Endoscopic third ventriculostomy in the management of communicating hydrocephalus: a preliminary study

Clinical article

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Object. The purpose of this study was to elucidate the efficacy of endoscopic third ventriculostomy (ETV), the procedure’s indications, and prognosis after treatment in patients with communicating hydrocephalus.

Methods. Between August 2002 and January 2007, 32 ETVs were performed in 32 patients with communicating hydrocephalus (24 men and 8 women) at the authors’ institution. The patients ranged in age from 25 to 82 years old (mean 61.4 years), and had a follow-up of 2–53 months (mean 14 months). The patients were divided into 2 groups according to the results of preoperative tests. The first group included 17 patients with idiopathic normal-pressure hydrocephalus, and the second group included 15 patients with secondary communicating hydrocephalus who experienced meningitis, spontaneous subarachnoid hemorrhage, or hypertensive intracranial hemorrhage. Both univariate and multivariate statistical analyses were performed to assess the prognostic relevance of the cause of communicating hydrocephalus, the preoperative Kiefer scale score, and hydrodynamic findings in predicting the results after ETV.

Results. Excellent results were achieved in 25% of patients, good results in 40.6%, satisfactory in 12.5%, and poor in 21.9% of patients. The authors found that the preoperative Kiefer score and the patient’s age had a high correlation with overall ETV outcome. Nineteen patients (59.3%) with comparatively mild symptoms (Kiefer Score 0–10) had a favorable course after ETV. Three patients in this group showed a satisfactory course, and 1 had a poor course. Among patients with Kiefer scores of 11–21 points, 6 (46%) had a favorable course, 1 (8%) a satisfactory one, and 6 (46%) had no relief from symptoms at all. Fourteen (88%) of 16 patients < 65 years of age had a favorable course after ETV. However, only 7 of 16 patients (44%) > 65 years showed definite improvement after ETV. Among the Kiefer score indicators, the preoperative mental state played an important role in predicting ETV outcome. The results of this test imply that the relative risk of ETV failure in a patient with a concentration disorder is about 2 times that in a patient without. Of the 7 patients with secondary communicating hydrocephalus who had elevated intracranial pressure (range 205–265 mm H2O), 5 patients had a favorable result from ETV. Meanwhile, in the same group, 5 (63%) of 8 patients with normal intracranial pressure had an excellent or good result. In comparing the findings on cine MR imaging before and after surgery, there was evidence of a decrease in the velocity and quantity of cerebrospinal fluid flow in the aqueduct after ETV.

Conclusions. The new hydrodynamic concept of hydrocephalus opens the possibility that ETV may be an effective treatment for communicating hydrocephalus. It thus constitutes an interchangeable alternative to shunting. Patient age, analysis of the causes of hydrocephalus, and mental state evaluation play important roles in outcome prediction in patients with communicating hydrocephalus who undergo ETV. Randomized clinical studies are needed to explore further the role of this treatment in communicating hydrocephalus therapy. (DOI: 10.3171/JNS/2008/109/11/0923)

Key Words • communicating hydrocephalus • endoscopic third ventriculostomy • hydrodynamics • normal-pressure hydrocephalus • prognosis

Abbreviations used in this paper: CI = confidence interval; CSF = cerebrospinal fluid; ETV = endoscopic third ventriculostomy; HIH = hypertensive intracranial hemorrhage; ICP = intracranial pressure; INPH = idiopathic normal-pressure hydrocephalus; RR = recovery rate; SCH = secondary communicating hydrocephalus; SE = standard error.

