Membranous Structures Affecting the Success of Endoscopic Third Ventriculostomy in Adult Aqueductus Sylvii Stenosis

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Key words
- endoscopic third ventriculostomy
- aqueductal stenosis
- Liliequist’s membrane
- hydrocephalus
- MRI

Abstract

Background: The purpose of the present study was to observe Liliequist’s membrane (LM) and membranous structures located in the prepon-tine cistern via 3-Tesla magnetic resonance imaging (MRI) with 3D driven equilibrium radio frequency reset pulse (DRIVE) sequence and multiplanar reformat (MPR) images and to evaluate the success of endoscopic third ventriculostomy (ETV) by assessing these membranes in adult aqueduct stenosis.

Patients: 29 patients (17 female, 12 male) with primary aqueductus sylvii stenosis were included in the study. 19 patients were diagnosed as long-standing overt ventriculomegaly in adults (LOVA) and patients had severe ventriculomegaly, macrocephalus, and aqueduct stenosis on MR imaging. 10 patients were diagnosed as aqueduct stenosis presented with acute onset of hydrocephalus with symptoms of raised ICP. All patients in the study group were analyzed of hydrocephalus with symptoms of raised ICP. 10 patients were diagnosed as aqueductus sylvii stenosis. In 2 patients, CSF flow was blocked by the LM accompanying prepontine membranes. Totally closed membranes were observed in the prepon-tine cistern in 5 patients (17.24%). 7 patients (24.1%) did not respond to ETV. Cerebrospinal fluid (CSF) flow was blocked by membranous structures located in the prepon-tine cistern in 4 of 8 patients. In 2 patients, CSF flow was observed through the stoma and the LM accompanying prepontine membranes. Correlation of the postoperative imaging findings of these membranes in a patient with obstructive hydrocephalus. High-field (∇ ≥ 3 Tesla) MR imaging also provides superior resolution and is expected to offer additional information about the membranes [1]. In our study, we compared the preoperative and post-operative MRI (3T-DRIVE sequences) with the intraoperative findings. We discussed the importance of LM and prepontine membranes on the success of third ventriculostomy (∇ Fig. 1).

Introduction

Liliequist’s membrane (LM) or membranous structures located at the prepontine cistern may block the cerebrospinal fluid (CSF) flow from the defect of the third ventricle floor, which can cause the failure of endoscopic third ventriculostomy (ETV). In normal healthy individuals, the LM can be visualized via magnetic resonance imaging (MRI); with some differences in visibility [1]. CSF artifacts exist to varying degrees, but do not block the visualization of LM in most of them [1]. The 3-dimensional (3D) constructive interference in steady state sequence is useful to visualize the configurations of LM and other membranous structures [1]. The success of ETV can be evaluated with MRI findings of these membranes in a patient with obstructive hydrocephalus. High-field (∇ ≥ 3 Tesla) MR imaging also provides superior resolution and is expected to offer additional information about the membranes [1]. In our study, we compared the preoperative and post-operative MRI (3T-DRIVE sequences) with the intraoperative findings. We discussed the importance of LM and prepontine membranes on the success of third ventriculostomy (∇ Fig. 1).

Materials and Methods

29 adult patients with LOVA (long-standing overt ventriculomegaly in adults) and primary aq-
Neuroradiological evaluation included cine-MRI of CSF months. Third ventriculostomy success is based on both the clinical and surgical follow-up. Minimum follow-up time was 6 months. Third ventriculostomy success is based on both the clinical and neuroradiological improvement. Neurosurgical evaluation included cine-MRI of CSF flow of the ventricle cistern postoperatively. All patients were analyzed via 3-T MR scanner (Philips Achieva Interia Release Einthoven, the Netherlands) with 80 mT/m maximum gradient strength, 346 mT/m/msec effective slew rate using 8-channel head coil, in the supine position. The 3D T2-DRIVE sequence, which provides T2 contrast with a higher fluid signal with fine anatomic details about CSF pathways, was performed in the supine position [4].

Retrospectively, 3-T-MRI with 3D DRIVE sequences of the patients were used to observe these membrane structures in all slices.

**Results**

22 patients (75.9%) responded to ETV. Successful outcome was considered by a combination of features including the partial or total relief of presenting symptomatology accompanied with postoperative MRI studies that demonstrated the patency and flow through the ventriculostomy. Ventricular size, although considered, was not routinely measured and was not considered as a defining outcome criterion. An unsuccessful outcome was considered in the case of a recurrence or lack of improvement of the presenting symptoms, whether or not verified with postoperative MRI findings of patency or flow through the ventriculostomy site.

In patients with LOVA, headache was the main presenting feature and improved in 13 of 16 patients (87.5%). Gait disturbance improved in 9 of 12 patients (75%). Aqueduct stenosis presenting as an acute onset of hydrocephalus with symptoms of raised ICP was present in 10 patients, and ETVs were successful in 8 patients (80%) with improved symptoms.

