ORIGINAL ARTICLE

Role of MRI CSF Flowmetry in Evaluation of Different Pediatric Neurological Diseases

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Abstract

Background: ***For CSF flow dynamics evaluation, phase contrast MRI is frequently applied in conditions such as communicating hydrocephalus, non-communicating hydrocephalus, and post-neurosurgical scenarios.***

Subjects and methods: ***28 patients (7 males and 21 females) aged 4 months to 15 years were referred to the MRI department at Al Zahraa University Hospitals. Participants were grouped into three categories according to clinical observations and conventional MRI results: communicating hydrocephalus, non-communicating hydrocephalus caused by aqueductal stenosis, and non-communicating hydrocephalus managed with a ventriculoperitoneal (VP) shunt.***

Results: ***Regarding communicating hydrocephalus, it is indicated by increased T2 flow void at the aqueduct of Sylvius (3D-DRIVE) and verified by the detection of CSF flow at the aqueduct of Sylvius on PCMRI. All individuals with suspected aqueductal stenosis showed absence aqueduct of Sylvius flow void by 3D-Drive and no CSF flow at the aqueduct of sylvius by PCMRI. Regarding patients who had ETV, 12 patients had jets of CSF flow through ventriculostomy, and 4 patients had inadequate CSF flow through the stoma, which was detected by PC-MRI. Regarding patients who had a VP shunt by PCMRI, one of them has a functioning shunt, and 2 patients have a nonfunctioning shunt by detection of CSF flow through the shunt.***

Conclusion: ***We suggest utilizing phase-contrast MRI in all cases that have ETV and VP shunt as it can detect its function that is the gold stander role of our recommended technique.***

Keywords: Phase contrast MRI; ETV; VP shunt

1. Introduction

The brain's ventricles and the subarachnoid spaces of the skull and spine (between the arachnoid mater and pia mater) contain the clear, colorless plasma ultrafiltrate known as cerebrospinal fluid (CSF). The subarachnoid spaces (125 ml) and ventricles (25 ml) contain an average CSF volume of 150 ml. The physiological values of CSF pressure, which determines intracranial pressure, range from 3 to 4 mmHg before the age of one year and from 10 to 15 mmHg in adults. A dynamic pressure system is the CSF space.[1]

The majority of CSF is made up of water (99%), with proteins, ions, neurotransmitters, and glucose making up the remaining 1%. [2]

One of the main uses of phase-contrast MRI is the study of CSF flow because it offers both qualitative and quantitative evaluation of a moving fluid. Bipolar gradients, which have the same positive and negative magnitude and application time for both, are the foundation of PC-MRI. They are positioned in a sequence following the radiofrequency pulse and prior to data collection during echo time (TE). The image becomes sensitive to the flow in only one direction if the bipolar gradient is applied on only one axis. In order to create a sequence that is sensitive to flow in any direction, it is necessary to apply the bipolar gradient in all three axes. The bipolar gradient's basic idea is to create a phase shift in spins traveling along the axis at a particular speed. The flow velocity and application time of the bipolar gradient are directly correlated with the amount of acquired net phase shift .[3]

Accepted 19 January 2025.
Available online 31 March 2025

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https://doi.org/10.21608/aimj.2025.446495
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An easy and non-invasive way to diagnose and monitor various neurological conditions that may result in aberrant CSF flow is by MRI CSF flowmetry .[4]

In non-communicating hydrocephalus, obstruction can result from synechiae within the ventricles or basal cisterns, or it may occur at the aqueduct of Sylvius, the fourth ventricular exit foramina, or the foramen of Monro. Due to its narrow caliber, the principal location of obstruction is the Aqueduct of Sylvius. This may be developed as a result of external compression or post-inflammatory adhesions, or it may be caused by congenital stenosis.[5]

Since there would be no CSF flow through the aqueduct of Sylvius and the curve would be uneven, phase-contrast imaging can identify the obstruction site and aid in the diagnosis of CSF flow obstruction .[4]

Hydrocephalus that communicates suggests that there is no blockage in the ventricles or cisterns. It is plausible that lower intracranial compliance causes an increase in the aqueductal CSF flow void in communicative hydrocephalus .[6]