The traditional treatment for communicating hydrocephalus is shunt placement, but high failure rates and numerous complications with this therapy have been reported.26,32,33,37 With the introduction of neuroendoscopic techniques, ETV has become the preferred method to treat obstructive hydrocephalus because of its minimally invasive nature.5,5,7,19,24,26,30,40 However, its utility in the treatment of patients with communicating hydrocephalus has not been proven conclusively. In the present study, we retrospectively analyzed the indications for ETV and the outcome afterwards in 32 consecutive patients who underwent ETV for communicating hydrocephalus.
Methods

Patient Population

Thirty-two patients (24 men and 8 women) underwent ETV for the treatment of communicating hydrocephalus at our institution between August 2002 and January 2007. The mean age of these patients was 61.4 years (range 25–82 years). Symptoms included headaches in 28 patients, vertigo in 32, memory disturbances and disorientation in 31, gait disturbances in 28, and urinary incontinence in 16, including 7 with permanent incontinence or incontinence of urine and stool. Basic patient information is displayed in Table 1. A diagnosis of communicating hydrocephalus was obtained by the intrathecal infusion/tap test on a lumbar route, cisternography, and CT and/or MR imaging. In 17 patients, cine phase-contrast MR imaging was performed pre- or postoperatively. Inclusion criteria for this study included the following: 1) presence of ≥ 2 of the 3 classic symptoms of the Hakim triad at the clinical examination on admission; 2) evidence of communicating hydrocephalus with enlarged ventricles on neuroimaging (patients with cerebral atrophy only were excluded because communicating hydrocephalus combined with mild cerebral atrophy can exist); 3) isotope clearance impairment and ventricular retrograde flow on radionuclide cisternography; 4) signs of high velocity flow on midbrain aqueduct on T2-weighted MR imaging (in 17 cases, cine phase-contrast MR imaging showed the high velocity and quantity CSF flow in aqueduct when compared with normal value); and 5) CSF pressure assessment and infusion/tap test.

Based on preoperative test results, we separated the patients into 2 groups. The first group included 17 patients with INPH, defined as primary communicating hydrocephalus, CSF pressure within the normal range, and no intracerebral lesions (lacunar infarction on MR imaging can exist). The second group included 15 patients with SCH who experienced meningitis, ventriculitis, spontaneous subarachnoid hemorrhage, and HIH. The follow-up period was 2–53 months (mean 14 months).

Endoscopic third ventriculostomy was performed with a freehand standard method using a rigid endoscope (Clarus Medical) in all 32 patients. Outcome was evaluated according to the data collected at the last follow-up visit. Clinical examination findings were classified according to the Kiefer chronic hydrocephalus grading system.22,27 We used an RR scale to relate postoperative im-

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* AI = aortic insufficiency; AS = aortic stenosis; CHD = coronary heart disease; EC = endocarditis; emphysema = emphysema; FU = follow-up; HT = hypertension; LI = lacunae infarction; PU = peptic ulcer; RHD = rheumatic heart disease; SAH = subarachnoid hemorrhage; TBM = tubercular meningitis.
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provement to the preoperative status: \( RR = \frac{\text{preoperative} - \text{postoperative Kiefer score}}{\text{preoperative Kiefer score}} \).  

Clinical outcome was defined as excellent (\( RR > 7 \) points), good (\( 5 \leq RR \leq 7 \) points), satisfactory (\( 2 \leq RR \leq 5 \) points) and poor (\( RR < 2 \) points). Any patient who died as a result of the ETV procedure or had to undergo shunt placement after ETV was described as having a poor outcome. Statistical analysis was conducted using commercially available software (SPSS, SPSS Inc.).

**Results**

There were no major intraoperative complications. One patient had a confirmed occlusion of the stoma 3 months postoperatively and had to undergo shunt placement. Other minor complications included transient fever and vomiting in 4 patients. There were no confirmed infections related to the ETV in this group. Two patients (mortality rate 6%) died in the follow-up period; 1 patient died of HIH related to a pulmonary infection and 1 died of heart failure caused by rheumatic heart disease (this patient died 6 months after ETV). Neither death was the direct result of ETV.

