

## Role of MRI CSF Flowmetry in Evaluation of Hydrocephalus in Pediatric Patients

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### ABSTRACT

**Background:** phase contrast MR imaging is a rapid, simple and non-invasive technique which is sensitive to even small CSF flows, and can be used to evaluate CSF flow both qualitatively and quantitatively. Cine phase contrast MR images show CSF flow in a dynamic, more easily appreciable, and in a more pleasing manner, allowing the delineation of obstruction, if present, along the portions of CSF pathway where obstruction is common (foramen of Monro, aqueduct of Sylvius)

**Patients and Methods:** the study includes 20 patients from the pediatric population with ventriculomegaly (diagnosed by a radiological report) referred from Ain Shams Pediatric Hospital, Neurosurgery department at Ain Shams University, clinic, and outpatients. Control group of 20 pediatric patients of matched age group underwent CSF flow study to obtain normal reference values. These patients had no hydrocephalus and came to our institute to undergo MRI for other neurological causes. CSF flowmetry was added to their study after obtaining oral informed consent from their parents.

**Results:** our study included 20 patients, 8 males and 12 females, with age range 2 months - 12 years and average age 3.5 years old. All patients included were diagnosed with hydrocephalus by a previous radiological report. All patients underwent conventional MRI brain and CSF flowmetry. Patients were given diagnosis based on findings of conventional MR images, and were categorized into groups according to their underlying etiologies. 9 patients had aqueductal stenosis, 4 patients had atrophy, 2 patients had communicating hydrocephalus, 2 patients had Arnold Chiari malformation, 1 patient had Dandy-Walker variant, 1 patient had obstruction at foramen of Monro, and 1 had obstruction at foramen of Magendi. CSF flowmetry was added to evaluate the cause of hydrocephalus.

**Conclusion:** phase contrast MR imaging is a rapid, simple and non-invasive technique which is sensitive to even small CSF flows, and can be used to evaluate CSF flow both qualitatively and quantitatively, and could be used in conjunction with conventional MRI in assessment of cases of hydrocephalus.

**Keywords:** hydrocephalus, pediatrics, Phase contrast MRI.

### INTRODUCTION

Hydrocephalus could be defined as disturbance of formation, flow or absorption of CSF. In infants, it leads to progressive macrocephaly, while in childhood the patient may present with signs of increased intracranial tension. It's classified into communicating and non-communicating/obstructive hydrocephalus<sup>(1)</sup>.

Phase contrast MR imaging is a rapid, simple and non-invasive technique which is sensitive to even small CSF flows, and can be used to evaluate CSF flow both qualitatively and quantitatively. Cine phase contrast MR images show CSF flow in a dynamic, more easily appreciable, and in a more pleasing manner, allowing the delineation of obstruction, if present, along the portions of CSF pathway where obstruction is common (foramen of Monro, aqueduct of Sylvius)<sup>(2)</sup>.

CSF flow measurement at the suspected level of obstruction gives reliable and reproducible results for more accurate diagnosis,

and can be used to guide therapeutic decisions in a more reliable manner, and follow up post treatment outcome<sup>(3)</sup>.

### AIM OF THE STUDY

to demonstrate the role of CSF flowmetry using phase contrast MRI in evaluation of hydrocephalus in pediatric population.

### PATIENTS AND METHODS

The study includes 20 patients from the pediatric population with ventriculomegaly (diagnosed by a radiological report) referred from Ain Shams Pediatric Hospital and Neurosurgery department clinic.

#### *Inclusion criteria*

- Patients with range of age between 1-18 years old diagnosed with hydrocephalus (clinically and radiologically).
- No gender predilection.

**Exclusion criteria**

- Patients known to have contraindications for MRI, e.g. an implanted magnetic device, pacemakers or claustrophobia.

- Patients above 18 years old.

Control group of 20 pediatric patients of matched age group underwent CSF flow study to obtain normal reference values. These patients had no hydrocephalus and came to our institute to undergo MRI for other neurological causes. CSF flowmetry was added to their study after obtaining oral informed consent from their parents.

**Ethical considerations:**

**The study was done after approval of ethical board of Ain Shams university and an informed written consent was taken from each participant in the study.**

**Patient preparation:**

- Detailed explanation of the procedure to the parents/patient.

