CHANGES IN VENTRICULAR AND INTRACRANIAL VOLUME IN HYDROCEPHALIC CHILDREN FOLLOWING SUCCESSFUL ENDOSCOPIC THIRD VENTRICULOSTOMY

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ABSTRACT

Objective: *To investigate the change in the ratio of ventricular to intracranial volume following successful endoscopic third ventriculostomy (ETV) in hydrocephalic infants suffering from pure aqueduct stenosis.*

Materials and Methods: *Using segmentation techniques, serial measurements of ventricular (VV) and intracranial volume (ICV) were performed on the preoperative and 12-month postoperative axial T-2 weighted MRI scans of 5 hydrocephalic infants who had successful ETV for aqueduct stenosis between 1999-2002. All patients remained asymptomatic, did not require shunting and demonstrated radiological evidence of stoma patency on Phase Contrast cine MR throughout the follow-up period extending from 2-4.5 years. There were 1 males and 4 females with a mean age at operation of 1.4 months (range 0.1 to 2 months). Each ventricular and intracranial volume measured was divided by the corresponding average normal volume for sex and age to calculate the "x normal" volume (xN). Each ventricular volume was divided by the intracranial volume to calculate a ventricular to intracranial volume ratio (VV/ICV).*

Results: *The mean ventricular volumes were: pre-operative: 295.3 cm^3 (19.2 xN), at 12 months post-operative: 174.2 cm^3 (10.9 xN). The mean VV/ICV ratios were: pre-operative: 0.29, at 12 months post-operative: 0.14. For comparison, normal mean VV/ICV was 0.018 for the first six years of life. All volumes and ratios pre and postoperatively were statistically higher than normal (p=.000).*

Conclusion: *In response to endoscopic third ventriculostomy (ETV), ventricular volume and the ratio of ventricular to intracranial volume fall to values lower than pre-operatively but higher than the normalised values for age and sex. This further indicates that third ventriculostomy creates a state of compensated communicating hydrocephalus, with ventricles and head larger than normal.*

Keywords:*Endoscopic third ventriculostomy, Hydrocephalus, Segmentation, Ventricular volume,*

INTRODUCTION

Endoscopic third ventriculostomy (ETV) is a well-established surgical option in the management of paediatric hydrocephalus[1-6] but the mechanism of its function is not fully understood, especially in very young children with aqueduct stenosis. Moreover, monitoring these patients long term, to assess continued procedural success, remains challenging. Definitions of successful ETV must include both radiological and clinical parameters but longitudinal monitoring of ventricular volume remains a useful approach in assessing the continued patency of the stoma. Although early reports did not document a consistent decrease in ventricular size after ventriculostomy, more recently CT and MR imaging have been used to reliably demonstrate that ventricular size does indeed fall[8,18].

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The pattern of change has also been characterized in some detail and it appears that successful ETV produces the state of a compensated communicating hydrocephalus with asymptomatic patients being left with persistent ventricular dilatation [18]. Although the presence of chronically enlarged ventricles is of concern[2], this may not adversely affect the patients' intellectual outcome[15,16].

The present study attempted to further define the volumetric changes occurring after ETV by examining both the intracranial and ventricular response to the procedure in a group of hydrocephalic children with aqueduct stenosis and compare to normal state, in an effort to derive information on the *modus operandi* of the procedure.

MATERIAL AND METHODS

Axial T2-weighted Magnetic Resonance images were used in this study to measure the intracranial (ICV) and ventricular volumes (VV) of 6 children with hydrocephalus due to pure aqueduct stenosis who had undergone successful ETV. A segmentation technique was used to calculate the preoperative and 12 month postoperative volumes for each patient. These measurements were then divided by the mean normalized volumes for age and sex to obtain the "_Normal" volume (_N). Normalized data were obtained from previous publications by our team on normal intracranial and ventricular volume changes in childhood[10,17]. The "xN" variable was used to indicate how many times larger than normal the ventricular or intracranial volume of each patient was at any stage. Normalization of the volumes improved the inherent quality of statistical analysis and removed the bias that sex and age could introduce. The ratio of Ventricular to Intracranial Volume (VV/ICV) was also calculated, to express that proportion of volume that CSF occupied in the head.