The causes of communicating hydrocephalus in the 15 patients with SCH was determined to be HIH in 4, posttraumatic hydrocephalus in 9 (in 5 patients this was combined with hypertension, diabetes, cerebral infarction, rheumatic heart disease, endocarditis, or peptic ulcer), spontaneous subarachnoid hemorrhage in 1, and tubercular meningitis in 1 patient. The 17 patients in the INPH group had a mean age of 66 years, and the 15 patients in the SCH group had a mean age of 56 years. The surgical outcome was analyzed in both groups (Table 2). The overall proportion of excellent/good clinical outcomes was 65.6%, of which 25% were excellent and 40.6% were good. Four patients of whole group (12.5%) had a satisfactory outcome, and 7 patients (21.9%) a poor outcome. A Kaplan–Meier analysis illustrated that the proportion of excellent/good results was 0.57 for the first 2 years and became stable at 0.5 after the 3rd postoperative year (Fig. 1 upper). We have previously reported on the use of ETV in obstructive hydrocephalus,9 and we compared the surgical outcome of these 2 studies with Kaplan–Meier analysis (Fig. 1 lower). In contrast to the results of ETV for communicating hydrocephalus, ETV is the preferred choice for obstructive hydrocephalus with 1-, 2-, and 3-year survival proportions of 0.87, 0.84, and 0.84, respectively.

A comparison of the proportion of patients with a functioning ETV in each subgroup was performed using a Kaplan–Meier survival curve (chi-square = 4.60, \( p = 0.0319 \), log-rank test; Fig. 2). On comparison of the results in the subgroups 1 year after ETV, both had a value of 0.58. However, in the INPH group the proportion dropped to 0.44 after the 2nd year, while the value in the SCH group maintained at 0.58 (Fig. 2 upper). In the SCH group, the posttraumatic subgroup had the best results with the excellent and good rate of 0.7 since the first postoperative year. Meanwhile, it was only 0.25 in the HIH subgroup (chi-square = 7.93, \( p = 0.0475 \), strata log-rank test; Fig. 2 lower).

A correlation between outcome after ETV and preoperative Kiefer score was documented in all 32 patients. In our study, the preoperative Kiefer score and the patient’s age had the highest correlation with overall ETV outcome. Of 19 patients with comparatively mild symptoms (Kiefer Score 0–10) 15 had a favorable course after ETV. Three patients (16%) in this group had a satisfactory outcome, and 1 (5%) had a poor outcome. Among the 13 patients with Kiefer scores of 11–21 points, 6 (46%) had a favorable course, 1 (8%) a satisfactory course, and 6 patients (46%)
showed no recovery of symptoms at all. Fourteen (88%) of 16 patients < 65 years had a favorable course after ETV. However, in only 7 (44%) of 16 patients > 65 years was obvious improvement observed after ETV. The Cox regression analysis confirmed that the Kiefer score (B = 0.1575, SE = 0.0773, Wald = 4.1517, significance = 0.0416, Exp (B) = 1.1705, 95% CI 1.006–1.3620) and patient age (B = 0.0722, SE = 0.0332, Wald = 4.7214, significance = 0.0298, Exp (B) = 1.0748, 95% CI 1.0071–1.1471) were significant prognostic factors for failed ETV. Our results demonstrate that every 1-point increase in preoperative Kiefer score decreases the probability of success ~ 17% (Exp (0.1575) = 1.1705) and every 10-year decrease in patient age would increase the success probability about 2-fold. Another point of interest is the comparison of the separated predictive value of the Kiefer indicators. The Pearson correlation test demonstrated that the predictive power of preoperative mental state score (Pearson correlation = 0.42, p = 0.017), gait disorder (Pearson correlation = 0.362, p = 0.042), and headache severity (Pearson correlation = −0.383, p = 0.03) was reliable. Preoperative vertigo and incontinence had no predictive effect on the surgical outcome. We used the Cox regression model to demonstrate the predictive effect of the Kiefer score indicators on outcome and determined that the preoperative mental state plays an important role on prediction of ETV outcome (B = 0.6765, SE = 0.2354, Wald = 8.2585, significance = 0.0041, Exp (B) = 1.9671, 95% CI 1.2400–1.3204). This finding implies that the relative risk of ETV failure in a patient with concentration disorder is about 2 times that than in a patient without such a disorder (Exp (B) = 1.9671).

