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The role of third ventricle bowing in the success of endoscopic third ventriculostomy in pediatric and adult patients

Krejčí Tomáš[a,b], Krejčí Ondřej[a], Večeřa Zdeněk[a,b], Chlachula Martin[a], Šalounová Dana[c], Lipina Radim[a,b,*]

[a] Department of Neurosurgery, University Hospital Ostrava, Czech Republic
[b] Faculty of Medicine, University of Ostrava, Czech Republic
[c] Department of Mathematical Methods in Economy, VSB - Technical University of Ostrava, Czech Republic

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ABSTRACT

Objective: Preoperative third ventricle deformation (known as 'bowing') is associated with higher endoscopic third ventriculostomy (ETV) success. In children, the effect of bowing has not to date been systematically studied. Aim of of this study is to determine the effect of bowing on ETV success in adult and child patients.
Patients and methods: In this retrospective, monocentric study were included 135 (70 adults and 65 children) of 157 patients who underwent ETV between 2008–2016, with mean follow-up 4.3 years. Presence and extent of bowing and its impact on ETV outcome were evaluated. Third ventricular anatomy was assessed on pre- and postoperative MR imaging.
Results: In patients > 6 months old, the ETV success rate was 91% in bowing-positive cases and 47.6% in bowing-negative cases. Among patients < 6 months old, ETV was successful in 37% of those with bowing and 36.4% of those without. Presence of bowing strongly indicates ETV success in patients older than 6 months ($p < 0.000\ 5$), including children of 7 months and older (p 0.001). This relationship was not confirmed in pediatric patients up to 6 months old (p 1.000). The extent of bowing does not influence ETV success (p 0.559). Bowing correction strongly correlates with ETV success ($p < 0.000\ 5$).
Conclusion: We confirmed significant correlation between bowing and ETV success in patients over 6 months old. This relationship was not determined in those younger than 6 months and therefore we do not recommend bowing in ETV indication criteria for this patient cohort.

1. Introduction

Nowadays ETV is considered a safe and effective treatment of first resort for obstructive hydrocephalus. There are a range of factors influencing success rates [1,2]. These can be variously categorized as pre-, intra- and postoperative [1,2]. One of the critical pre-operative factors affecting ETV success is patient age, with success rates seeming to decline in patients under 2 years old and especially in those under 6 months old [3–7]. Higher success rates can be expected from radiological findings of third ventricle deformation, which Dlouhy et al refer to as third ventricle 'bowing' [8] (Fig. 1). Bowing can be defined as deformation of the third ventricle floor below a defined reference line drawn from the middle of the optic chiasm to the superiormost aspect of the midbrain tegmentum, together with anterior bulging of the lamina terminalis between the chiasma and anterior commissure [8]. The positive relationship between bowing and ETV success was first noted by Kehler et al [9]. Dlouhy et al reported that ETV was 3 times more likely to be successful in patients exhibiting preoperative bowing compared with those without [8], as confirmed by other studies [10–12]. These authors have demonstrated that bowing is a predictor of ETV success in pediatric patients [10] or among mixed cohorts of child and adult patients [8,11,12]. In children younger than 6 months, in which ETV success rates are the lowest, the effect of bowing has not to date been systematically studied. The principal aim of this study is to determine the effect of bowing on ETV success in adult and child patients. In addition to bowing, other factors are also evaluated for their possible role in ETV success.

2. Patient and methods

In this retrospective study, 157 ETVs were carried out on 157 patients with obstructive hydrocephalus between January 2008 and

* Corresponding author at: Department of Neurosurgery, University Hospital Ostrava, 17. listopadu 1790/5, 70852 Ostrava Czech Republic.
E-mail address: neurosurgery@fno.cz (R. Lipina).

