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Functional analysis of third ventriculostomy patency with phase-contrast MRI velocity measurements

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Abstract Our purpose was to explore the utility of cine phase-contrast MRI velocity measurements in determining the functional status of third ventriculostomies, and to correlate the quantitative velocity data with clinical follow-up. We examined six patients with third ventriculostomies and 12 normal subjects by phase-contrast MRI. The maximum craniocaudal to maximum caudocranial velocity range was measured at regions of interest near the third ventricular floor, and in cerebrospinal fluid anterior to the upper pons and spinal cord on midline sagittal images. Ratios of the velocities of both the third ventricle and prepontine space to the space anterior to the spinal cord were obtained. The velocities near the third ventricular floor and in the pontine cistern were significantly higher in patients than in normal subjects, but the velocity anterior to the spinal cord was similar between the groups. The velocity ratios, used to normalize individual differences, were also higher in patients than in controls. Two patients had lower velocity ratios than their fellows at the third ventricular floor and in the pontine cistern; one required a shunt 11 months later, while in the other, who had a third ventricular/thalamic tumor, the lower values probably reflect distortion of the third ventricular floor. We conclude that phase-contrast MR velocity measurements, specifically the velocity ratio between the high pontine cistern and the space anterior to the spinal cord, can help determine the functional status of third ventriculostomies.

Key words Magnetic resonance imaging · Cerebrospinal fluid · Ventriculostomy · Hydrocephalus

Introduction

Percutaneous endoscopic third ventriculostomy, the formation of a cerebrospinal fluid (CSF) diversionary route between the third ventricle and the basilar cisterns, is increasingly being used in patients with noncommunicating hydrocephalus. The morbidity of this procedure is low and reported success rates, with obviation of subsequent shunting, have been extremely encouraging [1–10]. A favorable outcome is dependent on prolonged patency of the ventriculostomy and adequate resorptive capacity of the peripheral subarachnoid space [3–8]. Patency can be confirmed by demonstrating decrease in the size of the ventricles on follow-up imaging. Additional information can be obtained by repeat endoscopy or isotope or contrast ventriculography, or noninvasively with MRI assessment by spin-echo and cine display of phase-contrast images [3–5, 8, 10].

Our aim was to assess the usefulness of cine phase-contrast MR velocity measurements as an adjunct to routine imaging in determining the functional status of third ventriculostomies. We also attempted to correlate quantitative velocity data with clinical follow-up.

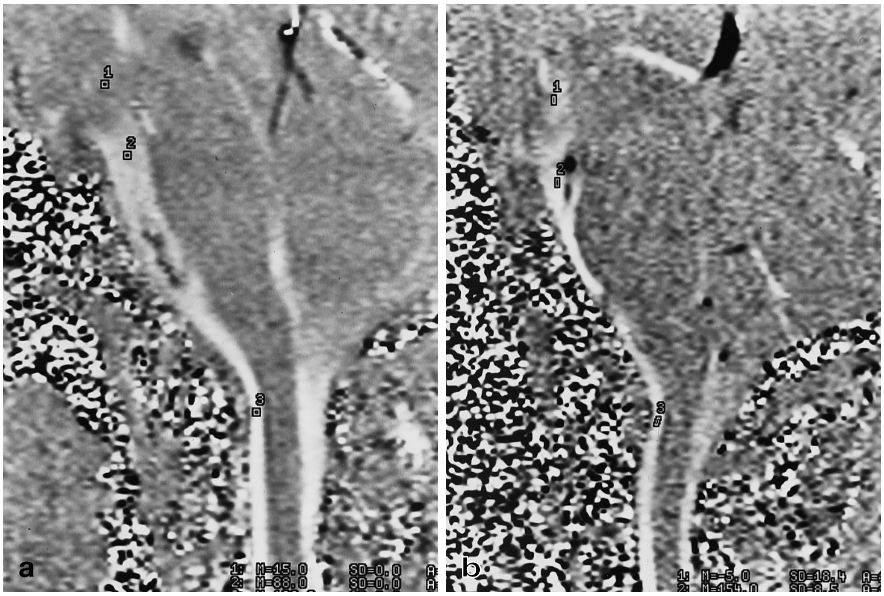

Fig. 1 Sagittal midline phase-contrast MRI from a normal subject (**a**) and a patient with a third ventriculostomy (**b**). Both represent the same point in mid-systole. Cursor regions of interest are at the floor of the third ventricle *(1)* and in high pontine cistern *(2)*, and subarachnoid space anterior to the spinal cord *(3)*

Patients and methods

We examined six patients who had undergone third ventriculostomies for obstructive hydrocephalus and 12 control subjects on a 1.5-T imager. The patients' ages ranged from 3 to 69 years and there were three women and three men. The controls consisted of seven men and five women aged 3–42 years. The adult controls were normal volunteers; the children had MRI for indications other than suspected CSF flow abnormalities. All patients had MRI within 4 months of ventriculostomy. Clinical follow-up took place between 6 weeks and 2 months, and continued for at least a year.