Retrospective evaluation of the preoperative MRI studies of the cases revealed that 7 patients had membranes in the prepontine area, which were interrupted during their courses (partial) on MPR sequences. In 2 patients, continuous membranous structures were visualized in the prepontine area (totally closed) (Fig. 2). In 13 patients we did not notice any membranous structures located through the prepontine cistern on MPR sequences (Fig. 3).

Totally closed membranes of the 2 cases and 5 of 7 partially closed membranes could be demonstrated intraoperatively. Totally closed membranes were opened during the surgery (Fig. 2d, e), but nothing was done for the 5 partially closed membranes since they had enough openings allowing CSF flow. Postoperative images demonstrated no closed membranes through the prepontine cistern blocking the CSF flow in all 22 patients who responded well to the ETV procedure.

In our series, 7 patients (24.1%) did not respond to ETV. In 4 of those 7 patients who did not respond to ETV, preoperative MRI studies demonstrated membranous structures in the prepontine cistern progressing without interruptions (Fig. 4). However, in only 1 of these 4 cases, the membranous structures could be demonstrated during the surgical procedure but could not be opened due to a high risk of injury to the surrounding vascular structures. In all of those 4 cases, both tuber cinereum and LM have been opened allowing the CSF flow through the stoma, which were later proven by the postoperative cine MRI studies. However, 2 or more membranous structures enveloping the prepontine cistern were observed on 3D DRIVE with MPR sections. We suggest that those membranous structures can be the reason for blocked CSF accumulation leading to ETV failure in these cases. These membranes could not be visualized on preoperative 1.5-T MRI studies.

Among the remaining 3 of the 7 patients who did not respond to ETV, 1 case showed a completely closed stoma and unimpaired LM postoperatively, in spite of their successful opening during the neuroendoscopic procedure. In this patient, no significant
membranous structure was visualized in the prepontine area on both preoperative and postoperative MRI studies. In the other 2 patients; insufficient opening was observed allowing low volume CSF accumulation through the stoma and both diencephalic (DL) and mesencephalic (ML) leaves, accompanying various membranes through the prepontine cistern on the postoperative MRI in 1 patient (Fig. 5). Preoperative MRI demonstrated membranous structures in the prepontine cistern progressing without interruptions in this patient. When reviewed, the video records of the procedure demonstrated that the membranous structures have been seen during the surgery but have left uninterrupted due to dense vascular structures surrounding them. In the other patient, a deteriorated CSF flow through the stoma and DL was blocked by the ML (Fig. 6). There was no significant membranous structure located through the prepontine cistern in this patient.

LM was verified in all patients intraoperatively that were also demonstrated on the preoperative MRI. Independently from the LM, membranous structures located through the prepontine cistern, which blocked the CSF accumulation were seen in 5 of 29 patients (17.2%) on the postoperative images. Only in 2 of these cases, the membranes that have been seen on the preoperative MR images could be visualized during the surgical procedure. However, we did not succeed to dissect or open those membranes due to the high risk of injury to the surrounding vascular structures.

Details of patients’ information and results are listed in Table 2 and preoperative, postoperative images and intraoperative verification are demonstrated in Table 3.

Discussion

Aqueductal stenosis (AS) is the most common form of non-com municating hydrocephalus in adults [5]. Recently, aqueduct stenosis is also being described as LOVA accompanying severe triventriculomegaly, macrocephalus and other criteria defining a special form of aqueduct stenosis [2, 3].

ETV is now a commonly used procedure for aqueduct stenosis [5–9]. Surgical procedure success depends on not only the opening of the tuber cinerum but also providing the CSF flow through the prepontine cistern. ETV has been successful in most cases, but the LM and firm membranous structures located in the prepontine cistern may block the flow of CSF through the prepontine cistern, causing unsatisfactory results [1].

ETV is an internal bypass between the third ventricle and the cortical subarachnoidal space [10]. Patent basal cisterns are important to allow the flow from the third ventricle into the mesencephalic and pontine cisterns [11, 12]. The communication between the third ventricle and subarachnoidal spaces formed via ETV can be obstructed at any time due to progressive scarring of the orifice at the level of the third ventricle floor or by arachnoid membrane formation in the interpeduncular and prepontine cisterns or both [13].

On comparing the preoperative and postoperative magnetic resonance ventriculography (MRV) images, Singh et al. [14] demonstrated that flow of contrast into the basal and lateral subarachnoidal space is the most significant factor to predict a good outcome. They have indicated that there was no difference in preoperative or postoperative MRV in patients with non-func-
tional ETV. However, patients with functional ETV have been reported to show an immediate flow of contrast into the prepon- 
tine cistern with a gradual flow into the basal and lateral sub-
arachnoid space with no flow into lateral subarachnoid space [14].

In the literature it is described that an increase in the systolic phase of cerebral blood volume enables the accumulation of CSF from the third ventricle, through the aqueduct into the fourth ventricle, and from the basal cisterns to the spinal canal in healthy individuals. A decrease in the diastolic phase of cerebral blood volume provides CSF to return along the same pathways [15–17]. This cardiac cycle-related pulsatile bidirectional CSF motion through the aqueduct is impaired in patients with aqueduct stenosis. After ETV, CSF out 
flow is then from the inferior third ventricle into the interpeduncular fossa and preponine cistern, bypassing the cerebral aqueduct. The low resistance obtained by the ventriculostomy ori-
fice permits increased CSF pulsation during the cardiac cycle [17].