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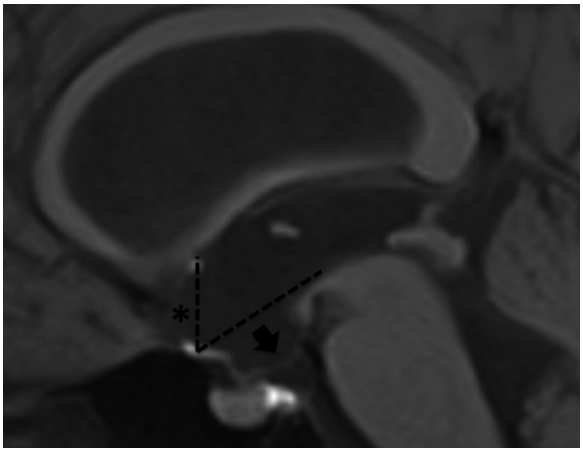

Fig. 1. Neuroimaging study demonstrating third ventricular bowing. Bowing can be described as deformation of the third ventricle floor (**arrow**) below a defined reference line drawn from the middle of the optic chiasm to the superiormost aspect of the midbrain tegmentum, together with anterior bulging of the lamina terminalis (*) between the chiasma and anterior commissure.

December 2016. ETV was indicated after MRI studies revealed signs of ventricular obstruction (idiopathic or secondary aqueductal stenosis, third ventricle outflow obstruction). All patients were deliberately examined preoperatively, as part of the decision to indicate ETV, for signs of third ventricle deformation, i.e. bowing. Patients were included in the study if third ventricle morphology was possible to determine (and therefore the presence of bowing) and were followed up for at least 3 months. Bowing can be described as deformation of the third ventricle floor below a defined reference line drawn from the middle of the optic chiasm to the superiormost aspect of the midbrain tegmentum, together with anterior bulging of the lamina terminalis between the chiasma and anterior commissure [8]. This reference line was chosen in accordance with other studies determining the influence of bowing on ETV success [10–12]. We considered absence of bowing if this reference line overlaid the floor or if the floor resided superiorly to this line. In our study, patients with depression of the anterior third ventricular floor were considered to be bowing-positive even if anterior curvature of the lamina terminalis was not readily apparent. The preoperative third ventricular anatomy analysis and classification of the third ventricle floor as bowed or not bowed was assessed in the midsagittal plane on MR imaging studies by authors of the study (K.T. and L.R.). The third ventricle floor was marked as positive only if both authors agreed.

The primary aim was to confirm the positive effect of bowing in ETV success in both adult and child patients, postulating that the presence of bowing improves ETV outcome in these patients. Given that children younger than 6 months are considered to have the lowest ETV success rates, and ETV indication being additionally disputed in such patients, this age group has been evaluated separately. The ROC curve was calculated to verify the selected threshold value of 6 months. In addition to its incidence, the quantifiable extent of bowing was noted in our study patients. Third ventricle floor depression was measured in millimetres using an open-source DICOM viewer (Medixant, Poznan, Poland), to measure its distance below a reference line (superiormost aspect of the midbrain and optic chiasm). Postoperative MRI studies monitored the correction of this deformation following successful ETV.

2.1. Patient populations

The study group comprised 87 women (55.4%) and 70 men (44.6%), from 19 days to 80 years old. The average age was 28 years (median 20 years). There were 71 children making up 45% of the cohort, of which 44 (28% of the study overall) were younger than 6 months. For classification of patients according to etiology see Table 1 and Fig. 2. Of the 157 patients, 135 were inducted to the study evaluating the effect of bowing. There were 7 patients who were lost from monitoring or followed up for less than 3 months. In 15 patients anatomical changes made it impossible to determine the morphology of the third ventricle due to (for example) tumor invasion or post-hemorrhagic condition. For the purposes of the study, patients were followed up until December 2017. The mean length of monitoring was 4.3 years (range 0.25 to 8.9 years). ETV was defined as successful if preoperative symptoms of hydrocephalus abated and no reoperation was required.

Table 1
Patient characteristics according to etiology of hydrocephalus.

Etiology	n	%
Aqueductal stenosis	59	37.6
Post-hemorhagic	45	28.6
Secondary aqueductal stenosis	27	17.2
Fourth ventricular outlet obstruction	8	5.1
Dandy-Walker syndrome	8	5.1
Other	10	6.4

The IBM program SPSS Statistics (version 24) was used for statistical data analysis. Statistical significance was set at $p < 0.05$.