All patients initially underwent CT, establishing the diagnosis of hydrocephalus. Routine MRI was subsequently performed, consisting of sagittal and axial T1-weighted [500/20 (repetition time/echo time)] images, as well as axial proton-density and T2-weighted fast spin-echo (2500/17; 4000/102) images.

A commercially available phase-contrast sequence (cine PC) was utilized to examine the CSF pulsations retrospectively [11–13]. The postprocessing software was modified to reconstruct true instead of weighted phase images so that the velocities could be obtained directly from the signal intensities [11, 12]. On true phase images, the areas containing bone and air appear noisier than on weighted phase images. The signal-to-noise in other part of the image, however, is unchanged. To eliminate additive errors produced by gradient-induced eddy currents, actual velocity values from these images were obtained by subtracting the average value of a neighboring brain region [11–14]. The time-points acquired during the cardiac cycle varied according to the heart rate of the subject [11].

Sagittal midline cine phase-contrast flow studies were performed, showing the aqueduct, third and fourth ventricles, basal cisterns and cervical subarachnoid space to C4.

The technical factors for the cine PC sequences were: 50/11.5–12.8/2 (repetition time/echo time/excitations), 15 ° flip angle, 22 cm field of view. Matrix sizes 256 × 192-256 and image thickness 3 mm were employed. The velocity encoding was 5–10 cm/s. The direction of flow encoding for all studies was superior-inferior. Peripheral pulse (photo plethysmograph) triggering was used for detection of the R-wave of the cardiac cycle [13].

The phase images were transferred to a workstation for subsequent analysis. A cursor region of interest (ROI) consisting of 2 pixels was placed in the CSF at the following points (Fig. 1):

(1) inferior third ventricle, immediately above the interpeduncular fossa, in normals (a), and immediately above the ventriculostomy orifice in patients (b); (2) high pontine cistern, immediately below the pons-midbrain junction; and (3) anterior subarachnoid space immediately below the foramen magnum at about C1.

We attempted to place the ROI as centrally as possible within the latter two regions to minimize contamination by partial volume effects from the stationary nearby structures. Minor variations in individual anatomy (i. e., the course of the basilar artery within the pontine cistern) may account for subtle differences in ROI positioning at each site. The range of velocities, representing the sum of the maximum systolic (craniocaudal) and diastolic (caudocranial) velocities, was determined for each ROI. In order to normalize differences between individuals, ratios of the velocities in the third ventricle and in the pontine cistern to that in the anterior cervical subarachnoid space were also obtained. The results for the patients and controls were compared by ANOVA. A *P* value of less than 0.05 was considered significant.

Results

The velocities in the three ROI and the ratios for both patients and controls are shown in Table 1.

Velocities

Third ventricle floor: the mean velocity of the patients (32.9 mm/s) was significantly higher than that of the controls (4.31 mm/s).

Table 1 Measurements in 12 controls and six patients with ventriculostomies

Measurement	Controls		Patients
Velocity (mm/s)[a]			
at floor of third ventricle (3V)			
range	2.25–9.8		13–66
mean (SD)	4.3 (1.96)		32.9 (19)
P[b]		< 0.001	
in pontine cistern (PC)			
range	8–81		40–176
mean (SD)	37 (20)		88.3 (46)
P		0.004	
in anterior cervical subarachnoid space (SAS)			
range	28–89		35–93.8
mean (SD)	50.1 (16.8)		54.5 (23.5)
P		not significant	
Velocity ratios			
3V/SAS			
range	0.03–0.27		0.3–1.05
mean (SD)	0.1 (0.06)		0.64 (0.33)
P		< 0.001	
PC/SAS			
range	0.25–1.33		1.05–2.45
mean (SD)	0.73 (0.3)		1.68 (0.6)
P		0.001	

[a] Sum of maximum systolic and diastolic velocities

[b] ANOVA (all comparisons)

Pontine cistern: the mean velocity of the patients (88.3 mm/s) was again significantly higher than that in controls (37 mm/s).

Cervical subarachnoid CSF space: there was no significant difference between the mean velocity in patients (54.5 mm/s) and controls (50.1 mm/s).

Velocity ratios

Third Ventricle floor to cervical subarachnoid space: the mean ratio in patients (0.64) was significantly higher than in controls (0.1).

Pontine cistern to cervical subarachnoid space: the mean ratio in patients (1.68) was again significantly higher than in controls (0.73).

The ratios were higher for the pontine cistern than for the third ventricle in every patient.

Correlation of quantitative data with clinical follow-up

The histories, surgical outcome and velocity ratios of all patients are presented in Table 2.

All patients demonstrated initial clinical improvement. Patients 1 and 5 had lower velocity ratios than their fellows both at the third ventricular floor and in the pontine cistern. Patient 1 required a shunt 11 months later. Patient 5, with a thalamic tumor, remained symptom-free at 3 months. Patients 2–4 have remained stable for over a year.