Patient population

The study group included 5 children with pure aqueduct stenosis who were successfully treated endoscopically by a single surgeon (S.S.) at the Birmingham Children's Hospital for hydrocephalus between December 1999 and August 2002. They were selected from a group of 44 children who had endoscopic third ventriculostomy performed by that surgeon in the same period, as these patients had undergone imaging appropriate for the purpose of the study. There were 1 boys and 4 girls. The mean age at operation was 1.4 months (range 0.1–2 months).

The operation of endoscopic third ventriculostomy was performed through a right frontal burr hole at a precoronal location, using a rigid endoscope. The perforation of the floor of the third ventricle was performed using the Codman monopolar ME2 electrode (Codman, J&J, Raynham, MA, USA), and the stoma was dilated with an hour-glass inflatable balloon catheter (Neuro-balloon catheter, Integra Neurosciences, Sophia Antipolis, France).

Patients were included in the study if they had clinical and radiological evidence of a successful procedure: i. they showed improvement of presenting symptoms following ETV and remained asymptomatic thereafter, ii. stoma patency demonstrated on serial PCMR, iii. they did not require ventricular shunting at the latest follow-up, ranging from 2 to 4.5 years. Only patients with preoperative and a 12 month postoperative MRI studies were included to ensure that a trend of ventricular volume change could be ascertained.

Segmentation technique

Preoperative and 12-month postoperative MR scans were used for this study. We utilized MR scans obtained at 12 months after operation, because in a previous study we demonstrated that it takes 6-12 months for ventricular volumes to stabile after successful third ventriculostomy[18]. In all the postoperative studies, stoma patency was verified in Phase Contrast MR sequences. MR imaging examinations used for ventricular and intracranial volume measurements were axial T2-weighted sequences with 5-mm slice thickness and a 1.5-mm interval.

The technique of segmentation used in this study has been explained in detail in earlier reports[10,11]. Manual and semi-automatic outlining of the ventricular system and intracranial compartments were performed (Fig. 1) and the area of every outline was determined in each imaging slice. The volume was calculated by multiplying the area of the outline by the slice thickness. All four ventricles were delineated. The total volume of the ventricular system and the intracranial compartment was then calculated by adding the volumes of all the respective slices, including the calculated interslice gaps. The accuracy and validation of the technique has been reported already[11].