2.2. Surgical technique

All patients underwent ETV in which 3 mm-diameter 0° (Paediscope, Aesculap AG) or 6 mm-diameter 0° or 30° (Aesculap AG) endoscopes were used. In all cases a burr hole craniectomy was carried out extending 3 cm from the midline to just anterior of the coronal suture. A right-sided approach was preferred. Following endoscopic insertion and morphological revision of the lateral ventricles, the endoscope was advanced into the third ventricle through the foramen of Monro. Here the mammillary bodies and infundibular recess which constitute the third ventricle floor were identified. The site of third ventricular puncture into the interpeduncular cistern was anterior to the mammillary bodies in the region of the tuber cinereum. The initial fenestration was typically performed using closed blunt forceps or monopolar coagulation, then dilated with a 2–4 F Fogarty balloon catheter (Edwards Lifesciences Co.). The interpeduncular cistern was then visually examined for the possible presence of membranes obstructing passage into the prepontine cistern. If necessary, perforation and dilation of arachnoid membranes (part of the membrane of Liliequist) was carried out with the Fogarty catheter. Any bleeding around the stoma was controlled by irrigation or the balloon catheter.

3. Results

3.1. Third ventricle bowing as an indicator of ETV success

135 out of 157 patients fulfilled the criteria for inclusion in the study. ETV was successful in 84 patients (70.1%) and failed in 51 (29.9%). Bowing was observed in 82 patients (60.7%). Since the relationship between bowing and ETV success has not been thus far examined in patients younger than 6 months, we evaluated this age group separately. The study was divided into 2 groups: patients older than 6 months were assigned to group A; patients younger than 6 months were placed in group B.

3.1.1. Group A: patients older than 6 months

This group comprised 97 patients, 59 women and 38 men (60.8% and 39.2% of the cohort respectively). Average age was 39.2 years (median 42) ranging from 7 months to 80 years. There were 27 children from 7 months to 16 years of age, representing 27.8% of cases. ETV was successful in 70 cases (72.2%) and failed in 27 (27.8%). Among the 27 children, ETV was successful in 20 (74%) and failed in 7 cases (26%).