- Obtaining informed consent from the parents.

NB: children who are not able to maintain stationary position on the MRI table throughout the whole procedure time will be referred to an attending anesthesiologist who will be responsible for administration of sedative and any preparation and examination required prior to sedation.

**Technique and MR imaging data acquisition:**

- The study was performed on 1.5 Tesla MRI machine using cardiac-gated cine-phase contrast MRI technique and CSF quantification software.

- Patient lie in supine position, using head coil, on MRI table.

- All patients underwent routine MR brain imaging, including:

\* axial DWI: TR = 3700 ms, TE = 108 ms.

\* axial FLAIR WIs: TR= 11000 ms, TE = 140 ms, TI =2800 ms.

\* axial T2WIs: TE =120 ms , TR =4130.

\* axial T1WIs: TE =10 ms , TR = 538 ms.

and additional sagittal T2WIs.

- All patients had phase contrast MR imaging sequence added to the conventional brain MR imaging protocol.

- Phase contrast MR images were gated to the cardiac cycle by ECG, so that the frames obtained covers the entire cardiac cycle.

- Sagittal and axial phase contrast MR imaging were performed with the following acquisition parameters:

\* Flip angle: 10 degrees.

\* TR/TE: 21/6.8.

\*section thickness: 10 mm.

\* FOV: AP 190.

\* matrix size: 236x182.

\* encoding velocity: 8-12 cm/s (varied according to expected velocity in each patient).

\* encoding direction: cranio-caudal or caudocranial.

**Image Interpretation:**

*Conventional MR images*

- For descriptive purposes, conventional MR images was reviewed for:

\* Signs of hydrocephalus (lateral ventricular dilatation, 3<sup>rd</sup> or 4<sup>th</sup> ventricular dilatation).

\* Presence or absence of aqueductal flow void on T2 WIs.

\* Underlying cause for hydrocephalus (if present).

*Phase contrast MR images*

- Images were analyzed qualitatively for abnormal patterns of flow such as attenuated, flow, signal inhomogeneity, simultaneous bidirectional flow.

- Images were analyzed quantitatively in terms of the following parameters obtained at different levels of flow quantification:

Velocity Parameters

\* Peak systolic velocity (PSV).

\* Peak diastolic velocity (PDV).

\* Mean peak velocities (MPV).

**Statistical analysis**

Phase contrast imaging is performed in two planes; one in the sagittal plane for qualitative assessment of CSF flow, and one in the axial plane for quantitative assessment of CSF flow. For the axial images, a plane perpendicular to the axis of the area of interest is selected for imaging (e.g. aqueduct of Sylvius or foramen magnum). For the sagittal images, mid-sagittal plane is chosen for imaging to better demonstrate the aqueduct of Sylvius. Depending on the direction of the velocity encoding; whether it cranio-caudal or caudocranial, systolic CSF flow which occurs in a caudal direction may appear bright or dark respectively and diastolic flow which occurs in a cranial direction may appear dark or bright respectively<sup>(4)</sup>.

CSF flow is pulsatile and synchronous with the cardiac cycle, therefore cardiac gating can be used to provide increased sensitivity. By synchronizing the acquisition with the cardiac cycle, the series of images generated contains velocity information that can be mapped to the phases of the heartbeat. From this, velocity can

be plotted as a function of the cardiac cycle, providing the ability to calculate stroke volume, flow rate, mean velocity, and peak systolic/diastolic flow. The measurements obtained from PC acquisitions are the result

from data collected over a large number of cardiac cycles. The final velocity waveform represents an average measurement of those cycles, but it is presented as one cycle<sup>(5)</sup>.

**RESULTS**

**Findings of CSF flowmetry**

Aqueductal stenosis

- Quantitative:

**Table 1 : Quantitative values of aqueductal stenosis**

Parameters	Aqueductal stenosis average values	Healthy individuals average values	P value (<0.05)*
PSV (cm/s)	1.49	6.43	0.004868*
PDV (cm/s)	1.24	6.14	0.006233*
MPV (cm/s)	1.37	6.26	0.005135*

- Qualitative:

All patients showed no flow through the aqueduct of Sylvius on systole and diastole, with normal flow through the foramen magnum. 3 of the patients underwent surgical ETV, with all of them showing positive flow through the its site.