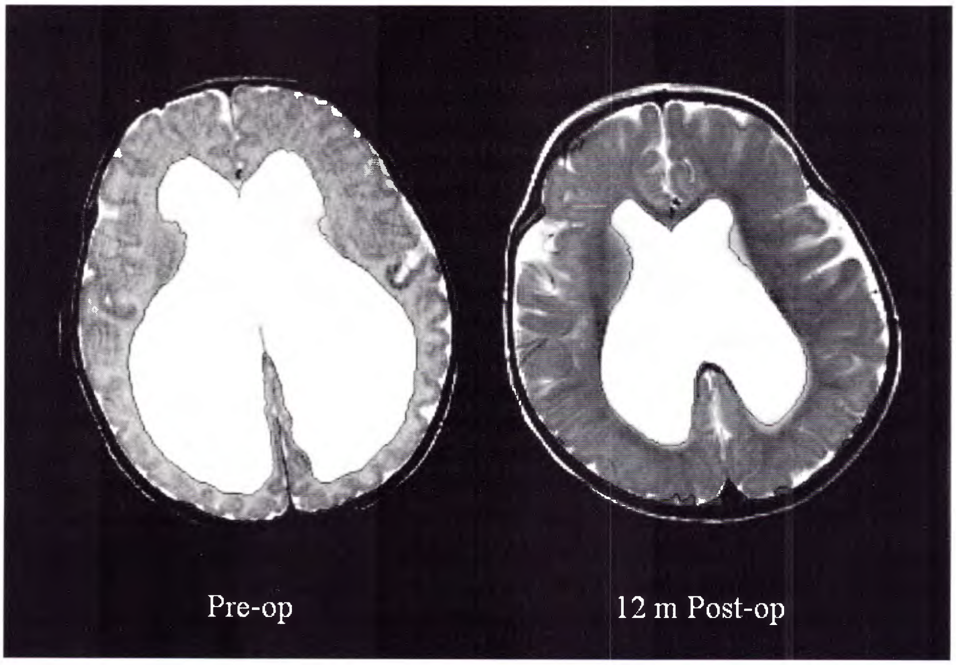

Fig. 1. Outline of the ventricular and intracranial compartments of a female patient treated endoscopically for aqueduct stenosis at the age of 2 months. The red lines outline the margins of the lateral ventricles and the inner table on axial T-2 weighted images. Left: Preoperative, Right: 12 months postoperative image

Statistical analysis

The _N ventricular volume and VV/ICV ratio at presentation and at 12 months post operatively were compared with normal state using the commercial statistical software SPSS (SPSS Inc., IL, USA). Normal values have been published before in a study of change of ventricular volume throughout childhood, including 71 individuals, 17 of them in the first two years of life[10]. A probability value of less than 0.05 was considered statistically significant.

RESULTS

Table 1 shows the pre- and 12 months postoperative values for the ventricular volumes (VV) and VV/IVC ratios. The preoperative mean ventricular volume was 295.3 cm^3 (19.2_N), while the mean ventricular volume at 12 months was 174.2 cm^3 (10.9_N). This represents a fall of 43%. Preoperative and 12-month postoperative values were statistically significantly higher than normal ventricular volumes (p=.000), described in a previous publication [10]. The mean VV/ICV ratio at presentation was 0.29, which fell to 0.14 at 12 months. This represents a fall of 52%. Normal mean VV/ICV ratio is 0.018 through the first 6 years of life for males and females, as has been demonstrated before [10]. So the mean VV/ICV at 12 months after successful endoscopic third ventriculostomy remains 7 times higher than normal, which is statistically significant (p=.000).

Table 1. Preoperative and 12-month postoperative Ventricular and Intracranieral Volumes

VV (cm^3)		xNVV		VV/ICV ratio	
Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
338	142	22.50	9.20	0.346	0.080
300	190	20.00	12.66	0.356	0.180
285	146	19.00	9.40	0.282	0.132
280	144	16.50	7.20	0.311	0.109
274	249	18.26	16.00	0.180	0.190

The graph in Figure 2 depicts the change in the VV/ICV ratio for individual patients. In all but one patient the ratio decreased, towards normality, but all patients ended up having considerably

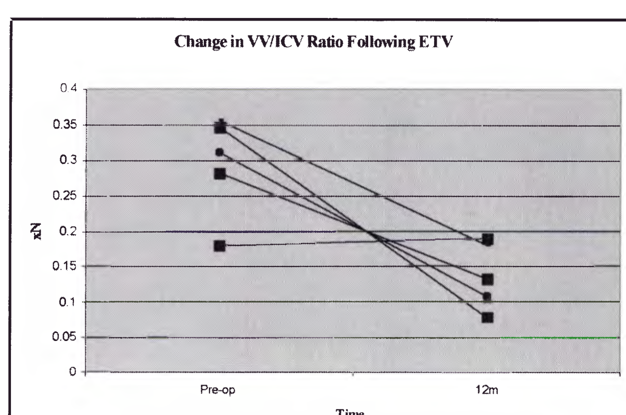

Fig. 2. Graphical illustration of change of VV/ICV as a result of ETV (each line represents one patient)

higher ratios than normal, indicating that they had a higher proportion of CSF in their heads than normal.

DISCUSSION

The role of ETV in the management of paediatric hydrocephalus is well recognized[1–6] and success rates of 70% and greater have been described for the treatment of isolated aqueduct stenosis[2,5–7]. Successful ETV procedures are associated with symptomatic improvement and shunt avoidance however the long term monitoring of these patients, to assess continued procedural success, remains challenging. Definitions of successful ETV must include both radiological and clinical parameters but longitudinal monitoring of ventricular volume remains a useful approach in assessing the continued patency of the stoma. Definition of success is potentially more important in children during the first two years of life, when the negative effects of insufficient treatment, or alternatively shunt insertion are more important.