Demographic analysis found no correlation between bowing

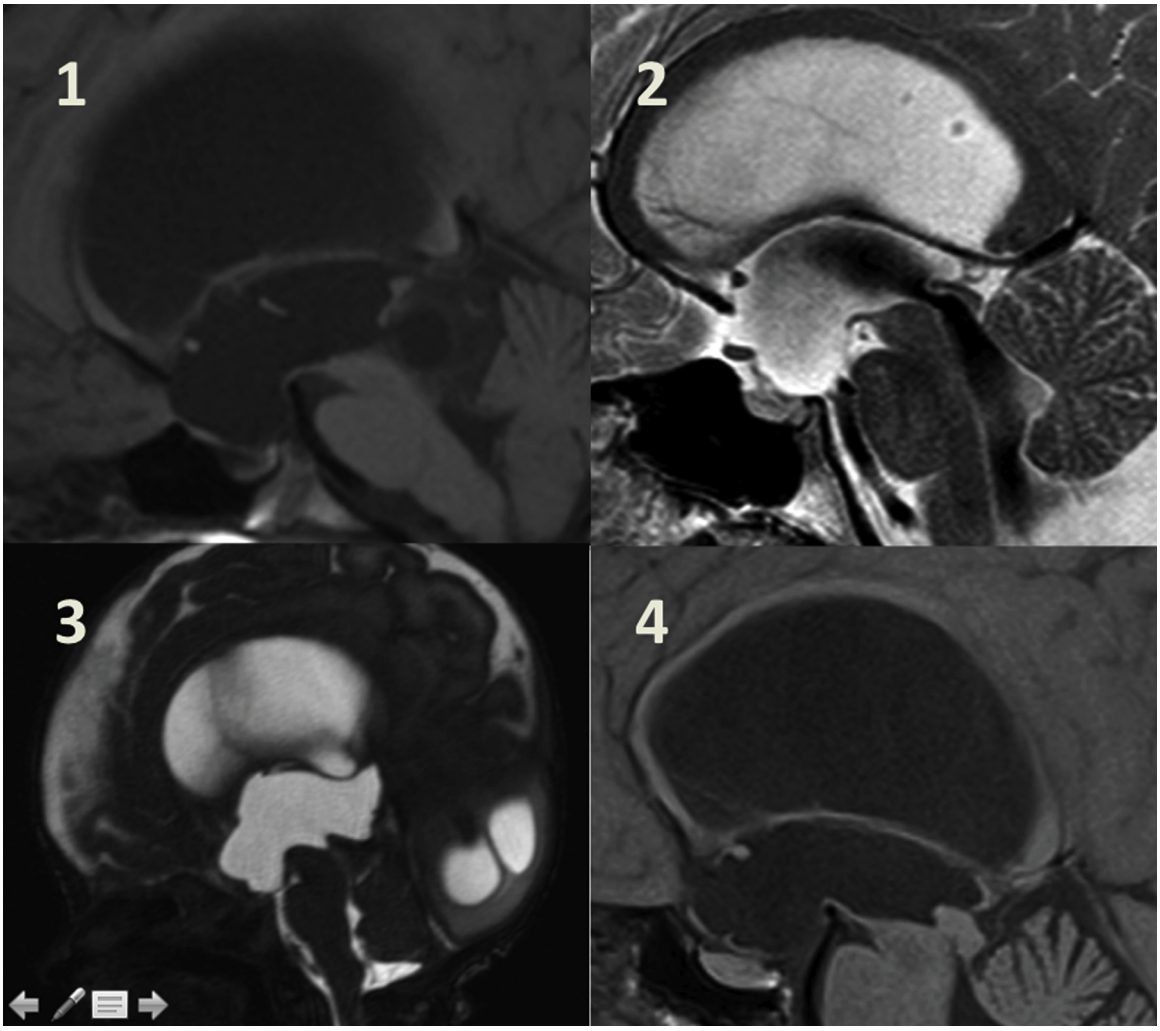

Fig. 2. Third ventricular bowing in patients with pineal region tumor (**1**), fourth ventricle outlet obstruction (**2**), posthemorrhagic hydrocephalus in premature newborn (**3**) and aqueductal stenosis (**4**).

incidence and age (p = 0.084, Mann-Whitney test) or gender (p = 0.679, Mann-Whitney test). Similarly, neither age nor sex were found to correspond with ETV failure (p = 0.425 and 0.366 respectively, chi-squared test).

On the basis of graphical findings (MR imaging studies) bowing was recorded in 55/97 patients (56.7%) and absent in the remaining 42 (43.3%). Among patients exhibiting bowing, ETV was successful in 91% of cases. In patients without bowing ETV was successful in 47.6% and failed in 52.4%. Statistical analysis confirmed that ETV is significantly more likely to be successful in patients with bowing (p < 0.000 5, chi-squared test) (Table 2**)**. Bowing was determined in 16 of the 27 children (59%). ETV was successful in 87.5% of these cases. In the remaining 11, the ETV success rate was 54.5%. As with this group as a whole, we confirmed that children older than 6 months who present with bowing have a significantly higher likelihood of ETV success (p = 0.001, chi-squared test) (Table 3**)**.

The clinical signs of bowing were quantitatively measures in millimetres and the results analyzed for any connection with ETV success.

Table 3
Relationship between bowing and ETV success in pediatric patients older than 6 months.

27 patients (n / %)	ETV success (n / %)	ETV failure (n / %)	p value (χ2 test)
Bowing-positive 16 / 59	14 / 87.5	2 / 12.5	p = 0.001
Bowing-negative 11 / 41	6 / 54.5	5 / 45.5	

The mean extent of bowing in the 55 patients was 6.5 mm (median 6.5 mm) ranging from 3 to 14 mm. No correlation was found between bowing extent and ETV success (p = 0.559, Mann-Whitney test).

Patients with bowing who successfully underwent ETV were examined at postoperative MR follow-up to determine if any correction of the deformation had taken place (Fig. 3). Resolution of third ventricle morphology was found in 48/50 patients (96%). This was true even for early MR follow-up (3–30 days postoperatively). MR imaging follow-up

Table 2
Relationship between bowing and ETV success in patients older than 6 months.