**Communicating hydrocephalus**

- Quantitative:

**Table 2: Quantitative values of communicating hydrocephalus**

Parameters	Comuunicating hydrocephalus average values	Healthy individuals average values	P value (<0.05)*
PSV (cm/s)	15.01	6.43	0.002099*
PDV (cm/s)	4.8	6.14	0.217324
MPV (cm/s)	10.34	6.26	0.026496*

- Qualitative:

All patients showed positive CSF flow through the aqueduct of Sylvius and foramen magnum on systole and diastole.

**Atrophy**

- Quantitative:

**Table 3: Quantitative values of atrophy**

Parameters	Brain atrophy average values	Healthy individuals average values	P value (<0.05)*
PSV (cm/s)	6.28	6.43	0.413103
PDV (cm/s)	4.58	6.14	0.222038
MPV (cm/s)	5.45	6.26	0.298233

- Qualitative:

All patients showed positive CSF flow through the aqueduct of Sylvius and foramen magnum on systole and diastole

**Arnold Chiari malformation**

- Quantitative:

**Table 4: Quantitative values of Arnold Chiari malformation at aqueduct**

Parameters	Arnold Chiari average values (at aqueduct)	Healthy individuals average values	P value (<0.05)*
PSV (cm/s)	3.69	6.43	0.112065
PDV (cm/s)	2.97	6.14	0.11049
MPV (cm/s)	3.33	6.26	0.12225

**Table 5: Quantitative values of Arnold Chiari malformation at foramen magnum**

Parameters	Arnold Chiari average values (at foramen magnum)	Healthy individuals average values	P value (<0.05)*
PSV (cm/s)	3.21	4.01	0.12605
PDV (cm/s)	2.58	2.86	0.19401

- Qualitative:

One patient showed positive CSF flow through the aqueduct of Sylvius and foramen magnum on systole and diastole. The other patient showed no flow through the aqueduct of Sylvius or foramen magnum on systole or diastole

### Dandy-Walker Variant

- Quantitative:

**Table 6: Quantitative values of Dandy-Walker malformation at aqueduct**

Parameters	DWV average values (at aqueduct)	Healthy individuals average values	P value (<0.05)*
PSV (cm/s)	6.06	6.43	0.162015
PDV (cm/s)	4.73	6.14	0.149012
MPV (cm/s)	5.32	6.26	0.13245

- Qualitative:

The patient showed positive CSF flow through the aqueduct of Sylvius and foramen magnum on systole and diastole.

### DISCUSSION

Hydrocephalus is an ambiguous diagnosis that may result from many different causes. In evaluation of patients with hydrocephalus, the visualization of the CSF pathways and functional information derived from analysis of CSF flow dynamics are very important in determining the type of hydrocephalus seen. Phase-contrast MRI is extremely sensitive to CSF flow and provides the potential for non-invasive CSF flow quantification. We studied 20 patients in whom the diagnosis of hydrocephalus was established. The study included 8 males and 12 females of age range of 2 months -12 years. No gender predilection was noted as reported in the literature. Patients with VP shunts were excluded from the study to avoid any fallacies in measurements that might be caused by the shunt. Velocity measurements of these patients were compared with that of a matched age control group of 10 pediatric patients who did not suffer from hydrocephalus<sup>(6)</sup>.

In the setting of non-communicating hydrocephalus, phase contrast MRI plays an important role in determining the level of obstruction, thus providing a useful tool that guides appropriate surgical procedures for the patients. Our study included 11 patients diagnosed with non-communicating

hydrocephalus; 9 were diagnosed with aqueductal stenosis, 1 was diagnosed with foramen of Monro obstruction, and 1 was diagnosed with foramen of Magendi obstruction<sup>(7)</sup>.

For evaluation of aqueductal stenosis, all of our 9 patients showed hypodynamic flow through the aqueduct, with average peak systolic velocity of 1.49 cm/s compared to normal PSV of 6.43 cm/s obtained from non-hydrocephalic individuals in the control group. No CSF flow was detected at the aqueduct of Sylvius on cine images. This was consistent with the work of **Lucic et al.**<sup>(1)</sup> and **Parkkola et al.**<sup>(2)</sup>. However, Parkkola reported a patient with aqueductal stenosis showing hyperdynamic flow through the aqueduct. This could be explained by the fact that the same amount of CSF passes a narrower space, causing rise in velocity<sup>(1,2)</sup>.