In many patients the situation remains unclear, as ventricular size may appear unchanged on routine postoperative imaging, despite clinical improvement[2,9]. Visual assessment of changes in the ventricular volume can be difficult and subtle variations in size may be missed. In a previous publication, we demonstrated that a 20% change in ventricular volume must occur before it is appreciated by the observer[12]. Not surprisingly, early reports did not consistently document a decrease in ventricular size after ventriculostomy. Schwartz et al. demonstrated that although ventricular size often shows no obvious visual change following successful ETV, careful measurement of ventricular diameters on CT scans will show a decrease in both third and lateral ventricular size if performed 1 month after surgery in patients with clinical improvement[13]. However, linear methods[9,14] are less sensitive to detecting change when compared to volumetric measurements and lateral ventricular volume measurements appear more accurate than those of the third ventricle due to the comparatively smaller size of the latter. These observations led Schwartz et al. to recommend using the entire ventricular system or the lateral ventricles alone to document volume change[8]. For the present study, we chose to measure the volume of the entire ventricular system for these reasons cited and in order to compare the findings with those of our previously published studies on changes in ventricular volume after shunting and ETV.

In response to ETV, there appears to be a slow increase in absorption through the arachnoid granulations, initially producing only small volumetric changes. The chronicity of the disease process correlates inversely with the magnitude of the decrease in ventricular size following successful ETV, i.e. the longer the duration of symptoms the smaller the postoperative volume change[8].

In a previous report[18] based on a group of 13 patients with hydrocephalus of varying aetiologies, we demonstrated that following ETV ventricular volume falls to a value lower than preoperatively but higher than the normalized value for age and sex. The patients were observed to have supranormal volumes in the long term with the ventricular volume stabilizing at 3–6 months. Although the presence of persistent ventricular dilatation post ETV has raised concerns[2], this may not adversely affect patients' intellectual outcome[15,16].

In his study we wanted to investigate to what extent that change in ventricular size after successful ETV is followed by change in intracranial size. This study demonstrated that following successful ETV, the ventricular size and ventricle to intracranial volume ratio decrease but the latter decreases more than the former, and both remain significantly larger-than-normal. This implies that endoscopic third ventriculostomy improves CSF drainage out of the head somewhat, but essentially it converts the previously active hydrocephalus to a compensated communicating hydrocephalus. For comparison, our study that looked in to the change of ventricular size following shunting [12] showed that after shunt placement, ventricular size stabilises between 6 and 12 months near normal values[12].

CONCLUSION

In response to ETV, ventricular and intracranial volumes fall at 12 months to values lower than preoperatively but higher than the normalized values for age and sex and remain high long term. This implies that in patients with aqueduct stenosis the absorptive mechanism works less than in normal subjects. It appears, therefore, that successful ETV produces a state of compensated communicating hydrocephalus with the head and ventricles remaining persistently enlarged. The long-term neurocognitive consequence of this may require further evaluation.