Sagittal phase images obtained through PCMRI demonstrated significant cerebrospinal fluid (CSF) flow through the aqueduct of Sylvius during both systole and diastole, while T2 DRIVE images confirmed a patent aqueduct, ruling out occlusion in communicating hydrocephalus individuals .[5]

Phase-contrast and 3D-DRIVE sequences are highly reliable for evaluating the flow through the third ventricle's floor and accurately identifying ventriculostomy dysfunction. It was discovered that a trustworthy indicator for the functional evaluation of third ventriculostomy was the existence of a flow void across the third ventricle's floor .[6]

A VP Shunt is a procedure where an outflow catheter is placed in the peritoneal cavity and an inflow catheter with a pressure-sensitive valve—which is in charge of draining any surplus CSF—is placed into the ventricles. PC-MRI can be utilized to assess the patency of the shunt due to its unidirectional, pulsatile flow. In addition to being shown to maintain patency, PC-MRI has also been considered as a possible postoperative outcome prediction technique .[3]

Aim of work: Detecting how MRI CSF flowmetry is utilized for evaluating pediatric CSF anomalies.

2. Patients and methods

This prospective study was conducted from October 2022 to April 2024, enrolling a total of 28 patients, comprising 21 females and 7 males. Their mean age ranged from 4 months to 15 years. They were referred from the pediatric department to the MRI department at Al Zahraa University Hospitals. Every participant underwent an MRI on a 1.5 Tesla (Philips Ingenia) machine, which is a closed magnet. All MRI scans were conducted utilizing a conventional head coil. The participants were categorized into the following subgroups in accordance with clinical findings and conventional MRI results: Communicating hydrocephalus (4 patients newly diagnosed and 2 patients underwent ETV), Non communicating hydrocephalus due to aqueductal stenosis (4 patients newly diagnosed and 14 patients underwent ETV), Non communicating hydrocephalus with VP shunt (3 patients diagnosed as aqueductal stenosis and one diagnosed as Chiari malformation type II).

Statistical Analysis

Version 27 of IBM SPSS, the Statistical Package for Social Science, was used to collect, edit, code, and enter the data. When the quantitative data were determined to be non-parametric, they were displayed as the median and inter-quartile range (IQR). Qualitative variables were also displayed as percentages and numbers. A variable's normality can be checked using the one-sample Kolmogorov-Smirnov test. The qualitative data from each group was compared utilizing the Chi-square test and/or Fisher exact test where the expected count in any cell was less than 5. In order to evaluate conventional MRI in the detection of ETV, the receiver operating characteristic curve (ROC) was utilized for determining the optimal cutoff point based on its sensitivity, specificity, positive predictive value, negative predictive value, and area under the curve (AUC).

3. Results

Table 1. Conventional MRI findings among the studied patients

CONVENTIONAL MRI FINDINGS	NO. = 28
MODERATE SUPRA AND MILD INFRATENTORIAL VENTRICULAR DILATATION	1 (3.6%)
MARKED SUPRA AND INFRAVENTRICULAR DILATATION	1 (3.6%)
MODERATE SUPRA AND INFTA TENTORIAL VENTRICULAR DILATATION	2 (7.1%)
MILD SUPRATENTORIAL VENTRICULAR DILATATION	5 (17.9%)
MODERATE SUPRATENTORIAL VENTRICULARDILATION	8 (28.6%)
MARKED SUPRATENTORIAL VENTRICULAR DILATATION	9 (32.1%)
MODERATE SUPRA AND INFRA TENTORIAL VENTRICULAR DILATATION	1 (3.6%)
MARKED PAN VENTRICULAR DILATATION WITH BANDS AT FORAMINA OF LUCHKA AND MAGENDI	1 (3.6%)

Table 2. Description of CSF flow findings among the studied patients

FLOWMETRY ASSESSMENT	COMMUNICATING HYDROCEPHALUS	NON COMMUNICATING HYDROCEPHALUS	ETV	VP SHUNT	TEST VALUE	P-VALUE	SIG.
	No. = 4	No. = 4	No. = 16	No. = 4			
	4 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	84.000*	0.000	HS
	0 (0.0%)	4 (100.0%)	0 (0.0%)	0 (0.0%)			
	0 (0.0%)	0 (0.0%)	1 (6.3%)	0 (0.0%)			
	0 (0.0%)	0 (0.0%)	11 (68.8%)	0 (0.0%)			
	0 (0.0%)	0 (0.0%)	3 (18.8%)	0 (0.0%)			
	0 (0.0%)	0 (0.0%)	1 (6.3%)	0 (0.0%)			
	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (75.0%)			
	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (25.0%)			