97 patients (n / %)	ETV success (n / %)	ETV failure (n / %)	p value (χ2 test)
Bowing-positive (55 / 56.7)	50 / 91	5 / 9	p < 0.000 5
Bowing-negative (42 / 43.3)	20 / 47.6	22 / 52.4	

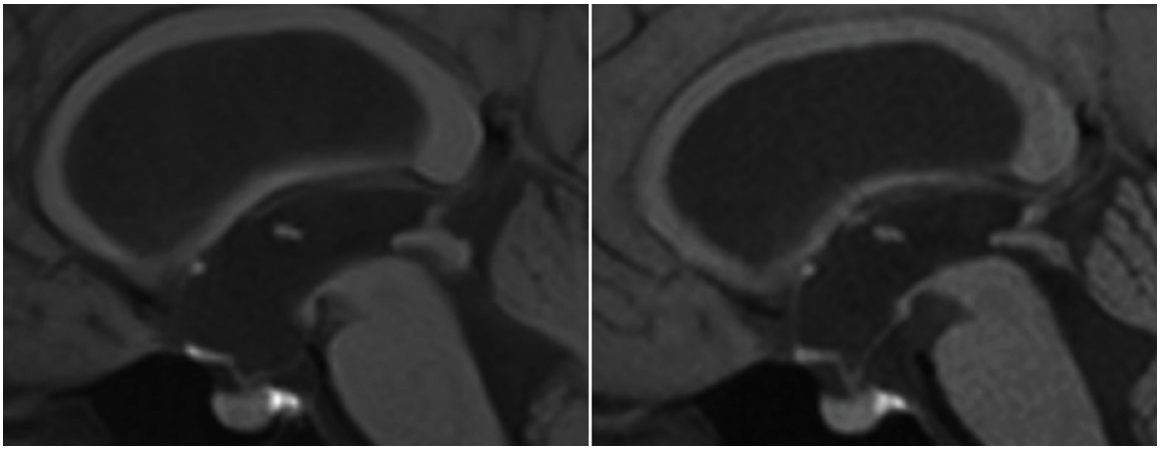

Fig. 3. Preoperative MR imaging study demonstrating bowing of the third ventricle (**left**) and postoperative imaging showing correction of third ventricle morphology after successful ETV (**right**).

took place an average of 64 days after ETV. Bowing regression was not observed in 4/5 patients (80%) in which ETV had been unsuccessful. ETV failure in these cases was due to the following: the failure of a previous shunt in 2 cases, one case of postoperative MR imaging revealing signs of blood clotting in the interpeduncular cistern and one case with intra-operative signs of elevated rigidity of the third ventricle, along with numerous fibrous membranes in the interpeduncular cistern. Bowing correction correlates highly with ETV success ($p < 0.000\ 5$, Fisher exact test).

In group A the most common cause of hydrocephalus was aqueductal stenosis in 46/97 cases, followed by secondary aqueductal stenosis (in expansion) in 23 cases. Additionally, there were 7 instances of post-hemorrhagic hydrocephalus, 8 instances of fourth ventricle outlet obstruction, 5 cases of Dandy-Walker syndrome, 6 cases of posterior fossa expansion and 2 instances of Arnold-Chiari malformation. Among patients with bowing, no statistical differences were found linking any specific etiology to ETV failure ($p = 0.527$, Breslow-Day test).

3.1.2. Group B: infants younger than 6 months

This group comprised 19 female and 19 male patients for a total of 38 cases. The average age was 65 days (9.28 weeks), median 8 weeks, ranging from 19 to 163 days old. ETV was successful in 14 cases (36.8%) and failed in 24 cases (63.2%). The results are very similar to those obtained in a previous study we conducted from 2005 to 2007 [20].

Analysis of demographic data found that the sex did not affect the incidence of either bowing ($p = 0.283$, chi-squared test) or ETV failure ($p = 1.00$, chi-squared test). Regarding etiology, post-hemorrhagic hydrocephalus was the most prevalent (30/38 cases). There were additionally 4 cases of idiopathic aqueductal stenosis, 2 cases of post-infectious aqueductal stenosis, and other causes in a further 2 cases.

