Phase-Contrast Magnetic Resonance Imaging of Intracranial Shunt Tube: A Valuable Adjunct in the Diagnosis of Ventriculoperitoneal Shunt Malfunction

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Malfunctioning of ventriculoperitoneal shunts is arguably the most common reason for patients to seek medical attention in a pediatric neurosurgical facility. Clinical symptomatology and computed tomography (CT) scans of head remain the mainstay of diagnosis.[1] Invasive shunt tap for diagnosis of malfunction, along with cerebrospinal fluid (CSF) analysis, is often used as an extension of the management protocol for suspected shunt malfunction.[2] However, shunt malfunctions may result in raised intracranial tension without ventricular dilatation.[3] Conversely, it is not uncommon to find a normal-functioning shunt at the time of revision surgery. It is well documented that shunt revision is a significant detrimental factor for future shunt survival and related complications.[4] Unnecessary shunt revisions also result in increased financial burden on society, besides leading to increased morbidity and psychosocial trauma to patients and parents.

A noninvasive diagnostic modality for improving the yield in diagnosis of shunt malfunction has been an active field of research for decades. Some ingenious methods to assess shunt malfunction in the past included radioisotope injections through a shunt,[5] thermal conduction technique,[6] and an implanted bubble-generating device.[7] However, none has been used clinically because of the technical complexities and inherent drawbacks of these techniques. Drake et al[8] reported the use of phase-contrast magnetic resonance imaging (MRI) for shunt malfunction in the early 1990s; this research remained mainly experimental at that time.

With recent advances in MRI, phase-contrast MRI (cine MRI) has shown promise in assessing CSF flow in various conditions. This MR sequence has been shown to be useful for the evaluation of functional status of third ventriculostomy, aqueductal CSF flow velocities in hydrocephalic infants, and CSF flow across the foramen magnum in Chiari malformations.[9-12] This study aims to assess the efficacy of phase-contrast MRI in the diagnosis of shunt malfunction and its potential as an adjunct in the diagnostic algorithm for shunt malfunction in the emergency department.

MATERIALS AND METHODS

This prospective controlled study was carried out at a tertiary care university hospital over a period of 1 year. We wanted to test the hypothesis that flow velocities calculated with phase-contrast MRI of the intraparenchymal portion of the shunt tube inside the brain could be useful in assessing in suspected shunt malfunction. To test this hypothesis, patients were divided into 2 groups based on clinicoradiological presentation.

Test Group or Shunt Malfunction Group

The test (shunt malfunction) group included patients in whom a ventriculoperitoneal shunt had been placed for any primary pathology and who presented to the emergency department with an increase in ventricular size compared with the baseline scan on CT head and clinical symptoms suggestive of shunt malfunction, including headache, vomiting, altered sensorium, feeding difficulty, and fever. Patients were entered into the study after the surgeon decided on surgery to revise the shunt. Patients with a similar presentation who were not planned for surgery were excluded from the study.

Control Group or Functioning Shunt Group

This control group included asymptomatic patients who came to a routine follow-up outpatient clinic within 1 month of placement of a ventriculoperitoneal shunt and in whom a CT scan of the head showed well-decompressed ventricles compared with preoperative scans.

Only patients < 18 years of age were included in the study. Approval was obtained from the institutional ethics committee, and informed consent was given by the legal guardians of all study subjects.

Commercial shunt design, valve design, and pressure settings were not taken into consideration in both groups.

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Procedure

All study patients in both groups underwent phase-contrast MRI by a single radiologist using 1 machine (Philips Intera, 1.5 T) and standard parameters (repetition time, 17 milliseconds; echo time, 8 milliseconds; field of view, 80 mm; flip angle, 15°; matrix, 256 × 256; phase-coding velocity, 10 cm/ s). Velocities and flow parameters were calculated with the built-in Intera Release 10.6 Windows-based software. Before the actual imaging, all patients were asked to be kept in the supine position for at least 1 hour to avoid gravitational overdrainage just before imaging. Patients were sedated with oral syrup promethazine if required. No anesthesia was used in any child. Initially, T2-weighted coronal sections of the brain were acquired, and the shunt tube was traced in its intraparenchymal course. The region of interest was defined across the area of the shunt tube, and the predetermined phase-contrast MRI sequence was run to obtain the CSF flow parameters across the tube. Sequence run time was approximately 6 minutes, with total imaging time < 15 minutes in routine cases.