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

*: Chi-square test

Table 3. Percentage of aqueductal patency among the studied patients

		NO. = 28
AQUEDUCTAL PATENCY	Patent	6 (21.4%)
	Obstructed	22 (78.6%)

Table 4. Comparison between conventional MRI and CSF flowmetry to detect ETV among the studied patients

		CONVENTIONAL MRI	MRI CSF FLOWMETRY	TEST VALUE	P-VALUE	SIG.
		No. = 16	No. = 16			
ETV	Patent	16 (100.0%)	12 (75.0%)	4.571*	0.033	S
	Occluded	0 (0.0%)	4 (25.0%)			

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant

*: Chi-square test

Table 5. Relation between conventional MRI and CSF flowmetry in detection of ETV among the studied patients

		ETV IN MRI CSF FLOWMETRY (GOLD)		TEST VALUE	P-VALUE	SIG.
		Patent	Occluded			
		No. = 12	No. = 4			
ETV IN CONVENTIONAL MRI	Patent	12 (100.0%)	4 (100.0%)	–	–	–
	Occluded	0 (0.0%)	0 (0.0%)			

	TP	TN	FP	FN	Sensitivity	Specificity	PPV	NPV	Accuracy
ETV	0	12	0	4	0.0%	100.0%	0.0%	75.0%	0.750

TP: True positive; TN: True negative; FP: False positive; FN: False negative; PPV: Positive predictive value; NPV: Negative predictive value

A 6-year-old girl patient had convulsions, delayed speech and walking, and hydrocephalus (Evan index =0.44) on MRI (a) axial T2 WI at the lateral ventricle level. b) Sagittal T2 WI with the blue arrow indicating the signal void sign at the aqueduct. (C) Patent typical aqueduct in a 3D DRIVE picture. (d) Systolic sagittal phase picture displaying CSF flow in the Sylvius aqueduct as white hues.

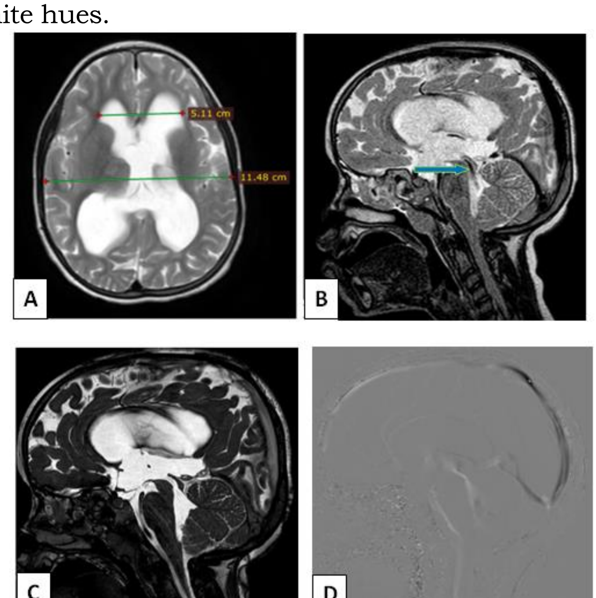
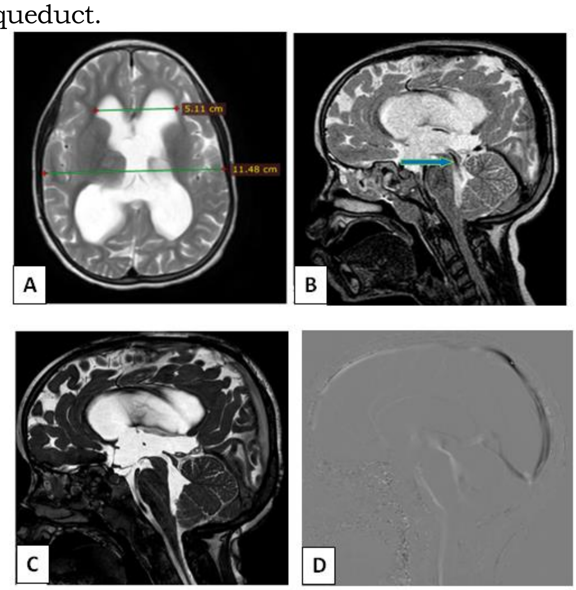