Among the 15 patients in the SCH group, 7 patients had ICP in excess of 200 mm H₂O (range 205–265 mm H₂O) as measured preoperatively by lumbar puncture. There is no statistical difference in outcome between those with elevated and normal ICP (Pearson chi-square = 0.134, p = 0.714). Five (71%) of 7 patients with an elevated ICP achieved favorable results after ETV; meanwhile, in the same group, 5 (63%) of 8 patients with normal ICP had an excellent or good result. Signs of high-velocity flow in the midbrain aqueduct were detected in 25 patients on T2-weighted MR images obtained before ETV. In 17 patients, cine phase-contrast MR imaging demonstrated the high velocity and quantity CSF flow in the aqueduct compared with the reference value; the outflow and inflow peak velocity were 51.36 ± 17.23 mm/second and 49.76 ± 18.89 mm/second, respectively, while the quantity of outflow and inflow were 3.3886 ± 1.127 ml/second and 3.3891 ± 1.119 ml/second, respectively. In comparing with the findings on cine MR images obtained before ETV, there was a slight decrease in the velocity and quantity of CSF flow in the aqueduct after ETV. This difference did not reach statistical significance. The outflow and inflow peak velocities after ETV were 47.76 ± 11.38 mm/second and 47.41 ± 15.63 mm/second, respectively (p = 0.86 and p = 0.85, paired t-test). The quantity of outflow and inflow were 3.076 ± 1.431 ml/second and 2.986 ± 1.362 ml/second, respectively (p = 0.63 and p = 0.71, paired t-test). In our opinion, the infusion/tap test is not an important factor in determining whether a patient should receive an ETV or not. In our patients, only 13 underwent the lumbar infusion test, and only 1 the ventricular infusion test. Most patients refused the ventricular infusion test because of its invasiveness. In fact, we did not get useful information from the tap/infusion test and have found that the results are often unclear and not explanatory.

Discussion

Endoscopy has changed neurosurgical treatment in many ways. Many authors consider ETV to be a safe and effective treatment for obstructive hydrocephalus, but it has not yet been proved as a safe surgical option in patients with communicating hydrocephalus. Indeed, this indication for ETV is not scientifically established and remains under intensive investigation.

The precise underlying mechanisms of communi-
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cating hydrocephalus remain unknown. Communicating hydrocephalus treated with ETV is unsupported by the traditional bulk flow theory. In a critically important but rarely quoted work, Ransohoff and associates\textsuperscript{35,36} brilliantly suggested that the nomenclature be changed so that obstructive hydrocephalus would be called “intraventricular obstructive hydrocephalus” and include both obstruction of the aqueduct and occlusion of the outlet foramina of the fourth ventricle in its definition. All other forms of hydrocephalus would be called “extraventricular obstructive hydrocephalus” and all hydrocephalus is indeed obstructive and, therefore, explainable by bulk flow models. Rekate\textsuperscript{37} explored the sites of obstruction to the flow of CSF that causes hydrocephalus. These sites include not only the aqueduct and outlet foramina of the fourth ventricle but also the basal cisterns blocking the CSF flow. This work also implies that all hydrocephalus is, in some ways, obstructive. The modified bulk flow theory is able to explain the effectiveness of third ventriculostomy in treating some types of communicating hydrocephalus, such as posttraumatic, posthemorrhagic, and postmeningitis hydrocephalus. It is a common belief that there are some extents of adhesive obstruction in the basal cisterns of communicating hydrocephalus caused by traumatic injury, HIH, and tubercular meningitis during ETV. However, there are still some aspects that do need to be analyzed. For example, it is hard to explain why the fourth ventricle is usually not dilated in patients with communicating hydrocephalus, and it seems improbable that communicating hydrocephalus and obstructive hydrocephalus, which behave quite differently with respect to CSF flow, have the same causes.