All patients in the test group underwent the previously planned shunt revision surgery after the MRI, regardless of MRI findings. The operating surgeons were blinded to the phase-contrast MRI findings.

RESULTS

Seventeen patients with a mean age of 5.2 ± 4.1 years (range, 0.25-15 years) were studied: 9 in the shunt malfunction (test) group and 8 in the control group. The primary pathology for which the shunt has been placed included congenital hydrocephalus with aqueductal stenosis (n = 11), postmeningitic hydrocephalus (n = 3), tubercular meningitis sequelae (n = 2), and posterior fossa tumor (n = 1).

The mean area across which velocities were measured was 1.65 ± 0.22 mm^2, which corresponded closely to the internal cross-sectional area of the shunt tube. The peak velocities (0.38 ± 0.98 cm/s) and mean velocities (0.24 ± 0.66 cm/s) in the test group (Figure 1) differed significantly from the peak velocities (1.62 ± 1.41 cm/s) and mean

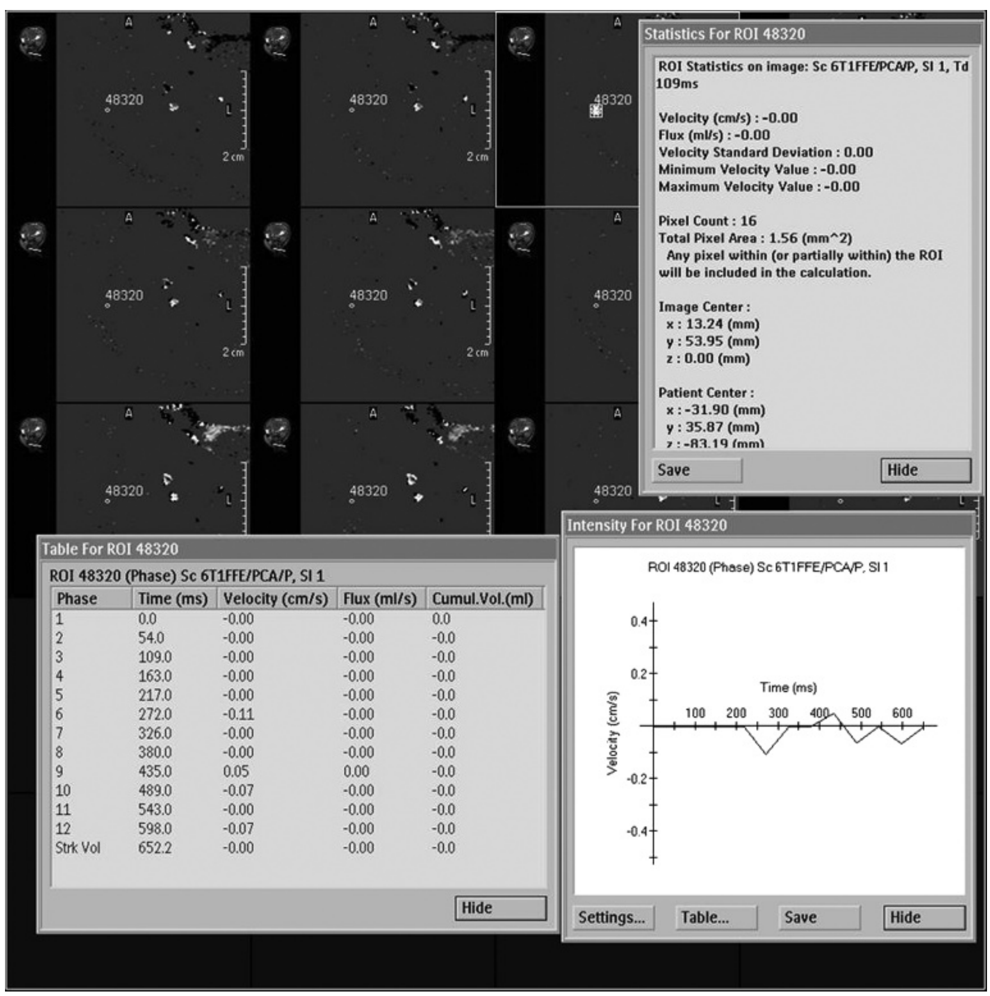

FIGURE 1. Magnetic resonance imaging details of the patient with suspected shunt malfunction. There is no net CSF flow across the shunt tube, reflected by the null velocities calculated from the MRI findings. The graph also shows almost no pulsatility of the CSF column across the shunt tube. Shunt was also found to be nonfunctional at surgery.

velocities (0.78 ± 0.66 cm/s) in the control group (Figure 2; $P = .01$, $P = .002$, respectively).

