment of the shape and thickness of the floor of third ventricle. Furthermore, radiological measurements of the thickness of the floor of the third ventricle significantly correlated with intraoperatively observed thickness and transparency (Types I–III). Three-dimensional CISS MR imaging seems to be a more precise investigation for planning ETV, and can be performed with less technical effort than virtual endoscopy.

Prognostically Valuable Signs in Postoperative 3D-CISS Imaging

Apart from other reasons for clinical failure after ETV—such as insufficient ventriculostomy size, leading to secondary closure, bleeding, infection, or disturbed CSF reabsorption—the presence of unnoticed second membranes (Liliequist membrane) below the floor of third ventricle have also been described. To avoid stoma failure, a 3D-CISS sequence is recommended to detect additional membranes beneath the third ventricle floor. In our study, 3D-CISS imaging could reveal such membranes in 35% of all patients, and these additional membranes were identified intraoperatively in all cases with respective consequences on the operative strategy. Laht et al. found multiple membranes in the basal cisterns beneath the floor of the third ventricle that could not be seen on T2-weighted images but were detected by 3D-CISS MR imaging. Our results demonstrated that in most cases a positive flow-void phenomenon at the ventriculostomy and even through the underlying membrane could be confirmed with 3D-CISS MR imaging (Fig. 3). In cases of stoma failure, we could not identify a single patient in whom unfenestrated additional membranes were revealed to be the reason for failure of the first ETV.

Although the presence of a flow-void signal in the aqueduct did not allow the prediction of clinical course after ETV, the existence of a flow void in the ventriculostomy on postoperative images was shown to be a strong sign of stoma patency. The ventriculostomy itself could be identified in 76% of our patients. In 71% a flow void that was a positive prognostic factor for successful ETV was visible through the stoma. We also saw a positive trend toward a better outcome and fewer stoma failures in patients with postoperative flow-void signs in the third ventricle floor (p = 0.094). These findings are in accordance with those of Laht et al., whose data also confirm a positive correlation between the presence of a flow-void sign at the ventriculostomy and clinical outcome. These authors reported that 8 of the 12 patients who underwent ETV in their study had a good clinical outcome. In these 8 patients the ventriculostomy itself, and in 6 patients even a flow-void sign, could be detected by CISS MR imaging. In 4 patients in whom the procedure failed, no flow voids were seen. In our study, in 3 of the 4 patients who suffered stoma failure, no flow-void sign could be established on postoperative CISS MR imaging. Significant prognostic factors for a successful ETV have been reported to be an early postoperative improvement within 2 weeks after ETV and stoma patency on cine phase-contrast MR imaging.

In our study, a reduction in the mean diameter of the third ventricle was found postoperatively. However, as described by others, the size of the ventricular system is not a valid predictor of outcome. Often the ventricles remain dilated despite a complete clinical recovery. Consequently, no significant differences concerning success and failure rate were seen in our study in patients with postoperative reduction of ventricular size > 15% of the presurgical diameters and in patients who had had heavily dilated diameters of the third ventricle preoperatively. Based on our data, we conclude that changes in the ventricular size alone may be misleading.

The reported success rate after ETV is 66–83%. Our results using 3D-CISS MR imaging for preoperative imaging are favorable with a failure rate of altogether 10%, which required patients to undergo secondary shunting or repeated ETV. Due to improved diagnosis of AS and superior identification of additional membranes below the floor of the third ventricle by CISS MR imaging we reached an overall rate of good results in 75% of our patients, shunt independence in 90%, no deaths, and a postoperative transient complication rate of 12.5%.

Conclusions

Our finding that changes in the diameter of the third ventricle, especially in the early postoperative state, are not predictive of outcome is in accordance with the reports of others. We found that preoperative 3D-CISS MR imaging was very useful in facilitating surgical planning by allowing accurate identification of relevant anatomical structures and precise visualization of the basilar/posterior artery, its distance to the clivus, diameter of foramen of Monro, and extension of the third ventricle. Furthermore, space-occupying lesions in all patients with secondary stenosis, a membrane in the cerebral aqueduct in 89% of the patients with primary stenosis, and additional membranes beneath the floor of the third ventricle were also detected. We also found that the presence of postoperative flow-void signs at the site of perforation was a strong predictor of long-term outcome. New findings in this study were the exact judgment of shape and thickness of the floor of the third ventricle on 3D-CISS MR imaging. These measurements of third ventricle floor thickness significantly correlated with intraoperatively observed consistency and transparency. Intraoperative findings concerning the consistency of the third ventricle floor were significantly associated with outcome and failure rate.

Disclaimer

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

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