Analysis of the intracranial hydrodynamics related to the pulse pressure demonstrates that an explanation of communicating hydrocephalus only by bulk flow theory is an oversimplification. According to recent research into the dynamics of hydrocephalus, communicating hydrocephalus is a disorder of intracranial pulsations caused by decreased compliance.\textsuperscript{7,12–16} Cine flow-contrast MR imaging in patients with communicating hydrocephalus has shown that the total intracranial stroke volume in these patients is about half that observed in normal individuals. On ICP monitoring, a 6-fold increase in CSF pulse pressure compared with normal individuals has been reported.\textsuperscript{8} Intracranial compliance is thus decreased by an order of magnitude in communicating hydrocephalus, because compliance is the ratio between volume change and pressure change. Decreased intracranial compliance restricts the expansion of the arteries, causing breakdown of the Windkessel mechanism with increased pulsations in the brain capillaries.\textsuperscript{13,15} Because the artery cannot expand, there is decreased attenuation of pulse wave in the artery. The direct volume conduction from the artery to the bridging vein, which bypasses the brain capillaries, is decreased. Due to conservation of momentum, there must be a forced pressure and volume transmission of the pulse wave, from the artery into the capillary and brain tissue. The hydraulic energy of the pulse wave is absorbed in the capillary and the brain instead of the artery. This causes an increased cerebral pressure compared with the subarachnoid space, and a diminished pressure difference between the vascular system and brain tissue. Of utmost importance is the abnormal pressure and volume transmission into the brain capillaries, which increases ventricular pulse pressure, increasing pulsatile CSF flow in the aqueduct and causing dilation of the ventricles.

We do not yet have a widely accepted, perfected hydrocephalus theory. The new hydrodynamics theory, which prompts a new explanation for the development of communicating hydrocephalus, still needs further investigation. We think that future studies will focus on the precise site of CSF absorption and the alterations of CSF volume through the stoma, aqueduct, foramen magnum, and basal cisterns before and after ETV.

Patient Selection and Outcome Evaluation

Recently there have been several preliminary reports of successful treatment with ETV in patients with communicating hydrocephalus.\textsuperscript{10,11,20,25,29–31} The primary aim of ETV is to increase intracranial compliance; ETV causes an increase in the systolic outflow from the ventricles, and a decrease in the intraventricular pulse pressure and width of the ventricles. These effects dilate the compressed capacitance vessels and increase intracranial compliance. The dilated capillaries facilitate increased blood flow and CSF absorption. Mitchell and Mathew\textsuperscript{31} first reported improvement in 3 of 4 cases treated with ETV. They suggested that this procedure may relieve periventricular tissue stress and thus may improve local blood flow. Meier et al.\textsuperscript{29,30} have compared the results in 60 patients with normal pressure hydrocephalus treated with shunt placement with the results in 15 patients treated with ETV. Although the immediate results were similar, the ETV group showed a better late outcome (after 12–27 months) and a higher underdrainage rate than the shunted group. Gangemi et al.\textsuperscript{11} reported on their experience with ETV in 25 patients with INPH, with an overall rate of neurological improvement of 72%. These results are slightly higher than that found in their 14 patients (66%) with shunts.