Intraoperatively, shunt block at either the upper or lower end was physically confirmed by the operating surgeons in all but 1 patient. In this patient, free flow of CSF was observed once the lower end was taken out of the peritoneal cavity.

DISCUSSION

The rate of shunt malfunction has been documented to be as high as 27% in the first year of implantation, with more than half of the patients with uncomplicated shunt placement undergoing shunt revision surgery within 2 years of placement.[4-13] Its diagnosis remained a challenge for neurosurgeons. Clinical symptoms suggestive of shunt malfunction in children include headache, vomiting, altered sensorium, feeding difficulty, and fever. However, the clinical symptoms often are vague and the radiology is equivocal, which leads to problems in diagnosis. Undue shunt revisions lead to economic and psychosocial trauma to patients, besides increasing the procedural morbidity. Cardiac gated phase-contrast MRI seems to offer a potential advantage in these cases.

In recent years, phase-contrast MRI has shown promise in the evaluation of CSF flow dynamics in various conditions like third ventriculostomy and Chiari malformations. Quantification of CSF flow across the third ventriculostomy in terms of stroke volume, velocities, and pulsatility has also been correlated with outcome, and stroke volumes across the stoma were reported to be the reliable indicator in predicting outcomes.[14] Quantifications of CSF flow across the aqueduct have been used for research and clinical purposes. The dynamics of CSF around the foramen magnum in Chiari malformations is also a part of some management algorithms for asymptomatic Chiari malformations.[15] In 1991, Drake et al[8] pioneered the concept of using phase-contrast MRI to determine CSF flow across the abdominal part of the shunt tube in blocked and functional shunts. Using a 1.5-T MRI, they imaged the extracranial segment of shunt tube distal to reservoir with a surface coil and showed the absence of CSF