Figure 1. For follow-up, a 9-month-old female patient with a history of aqueductal stenosis had an ETV. Axial T2 WI at the lateral ventricle level on MRI (a) demonstrates hydrocephalus (Evan index = 0.69). b) Sagittal 3D DRIVE picture displaying an aqueduct obstruction. The sagittal magnitude image at ETV displays the CSF jet. (d) Systolic sagittal phase image demonstrating neither CSF jet at ETV nor CSF flow in the aqueduct.



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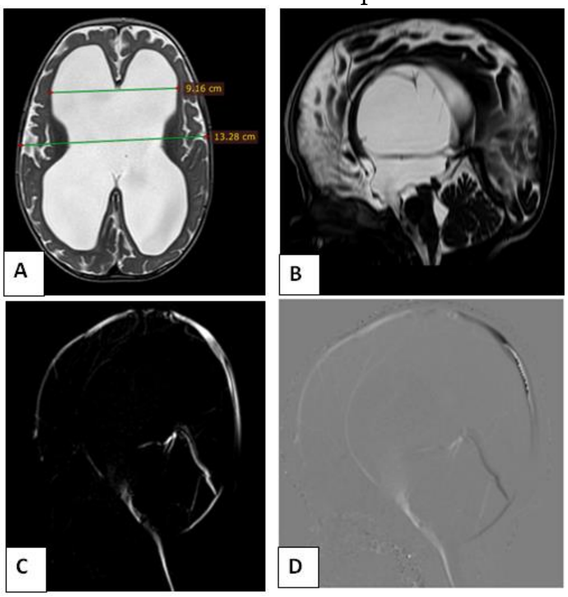

Phase contrast MRI protocol

Axial fluid attenuation inversion recovery (FLAIR), sagittal T1-weighted images (T1-WI), and brain imaging with T2-weighting in both the axial and coronal planes should all be part of the MRI protocol. The sagittal plane is used to capture a high-resolution, strongly T2-weighted volumetric sequence, often known as three-dimensional driven equilibrium, or 3D-DRIVE. The field of view stretches from Luschka's left foramen to its right. When intracranial neoplasms or suspected inflammatory processes are present, post-contrast T1-WI can be obtained in three planes. To more accurately identify cerebral hemorrhage as the source of hydrocephalus, axial T2*-WI may be obtained. 6

A localizer was positioned perpendicular to the Sylvius aqueduct in the midsagittal image; it should have passed through the aqueduct in the axial plane.7,6

The pulsatile flow of CSF during the cardiac cycle can be seen in a cine phase-contrast sequence. To track the CSF flow via the aqueduct and basal subarachnoid regions, it can be obtained in sagittal section (qualitative examination). Additionally, it can be obtained in an axial segment for quantitative evaluation, which measures the flow of CSF.6

Lowing CSF is depicted as a bright signal in the magnitude image, while suppressed stationary tissues are seen as a dark background. White and black signals, respectively, indicate forward and backward flows in the phase picture, which is phase-shift encoded (through-plane or in-plane). It includes the velocity information, which is quantitatively estimable and phase-dependent. PC MRI gating with the cardiac cycle allows for the depiction of pulsatile CSF flow in both types of imaging.3

In a single cardiac cycle, phase contrast pictures were acquired. At various cardiac phases, a number of phase and magnitude pictures were acquired. All of the photos were moved to the workstation apparatus using Q flow software following the data gathering. Following picture magnification to make the flow more visible, a region of interest was manually created to encompass all pixels on the phase images that reflected the CSF flow signals; the CSF flow parameters were then automatically retrieved.7

4. Discussion

Many neurological symptoms and indicators occur as a result of anomalies in CSF dynamics caused by various neurological illnesses.[5]

These diseases include communicating hydrocephalus and non-communicating hydrocephalus.[7]

All of the aforementioned neurological disorders can have their CSF flow abnormalities evaluated both qualitatively and quantitatively using phase contrast MRI CSF flowmetry .[7]

There are 28 people in this study who have been diagnosed with hydrocephalus. There are seven boys and twenty-one females, ranging in age from four months to fifteen years.