In our study, the overall proportion of excellent/good clinical outcomes was 65.6%, of which 25% were excellent and 40.6% were good. Four patients of the total study population (12.5%) showed a satisfactory course and 7 patients (21.9%) a poor course. Although these results are similar to that achieved in the shunt group in the study by Gangemi et al.\textsuperscript{11} the reviewed studies of patients treated with shunt placement did not specify the degree of dementia and the duration of the clinical evolution before diagnosis and treatment. Gangemi and colleagues\textsuperscript{13} used the Japanese Committee for Scientific Research on Intratable Hydrocephalus scale from 1966 to evaluate patients for inclusion in the study. This scale does not include the degree of headache or vertigo. The outcome evaluation in our study is defined as > 50% improvement in clinical symptoms, which, in our opinion, is a somewhat stricter standard than that used in their study. In our study, the preoperative Kiefer score and the patient’s age were highly correlated with overall outcome after ETV. Because of the pathophysiological link between the Kiefer score and the severity of communicating hydrocephalus, it is easy to see why patients with a comparatively mild degree of symptoms had favorable results after ETV.
The patient’s age, in our opinion, to some extent reflects the compensatory ability of the brain parenchyma. Considering the predictive role of the classic Hakim triad indicators, Gangemi et al.\textsuperscript{11} reported that the presence of gait disturbances and their onset before dementia is a favorable prognostic factor after ETV; in addition, gait disturbances showed the highest rate of improvement when compared with the other 2 symptoms. In recent research on outcome prediction in patients with communicating hydrocephalus treated by shunt implantation, Meier and colleagues\textsuperscript{27,28} showed that in patients without cerebral atrophy and a short course of disease, a small amount of dementia, and an implanted Miethke dual-switch valve were significant predictors of a good postoperative outcome.

In the present study, the Pearson correlation test demonstrated that preoperative mental state score, gait disorder, and headache severity were predictors of good outcome after ETV. Preoperative vertigo and incontinence was not predictive of surgical outcome. We used the Cox regression model to demonstrate the predictive effect of the different Kiefer indicators, and determined that the preoperative mental state plays an important role in the prediction of ETV outcome. This finding implies that the relative risk of ETV failure in a patient with concentration disorder is about 2 times that in a patient without such a disorder. We believe gait disturbance is just a reflection of local alterations in corresponding cortex and blood supply. However, mental state reflects the preserved grade of whole-brain compliance and the extent of massive parenchymal damage. Although our statistical results show that the patients in the SCH group had a better outcome after ETV than those in INPH group, we cannot reach a definitive conclusion for several reasons. First, there was an obvious age difference between the 2 groups; second, the SCH group was stratified and included patients with posttraumatic and HIH-related communicating hydrocephalus. Our analysis suggests that the posttraumatic subgroup of SCH patients had better results and a higher recovery rate after ETV than those in the HIH subgroup. It is well known that HIH-related communicating hydrocephalus is strongly associated with vascular disease. Arterial hypertension, cerebral arteriosclerosis, small vessel disease of theBinswanger type, diabetic microangiopathy, white matter lesions, and old age are all associated with HIH-related communicating hydrocephalus.\textsuperscript{16,23} It is highly likely that this long-term, underlying pathology causes massive damage to the parenchyma and decreases the possibility of recovery. It therefore seems appropriate to use the term “restricted arterial pulsation hydrocephalus” or “increased capillary pulsation hydrocephalus” to stress the vascular pathophysiology of communicating hydrocephalus.\textsuperscript{15,16,23,42}

**Hydrodynamic Study**

The application of preoperative CSF dynamic studies in patients with communicating hydrocephalus is an important consideration. It is very interesting to note that 7 patients in the SCH group with high ICP underwent ETV. A favorable result after ETV was achieved in 5 of these patients (71%), while in the same group, 5 of 8 patients (63%) with normal ICP had excellent or good results. There was no statistical difference in outcome after ETV between the groups with elevated and normal ICP. Although it is now widely recognized that a single, limited in time, CSF pressure measurement by lumbar puncture yields a poor estimation of the real ICP profile of patients with hydrocephalus, our results imply that some patients with communicating hydrocephalus and elevated ICP can benefit from ETV. Elevated ICP, in our opinion, is not an absolute contraindication for ETV. There is abundant literature on ICP monitoring demonstrating that even in patients with normal-pressure hydrocephalus,\textsuperscript{2,38,43} the CSF pressure may not actually be normal. The presence of numerous B waves on prolonged CSF pressure recordings indicates a general trend toward episodic high ICP levels. We have begun to treat these kinds of patients with ETV to better define the relationship between the extent of high ICP and the efficacy of this technique. A CSF tap or infusion test is often undertaken prior to shunt operations to simulate shunt placement or to study conductance and resistance to CSF outflow.\textsuperscript{18} Meier et al.\textsuperscript{30} reported on the use of the infusion test to establish an indication for ETV in patients with normal-pressure hydrocephalus, arguing that patients whose outflow resistance is increased in the ventricular infusion test but have normal results on a lumbar infusion test should be treated with ETV. Trantakis and associates\textsuperscript{41} demonstrated that there is a subgroup of patients with morphological communicating hydrocephalus characterized by a functional dissociation of hydromechanical properties of intracranial and spinal CSF compartment.