Froelich et al. [18] demonstrated the variations of the LM in their cadaveric study and illustrated them as the diencephalic leaf and mesencephalic leaf originating along the dorsum sellae and coursing separately toward the diencephalon and basilar bifur-
cation, or with 2 posterior leaves including the DL attached to the diencephalon and mesencephalic leaf toward the basilar bifurcation, or a single membrane attached posterosuperiorly to the diencephalon between the infundibulum and mamillary bodies. DL separates the chiasmatic and interpeduncular cis-
terns and ML separates the interpeduncular cistern from the preponine cistern. Buxton et al. [19] described that if the DL is not subsequently opened to permit communication with the preponine cistern, the procedure may fail. Froelich et al. [18] defined that in some cases the DL is opened during the puncture of the tuber cinerum. In these cases, the surgeon observes directly the ML. In some patients, the perforation on the third ventricular floor can be made in front of the DL and creates com-
munication between the third ventricle and chiasmatic cistern.

In some patients, leaves of LM may be firmer and thicker [20]. This form of the membrane complicates the surgical procedure and reduces the success of ETV [1].

Fushimi et al. [1] stated that high-field MR imaging of the LM provides superior resolution and 3-dimensional (3D) constructive interference in steady state (CISS) sequence is useful for visualizing the LM and is expected to offer additional information about the LM.

Dincer et al. [20] proved that conventional sequences are insen-
tive to obstructive membranes in CSF pathways not only in the fourth ventricular exit foramina and the basal cisterns but also in the preponine cisterns. They performed 3D-constructive interference in steady state (3D-CISS) sequence to assess the CSF pathways. 3D-CISS sequences identified obstructive membranes invisible in other sequences [20].

Dynamic flow studies are currently used modalities to define the CSF flow through the stoma [12,21–23]. In 4 patients, even though a good flow artifact was demonstrated at the level of the stoma, the symptoms of the patients were not improved and they were considered as failures. In the literature Cinalli et al. [24] defined that third ventriculostomy measurements of such cases may reveal a transient improvement and sagittal
T₂-weighted MR imaging performed after the procedure usually demonstrates a good flow artifact at the level of the stoma. They stated that cine MR imaging flow measurements of those cases may even disclose a good systolic/diastolic flow at the level of the stoma in spite of a slowly worsening clinical picture [24]. We suggest that this condition may be related to the existence of membranes located through the prepontine cistern. Both CSF flow studies and 1.5-T MRI cannot view these membranes which may be the reason of blocked CSF flow in failed ETV cases. 3-T MRI-DRIVE sequences should be performed in these patients.

We evaluated a retrospective analyses of all patients to whom 3-T MRI-DRIVE sequences were performed for visualizing the LM and prepontine membranes. MPR sections provide visualization of the course of these membranes in all sections. Thus, we can observe whether there is any interruption of the membranes during their courses.

In our series, 7 patients did not respond to ETV postoperatively. We concluded the reason of failure to be the insufficient opening or closure of the stoma and LM in 2 patients, and membranous structures located through the prepontine cistern in the other 4 patients.
In 1 patient, the failure was related to inadequate CSF flow through the stoma and LM but even if it was opened, it may be blocked at the level of the prepontine cistern due to membranes.

In our clinical series, membranous structures, which may be the reason for the blocked CSF, were seen in 5 of 29 cases (17.24%). Among these 5 patients, the membranous structures could be demonstrated in 2 patients intraoperatively. Considering all the patients and the results, we were able to view and open the membranes, which were located in the prepontine cistern superiorly (Fig. 2). However we could not visualize the membranes located in the prepontine cistern inferiorly (Fig. 4). The reason of this inability to view the prepontine membranes at the surgical procedure, which were visualized on MRI, may be related to their much inferior localization through the cistern, to the anatomic variations of the prepontine cistern or to the limitations of the endoscopic technique. Prepontine membranes may affect the success rate of ETV and clinical outcome. Inadequate opening of or a closed stoma can be overcome by repeating the procedure but VP shunting could be the alternative approach for the failed procedure related to the membranes located through the prepontine cistern inferiorily. However, further studies including more patients should be observed to recommend this suggestion.

**Conclusion**

The interpeduncular cistern and prepontine cistern are the major gateways for CSF to reach to the spinal subarachnoid space then to the cortical subarachnoid space. Blockage or resistance in these sites may affect the success of ETV procedures. 3D sequences performed preoperatively may help in planning the surgical approach by observing not only the LM but also other membranes located through the prepontine cistern, which may be the reason of failed ETV.

**Conflict of Interest:** None

**References**

16 Enzmann DR, Pec NJ. Normal flow patterns of intracranial and spinal cerebrospinal fluid defined with phase-contrast cine MR. Radiology 1991; 178: 467–474