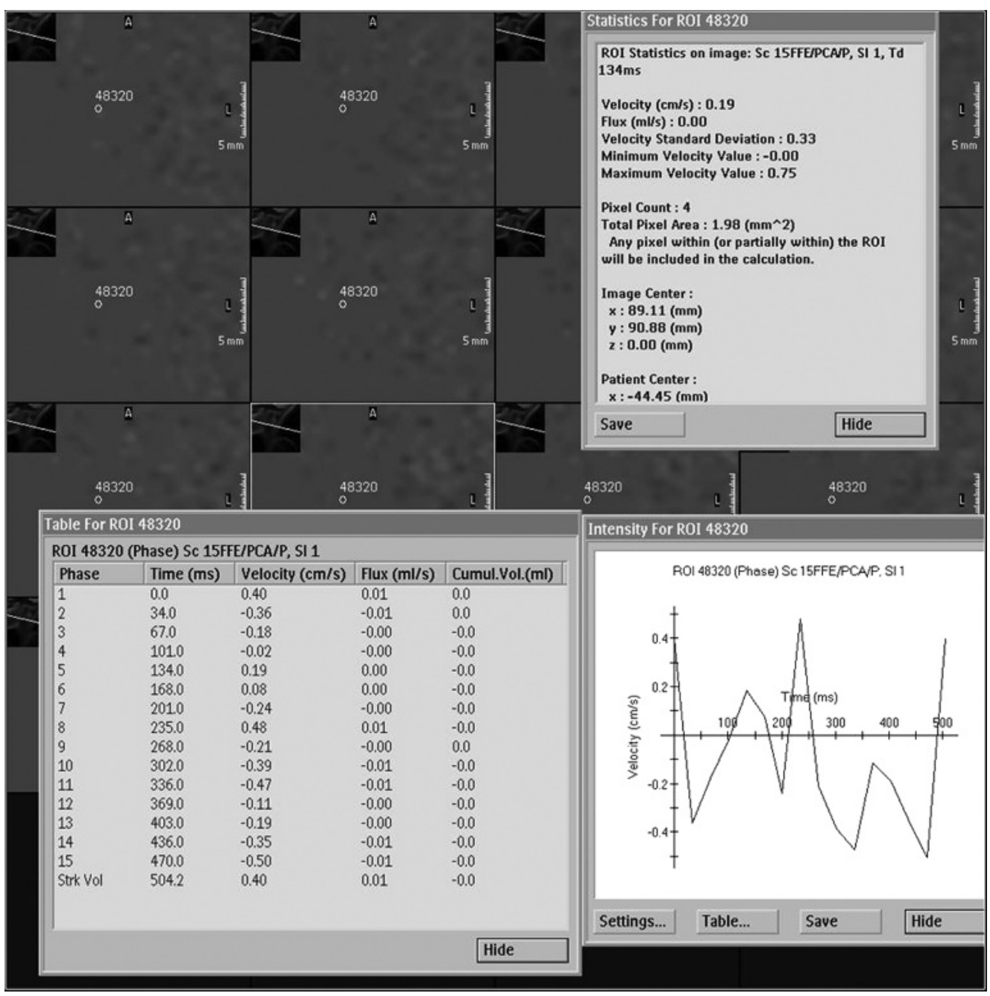

FIGURE 2. Phase-contrast MRI details of the well-functioning shunt system. Calculated peak and mean velocities indicate good CSF flow across the shunt tube and hence a functioning shunts. Pulsatility of the CSF column also indicates the CSF flow.

flow in the blocked shunts. Flow rates of 3 to 40 cm^3/h were observed in functional shunts, validating the usefulness of this technique in suspected shunt malfunction.

In our study, the peak velocities and mean velocities in test group differed significantly from the peak and mean velocities in the control group. This implies that patients with high peak velocities can be safely said to have a patent shunt. Patients with no flow can similarly be said to have shunt malfunction. However, low peak velocities by default do not imply a shunt malfunction. We could not define a ''cutoff'' value for peak and mean velocities to diagnose shunt malfunction because of the small sample size; this remains to be defined in future studies. The graphical representation of CSF velocities showed reversal of flow in the cardiac cycle based on the pulsatility of blood flow. However, we have considered only net mean velocities calculated by the software. Stroke volumes can also be calculated by the software; however, at the time of this study, we could not validate the reliability of these parameters owing to the small sample size. A previous study on the assessment of third ventriculostomy by cine-phase MRI could not find any correlation between stroke volumes or grading of flow voids and clinical outcomes.[16] Interpretation of graphical CSF velocities at various points of cardiac cycle will require more data points and experience with this technique. Nevertheless, as our study shows, phase-contrast MRI may be a helpful technique in patients with suspected shunt malfunction.

In our study, the gold standard for shunt malfunction was taken as ''intraoperative findings.'' Shunt block at either the upper or lower end was physically confirmed by the operating surgeon(s) in all but 1 patient. In this patient, free flow of CSF was observed once the lower end was taken out of the peritoneal cavity, and the possibility of omentum plugging the shunt cannot be ruled out. Although phase-contrast MRI findings were in concordance with the operative finding of shunt malfunction in all cases, sensitivity and specificity cannot be commented on because of the small sample size.

Procedural Issues

Gravity has a major effect on CSF drainage unless some type of antisiphon device is installed as part of the shunt insertion. None of our patients had an antisiphon device. We kept patients in a supine position for a minimum of 1 hour before imaging to avoid the gravity-related overdrainage or siphoning of CSF.

The shunt tube is a very small structure, and fixing the region of interest across the cross-sectional area of the shunt tube can cause errors. To ensure internal validity, we calculated the area across which we measured the CSF velocities to ensure that this area corresponded with the calculated internal area of shunt tube.

Because the study population was pediatric, movement artifacts were the major concern before the start of the study. However, all the patients responded well to syrup promethazine, and none required anesthesia. Imaging never had to be abandoned because of these issues. The planning and execution of MRI imaging took about 15 minutes in all cases with a phase-contrast sequence of about 6 minutes.

Study Limitations

Small study size remains the inherent limitation of the study, with heterogeneity in pathologies and shunt systems with different valve pressures. Because we calculated flow in the intraparenchymal part of the shunt tube inside the brain, we believe that the results of this study are valid and accurately reflect the functional status of the ventriculoperitoneal shunt.

CONCLUSIONS

Cerebrospinal fluid velocities calculated across the intraparenchymal portion of the shunt by phase-contrast MRI may reliably reflect the functional status of a ventriculoperitoneal shunt. Phase-contrast MRI can be useful in patients with suspected shunt malfunction. This simple, quick, cheap, and noninvasive investigation can improve the diagnosis of shunt malfunction.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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