In cases of regular CSF resorption but restricted CSF outflow from the ventricular system to the subarachnoid space, ETV may be an efficient therapy. However, we did not find a clear relationship between these test results and outcome after ETV. Infusion tests to study conductance and resistance to CSF outflow are rather invasive and have been unacceptable to most of our patients. In our patients, routine T2-weighted MR imaging and cine phase-contrast MR imaging are usually used to differentiate communicating hydrocephalus from obstructive hydrocephalus rather than using invasive methods. On routine T2-weighted MR images, CSF flow can be detected by the flow-related signal loss or flow void in these areas of rapid and turbulent flow. This conventional dual-echo sequence without flow compensation reliably demonstrates a flow void in the region of the aqueduct or ETV secondary to pulsatile flow. Phase-contrast MR imaging is a special technique that uses the relative phase angle of moving spins to quantify intracranial CSF flow. Bergstrand et al.\textsuperscript{7} performed the first dynamic MR imaging study of aqueduct CSF flow. The hyperdynamic flow in the aqueduct has been verified in a number of MR imaging studies, but not in all. The finding of a hyperdynamic CSF flow supports the diagnosis of communicating hydrocephalus, but its absence does not rule out such a case.\textsuperscript{6,24} This is understandable since an increased ventricular pulse pressure may not cause a hyperdynamic flow in a narrow aqueduct, due to the increased CSF flow resistance. After ETV, a clear-cut hyperdynamic CSF flow in the stoma is the rule. This shows that CSF pressure monitoring, in addition to providing an estimate of CSF stroke volumes, may be needed for a complete evaluation of intracranial dynamics. It is also important to
realize that an increased stroke volume in the aqueduct is a paradox due to the redistribution of the intracranial pulsations occurring in chronic hydrocephalus. In comparing our findings before and after ETV on cine MR images, we noted somewhat decreased velocity and quantity CSF flow in aqueduct postoperatively; this difference was not statistically significant. The patent aqueduct in patients with communicating hydrocephalus is too narrow to vent the CSF sufficiently. Endoscopic third ventriculostomy reduces the increased systolic pressure in the brain by venting ventricular CSF through the stoma. It would be interesting to explore the alteration of stroke volume and pulse pressure after ETV in a future study.

Conclusions

The new hydrodynamic concept of hydrocephalus emphasizes that communicating hydrocephalus is caused by decreased intracranial compliance increasing the systolic pressure transmission into the brain parenchyma. The increased systolic pressure in the brain distends the skull and simultaneously compresses the periventricular region of the brain against the ventricles. The result is the enlargement of the ventricles and narrowing of the subarachnoid space. The proposed concept opens a new avenue in that ETV may be an effective treatment also in communicating hydrocephalus. Endoscopic third ventriculostomy, if performed correctly, is a safe, simple, and effective treatment with an acceptable level of complications. It thus constitutes an interchangeable alternative to shunting. Patient age, etiological considerations, and mental state are important outcome predictors for ETV in communicating hydrocephalus. Further studies on hydrodynamics are needed to further our knowledge of the pathophysiology of communicating hydrocephalus, and randomized clinical studies are needed to compare ETV and shunt placement in communicating hydrocephalus therapy.

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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