Preoperative MRI of the brain revealed bowing in 27/38 patients (71%). Among patients with bowing, ETV was successful in 37% and failed in 63% of cases. In those without bowing the procedure was successful in 36.4% and failed in 63.6% of cases. In contrast to group A, bowing does not correlate with ETV success in this group ($p = 1.000$, Fisher exact test) – see Table 4. The selected age threshold value of 6 months was confirmed by calculating the ROC curve (area under curve 0.836; 95% confidence interval, 0.739-0.932; $p < 0.0005$) – see Fig. 4. Significantly higher rate of ETV failure was found in these children with bowing compared to older patients. In comparison with the child patients in group A (aged 7 months to 16 years) we determined significantly higher risk of ETV failure in children younger than 6 months ($p = 0.002$, chi-squared test).

Table 4
Relationship between bowing and ETV success in pediatric patients younger than 6 months.

38 patients < 6 months (n / %)	ETV success (n / %)	ETV failure (n / %)	p value (Fisher test)
Bowing: positive 27 / 71	10 / 37	17 / 63	p = 1.000
Bowing: negative 11 / 29	4 / 36.4	7 / 63.6	

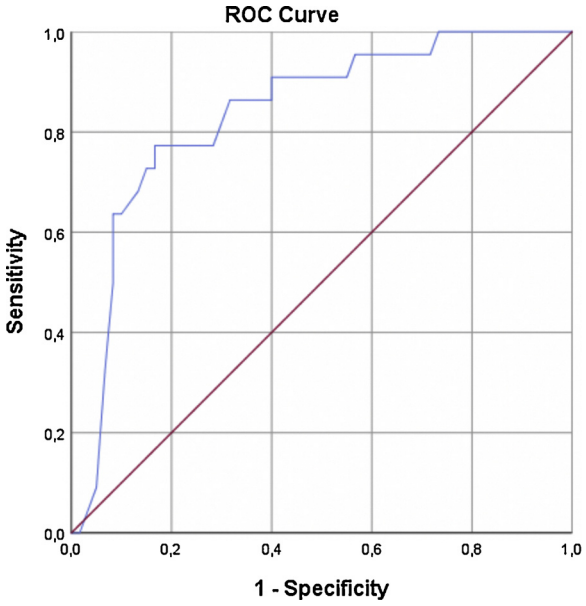

Fig. 4. ROC curve dependence of ETV failure on patient's age with bowing confirms threshold value of 6 months (area under curve 0.836; 95% confidence interval, 0.739-0.932; $p < 0.0005$).

As in group A, the extent of bowing was quantifiably determined and the results analyzed for their relationship to ETV success. In these 27 patients, the average extent of bowing was 4.3 mm (median 4 mm) in the range 3–9 mm. Bowing extent was not found to influence ETV success ($p = 0.786$, Mann-Whitney test).

In group B the degree of prematurity was also investigated for its possible influence on ETV success, alongside the incidence of bowing in given subgroups (Table 5). Although it is proven that severely premature neonates are significantly more likely to present with bowing ($p = 0.049$, Fisher exact test), bowing does not predict ETV success in this patient group. Indeed, neither bowing nor neonatal prematurity influenced ETV failure ($p = 0.262$, Fisher exact test).

Table 5
Influence of degree of prematurity on ETV failure.

DEGREES OF PREMATURITY (n / %)	ETV success (n / %)	ETV failure (n / %)	p value (Fisher test)
SEVERE (< 31 weeks) (22 / 57.9)	**8 / 36.4**	**14 / 63.6**	p = 0.262
Bowing-positive (20 / 91)	7 / 35	13 / 65	
Bowing-negative (2 / 9)	1 / 50	1 / 50	
MODERATE (32-35 weeks) (9 / 23.7)	**4 / 44.5**	**5 / 55.5**	
Bowing-positive (5 / 55.5)	2 / 40	3 / 60	
Bowing-negative (4 / 44.5)	2 / 50	2 / 50	
LIGHT OR PHYSIOLOGIC (7 / 18.4)	**1 / 14.3**	**6 / 85.7**	
Bowing-positive (3 / 43)	1 / 33	2 / 67	
Bowing-negative (5 / 57)	0 / 0	5 / 100	

4. Discussion

Nowadays the use of ETV is considered routine in the treatment of obstructive hydrocephalus. Some authors also present it as the treatment of choice in communicating hydrocephalus [13]. The advantages of ETV over VP shunts are primarily cost-effectiveness and the low risk of both complications [14] and late failure [15,16].