Tetraventricular dilatation on standard MR imaging is frequently used to imply the diagnosis of communicating hydrocephalus, and CSF flow at the aqueduct of Sylvius on PCMRI is used to confirm it .[5]

In our work, the patients with communicative hydrocephalus are assessed by PCMRI and conventional MRI, and CSF flowmetry shows a notable CSF flow through the Sylvius aqueduct.

Due to its narrow caliber, the principal location of obstruction is the Aqueduct of Sylvius. This may be acquired as a result of external compression or post-inflammatory adhesions, or it may be secondary to congenital stenosis .[5]

The obstructed/stenosed aqueduct can be precisely depicted and its morphology (either tubular narrowing, focal obstruction/stenosis, or associated proximal funneling) described using 3D-DRIVE .[5]

The absence of a T2 flow signal on sagittal T2 images is considered a complementary indication of aqueduct obstruction, but it is not a good indicator because the intensity of the flow signal relies on a number of variables, including the aqueduct's diameter, the CSF's velocity, and the PCMRI section thickness. This indication may be mild or nonexistent if the aqueduct is physiologically thin but not stenosed .[5]

All of the patients with suspected aqueductal stenosis in this investigation had supraventricular dilatation on conventional MRI, no flow void at the Sylvius aqueduct on 3D-Drive, and no CSF flow at the Sylvius aqueduct on PCMRI.

These findings are consistent with those of El-Sayed Sakr et al.[5] and Ahmad et al.[7] who similarly diagnosed aqueductal stenosis in their studies by observing conventional MRI results and the absence of CSF flow through the aqueduct of Sylvius on phase-contrast imaging.

The evaluation of the flow through the third ventricle's floor using Hase-contrast and 3D-DRIVE sequences is highly reliable when ventriculostomy dysfunction is correctly identified. PCMRI was discovered to be a valid sign for the functional evaluation of third ventriculostomy, in addition to the existence of a flow void across the third ventricle's floor .[6]

In our study there are 16 patients underwent ETV. By conventional MRI, All the 16 patients have dilated third ventricle with bulging floor & lamina terminalis as well as opened recesses (evidence of 3rd ventriculostomy opening related to its floor) measuring ranging from 4 – 10 mm. But 12 patients have jet of CSF flow through ventriculostomy and 4 patients have inadequate CSF flow through the stoma that can be detected by PC-MRI.

This is the gold standard role of the PCMRI, as it can detect the CSF dynamics through the ETV.

These findings align with those of Korbecki et al.[3] and Mohammad et al.[6] who studied the patency of ETV.

During a VPS surgery, an outflow catheter is placed in the peritoneal cavity, and an inflow catheter with a pressure-sensitive valve—which is in charge of draining any extra CSF—is placed into the ventricles. Because of the unidirectional, pulsatile flow, PC-MRI can be used to assess the shunt's patency. [3]

In our study, there are 4 patient who have VP shunts, by conventional MRI, 3 of the patients' shunt in their normal place at the right lateral ventricle and one patient has a VP shunt out of its normal place.

But by PCMRI, one of them has a functioning shunt, and the other 2 patients have a non-functioning shunt by detection of CSF flow through the shunt.

And this is also a gold stander role of PCMRI as it can detect the CSF dynamics through the shunt.

These findings were in agreement with those of Korbecki et al.[3] who studied the functioning and malfunction of the VP shunts.

Limitations: We can get better results with more sample size as this study is a limited study that evaluate only 28 pediatric patients. We also need to study pediatric patients who are diagnosed with Chiari malformations, arachnoid cysts, and achondroplasia.

4. Conclusion

This study found that phase contrast MRI-based CSF flowmetry plays a critical role in differentiating between pediatric hydrocephalus types and is a gold standard since it can identify CSF dynamics through the shunt and ETV.

Disclosure

The authors have no financial interest to declare in relation to the content of this article.

Authorship

All authors have a substantial contribution to the article

Funding

No Funds : Yes

Conflicts of interest

There are no conflicts of interest.

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