Acknowledgements

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References

1. Tuli S, Ashail E, Drake J. Third ventriculostomy versus cerebrospinal fluid shunt as a first procedure in pediatric hydrocephalus. **Pediatr Neurosurg** 1999; 30: 11–15
2. Goumnerova LC, Frim DM.Treatment of hydrocephalus with third ventriculocisternostomy: outcome and C.S.F. flow patterns. **Pediatr Neurosurg** 1997; 27: 149–152
3. Buxton N, Macarthur D, Mallucci C, Punt J, Vloeberghs M. Neuroendoscopic third ventriculostomy in patients less than 1 year old. **Pediatr Neurosurg** 1998; 29: 73–76
4. Brockmeyer D, Abtin K, Carey L, Walker ML. Endoscopic third ventriculostomy: an outcome analysis. **Pediatr Neurosurg** 1998; 28: 236–240
5. Cinalli G, Sainte-Rose C, Chumas P, Zerah M, Brunelle F, Lot G, Pierre-Khan A, Renier D. Failure of third ventriculostomy in the treatment of aqueductal stenosis in children. **J Neurosurg** 1999; 90: 448–454
6. Hopf N, Grunert P, Fries G, Resch K, Perneczky A. Endoscopic third ventriculostomy: outcome analysis of 100 consecutive cases. **Neurosurgery** 1999; 44: 795–804
7. Fukuhara T, Luciano MG, Kowalski RJ. Clinical features of third ventriculostomy failures classified by fenestration patency. **Surg Neurol** 2002; 58: 102–110
8. Schwartz TH, Ho B, Prestigiacomo CJ, Bruce JN, Feldstein NA, Goodman RR. Ventricular volume following third ventriculostomy. **J Neurosurg** 1999; 91: 20–25
9. Kulkarni AV, Drake JM, Armstrong DC, Dirk PB. Imaging correlates of successful endoscopic third ventriculostomy. **J Neurosurg** 2000; 92: 915–919
10. Xenos C, Sgouros S. Natarajan K. Ventricular volume change in childhood. **J Neurosurg** 2002; 97: 584–590
11. Sgouros S, Goldin JH, Hockley AD, Wake MJ, Natarajan K. Intracranial volume change in childhood. **J Neurosurg** 1999: 91: 610–616
12. Xenos C, Sgouros S, Nataranjan K, Walsh AR, Hockley A. Influence of shunt type on ventricular volume changes in children with hydrocephalus. **J Neurosurg** 2003; 98: 277–283
13. Schwartz TH, Yoon SS, Cutruzzola FW, Goodman RR. Third ventriculostomy: post-operative ventricular size and outcome. **Minim Invasive Neurosurg** 1996; 25: 57–63
14. O'Hayon BB, Drake JM, Ossip MG, Tuli S, Clarke M. Frontal and occipital horn ratio: a linear estimate of ventricular size for multiple imaging modalities in pediatric hydrocephalus. **Pediatr Neurosurg** 1999; 29: 245–249.
15. Cinalli G, Sainte-Rose C, Chumas P, Zerah M, Brunelle F, Lot G, Pierre-Kahn A, Renier D. Failure of third ventriculostomy in the treatment of aqueductal stenosis in children. **J Neurosurg** 1999; 1999; 90: 448–454.
16. Sainte-Rose C, Chumas P. Endoscopic third ventriculostomy. **Tech Neurosurg** 1995; 1: 176–184.
17. Sgouros S, Goldin JH, Hockley AD, et al. Intracranial volume change in childhood. **J Neurosurg** 1999; 91: 610-616.
18. St. George EJ, Natarajan K, Sgouros S (2004) Change in ventricular volume in hydrocephalic children following successful endoscopic third ventriculostomy **Childs Nerv Syst** (DOI: 10.1007/s00381-004-0939-x)

RESUMEN

Objetivo. *Investigar los cambios de la relación del ventrículo con el volumen intracraneano a continuación de una tercer-ventriculostomía satisfactoria en niños con hidrocefalia secundaria a estenosis acueductal.*
Material y método. *Se usó una técnica de segmentación, se tomaron medidas seriadas en IRM del volumen ventricular e intracraneano antes de las cirugías y 12 meses después de ellas en 5 niños hidrocefálicos operados entre 1999 y 2002. Todos los pacientes quedaron asintomáticos sin requerir el implante de derivaciones con evidencia por resonancia dinámica del flujo de LCR, de la persistencia de permeabilidad del estoma. Seguimiento hasta 5 años.*
Resultados. *Todos los volúmenes y relaciones entre el pre y postoperatorio fueron estadisticamente más altas que la normal.*
Conclusión. *La III ventriculostomía crea un estado de la hidrocefalia comunicante compensada con un perímetro cefálico y tamaño ventricular mayor que el normal.*

Palabras clave. *hidrocefalia, III ventriculostomía, volumen ventricular*