Criteria indicating ETV are relatively loosely defined. There are a range of factors influencing ETV success, which can be variously categorized as pre-, intra- and postoperative [1,2]. We consider pre-operative factors to be the most critical, influencing as they do the decision to indicate ETV. We consider radiological findings of third ventricle deformation, which Dlouhy et al refer to as 'third ventricle bowing' [8], one of these key preoperative factors. Such findings typically indicate obstructive hydrocephalus (dilation above an obstruction), that is, a pressure differential between the third ventricle and interpeduncular cistern [11]. The positive effect of bowing on ETV success has been confirmed in both adult and pediatric patients [8–12]. Although the studies of Foroughi et al and Vogel et al included pediatric patients under 6 months old in which the influence of bowing was not separately studied, the authors seem to conclude that bowing indicates ETV success in all pediatric patients [10,12]. In our study we confirmed the significant association between bowing and ETV success in patients older than 6 months: ETV is 5 times more likely to fail in bowing-negative patients. This relationship was also confirmed in pediatric patients from 6 months to 16 years old but not in those younger than 6 months. This patient subgroup thus constitutes an exception and thus we are able to amend the conclusions of studies which recommend bowing as an indicator in pediatric patients generally [8,10,12]. The most probable reason for failure in patients younger than 6 months is 'underdeveloped' absorption capacity [17], as well as skull elasticity and low pressure gradient [3], but also, as confirmed by Wagner et al, higher tendency to spontaneous closure of stoma and new membrane formation in the interpeduncular cistern [18].

This subgroup typically constitutes premature neonates; however, we found nothing to suggest that the degree of prematurity affects ETV outcome. Furthermore, although incidence of bowing is higher among pediatric patients under 6 months old, this only concerns severely premature neonates with hydrocephalus. This higher incidence of bowing is most likely due to increased cerebral compliance, as is generally observed in premature neonates [19].

On the other hand, it is important to stress that the preoperative absence of bowing does not automatically indicate ETV failure: 47.6% of bowing-negative patients in our study successfully underwent ETV. Other studies observed success rates for these patients ranging from 0 to 46% [8,10–12]. The reason these patients do not present with bowing can be attributed to varying cerebral compliance, that is stiffness or turgor of the brain as presented by Rekate et al [20]. This manifests similarly to slit-ventricle syndrome (for example) where elevated intracranial pressure does not necessarily lead to ventricular dilation [8,20]. Speaking from empirical experience, third ventricle floor stiffness can vary from patient to patient thereby affecting bowing expression even in patients with elevated intraventricular pressure.

With regard to Kehler's ETV Success Score (ETVSS) we attempted to determine if the extent of third ventricular deformation correlated with ETV success [11]. In our study no such correlation could be identified in either patient group. Our findings suggest it is only the presence, not the extent, of bowing that affects ETV success. Kehler et al only evaluated ETV outcome against ETVSS [11] and did not separately investigate the relationship between bowing extent and ETV success as we did. Therefore, we assert that this division of significance of 5 mm is merely incidental [11].

Postoperative MR findings determined that ETV was successful in 96% of patients over 6 months old in which preoperative signs of bowing had corrected. We determined significant association between bowing correction and ETV success. This was similarly described in the study of Foroughi et al. [10]. One explanation for the lack of bowing correction observed in all such patients who successfully underwent ETV could be the timing of MR image acquisition relative to the cardiac cycle [21]. As can be generally observed on intra-operative, but also postoperative radiological imaging using True FISP (fast imaging with steady-state precession) cardiac-gated MR imaging sequences, the floor of the third ventricle moves with cardiac systole and diastole [21]. Our MRI protocol did not utilize cardiac gating.

5. Conclusion

We confirmed significant correlation between bowing and ETV success in patients over 6 months old. This relationship was not determined in those younger than 6 months and therefore we do not recommend bowing in ETV indication criteria for this patient cohort. Our findings suggest it is only the presence, not the extent, of bowing that affects ETV success.

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No funding was obtained.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee (name of institute/committee) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Competing Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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