Discussion

In normal individuals, systolic increase of the cerebral blood volume results in passage of CSF from the third ventricle, through the aqueduct into the fourth ventricle, and from the basal cisterns to the spinal canal. Diastolic decrease of the cerebral blood volume then allows CSF to return along the same pathways [11, 14]. This cardiac-cycle-related pulsatile bidirectional CSF motion through the aqueduct is impaired in patients with aqueduct stenosis, and the resulting physical strains may produce tissue damage and progressive hydrocephalus [15]. Third ventriculostomy provides an effective alternative internal pathway for the drainage of CSF from the third ventricle, eliminating the need for long-term extraventricular shunting with its potential mishaps such as shunt infection and migration [1–10]. CSF outflow is then from the inferior third ventricle into the interpeduncular fossa and pontine cistern, bypassing the cerebral aqueduct. The low resistance offered by the ventriculostomy orifice permits increased CSF pulsation during the cardiac cycle. This vigorous pulsatile motion can be viewed on a cine-loop to demonstrate patency of the ventriculostomy. We sought to quantitate the expected increased flow velocities, reflecting the increased CSF flow pulsation volumes, along the new route of egress.

Since preoperative CSF flow studies were not available on most of our patients, who underwent surgery on the basis of routine CT and MRI alone, subjects without overt disturbances of CSF circulation were used as a control group. As anticipated, velocities at the third ventricular floor and in the high pontine cistern were significantly higher in patients than in these controls. The velocities recorded anterior to the upper cervical spinal cord, further removed from the ventriculostomy orifice, did not differ significantly from those in controls, indicating that CSF dynamics were not altered at this level. We were therefore able to normalize the velocities at the third ventricular floor and in the pontine cistern by means of velocity ratios. These concurred with the velocity measurements, and may be more meaningful than actual velocities in the assessment of ventriculostomy patency, because they may compensate for both individual variations in flow velocities and for minor differences in positioning of the ROI.

In the patients, the velocities and velocity ratios were lower at the ventriculostomy than in the pontine cistern. This may be related both to turbulent flow at the ventriculostomy, and to anatomic differences between the interpeduncular fossa and pontine cisterns.

One of the patients with low velocities and ratios (patient 1) had undergone multiple prior shunt revisions

Table 2 Clinical findings and velocity ratios in six patients with ventriculostomies. Abbreviations as in Table 1

Patient	Sex/age (years)	Symptoms	Functioning shunt at time of study	Preoperative imaging (CT and MRI)	Surgical outcome	Velocity ratios	
						3V/SAS	SPC/SAS
1	F/23	Headache, papilledema	No	Hydrocephalus, large upper aqueduct, aqueduct stenosis	Improved (required shunt 11 months later)	0.28	1.06
2	M/3	Ataxia, tremors, developmental delay	No	Hydrocephalus, aqueduct stenosis	Improved	0.42	1.88
3	M/17	Headache, papilledema	No	Hydrocephalus, aqueduct stenosis	Improved	0.94	2.3
4	F/9	Headache, papilledema visual obscurations	No	Hydrocephalus, large upper aqueduct, aqueduct stenosis	Improved	1.05	1.33
5	F/22	Headache, photophobia, poor concentration	No	Hydrocephalus, left thalamus mass	Improved	0.34	1.05
6	M/69	Ataxia, incontinence, poor cognition	No	Hydrocephalus, aqueductal web, large upper aqueduct	Improved	0.82	2.44

for infection. Although she improved initially, subsequent deterioration required placement of a lateral ventricular shunt. A successful surgical result is dependent not only on patency of the ventriculostomy, but also on the adequate resorptive capacity of the arachnoid granulations [2–7]. If this were impaired, CSF flow through an otherwise patent ventriculostomy might cease. The low ratios in patient 1 may therefore reflect resorptive impairment at the arachnoid granulations. In patient 5 a third ventricular/thalamic tumor produced aqueduct stenosis. Her low velocities and ratios may reflect distortion and rigidity of the third ventricle floor, which can increase both resistance and turbulence at the ventriculostomy.

Both conventional spin-echo MRI and cine PC imaging have been employed to document ventriculostomy patency [1, 3–5, 8, 10]. Jack and Kelly [4] described a CSF flow void (indicative of rapid, turbulent flow) at the anterior/inferior third ventricle on T2-weighted images as indicating a functioning ventriculostomy. They noted, however, that the absence of a flow void does not necessarily preclude adequate function; Use of flow-compensation techniques, for example, may yield false-negative results. Furthermore, vigorous pulsation of the basilar artery may interfere with the interpretation by producing a flow void in the pontine cistern. Although there have been attempts to assess CSF flow void by measuring its extent [16] or the relative degree of signal loss [17], velocity measurements by motion-sensitive MRI methods should be more accurate in quantitating the to-and-fro motion of CSF [17].

The PC-MRI method we employed can be viewed in a cine loop. Researchers have demonstrated oscillatory motion through patent ventriculosomies utilizing this technique. Although the cine format may be sufficient for demonstrating patency, it is subjective. Measuring the actual velocities at various strategic sites can provide additional physiological and prognostic information. The cine PC images can be acquired in both sagittal and coronal planes to assess ventriculostomy flow. We believe that sagittal acquisitions have an added advantage of including the pontine cistern and cervical subarachnoid space. Valuable information can be gathered from these regions, as our analysis has shown. Furthermore, utilizing sagittal rather than the coronal images increases the likelihood of demonstrating the midline ventriculostomy.

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