In evaluation of foramen of Magendi obstruction, 1 patient was examined by phase contrast MRI in our study. Foramen of Magendi obstruction is usually congenital in children. In our patient, a membranous obstruction was seen at foramen of Magendi with no flow noted between the 4<sup>th</sup> ventricle and cervical subarachnoid space. The patient showed normal to and fro CSF movement on cine images and normal PSV velocity at the aqueduct of Sylvius.

This was consistent with the findings that was reported by Kasapas *et al.*<sup>(6)</sup> Additionally, Kasapas *et al.*<sup>(6)</sup> stated that phase contrast MRI could aid in guiding the appropriate surgical procedure which included incision and removal of membrane with or without ETV or shunting. Our patient however underwent ETV to relieve his symptoms before undergoing the CSF flowmetry<sup>(6)</sup>.

In evaluation of foramen of Monro obstruction, 1 patient was examined by phase contrast MRI in our study. The patient showed positive CSF flow on cine images and normal PSV through the aqueduct of Sylvius, yet no CSF flow was noted through the right foramen of Monro. This was consistent with Boruah *et al.*<sup>(7)</sup>, who reported similar findings in 3 patients. Also, phase contrast MRI plays an important role in follow-up of patients after surgery to evaluate the efficacy of the procedure<sup>(7)</sup>.

In evaluation of communicating hydrocephalus, we examined 2 patients who showed hyperdynamic flow through the aqueduct of Sylvius compared to that of non-hydrocephalic individuals. Average PSV was 15.01 cm/s in the patients compared to that of non-hydrocephalic individuals. Lucic *et al.*<sup>(9)</sup> reported similar findings in his study on 100 patients who suffered communicating hydrocephalus. This is thought to be due to decreased arterial compliance, leading to increased capillary pulse pressure and increased brain parenchymal expansion, which is directed inwards towards the ventricular system. This causes increased intraventricular pulse pressure and increased systolic CSF flow through the aqueduct<sup>(9)</sup>.

For evaluation of brain atrophy, 4 patients with brain atrophy were included in our study. Average PSV measured at the aqueduct of Sylvius was normal (6.28 cm/s), and positive CSF flow was seen on cine images. These findings were different from the findings of Baker *et al.*<sup>(10)</sup> who reported a low aqueductal CSF flow velocity in his patients. His finding was explained by the fact that in case of cerebral atrophy, there's reduction in brain parenchymal size, leading to decreased compression on ventricular system caused by inward expansion of brain parenchyma, thus decreasing flow of CSF through the aqueduct. In our study, 3 patients showed normal CSF flow, and only 1 patient showed hypodynamic flow at the aqueduct of Sylvius. This discrepancy might be explained by the fact that the degree of changes

in CSF dynamics is influenced by the degree of brain atrophy present<sup>(10)</sup>.

In the setting of Arnold-Chiari malformation, its often difficult to distinguish between chiari malformation and asymptomatic tonsillar ectopia. In 2007, Hofkes *et al.*<sup>(11)</sup> stated that although asymptomatic tonsillar ectopia can be identified effectively on conventional MR images, the presence and magnitude of tonsillar ectopia do not correlate with the presence and severity of signs and symptoms. Since symptomatic patients with abnormal CSF flow may benefit more from decompression surgery than patients with normal CSF flow, phase contrast MRI may provide a useful pre-operative assessment of the degree of tonsillar ectopia and its effect on CSF flow. Hofkes *et al.*<sup>(11)</sup> also stated that although quantitative methods of assessing CSF flow have been reported, non-quantitative visual assessment of CSF flow has been used in clinical studies and in many published reports. In those reports, reduced flow in the posterior subarachnoid space in phase-contrast MR images is generally considered a sign of abnormal CSF flow. Our study included 2 patients who were diagnosed with Arnold-Chiari malformation. One of them showed positive CSF flow at both foramen Magnum and aqueduct of Sylvius with average PSV of 3.21 cm/s and 5.27 cm/s, respectively. In the other patient however, no flow was detected in the posterior cervical subarachnoid space as well as in the aqueduct of Sylvius. PSV of CSF at aqueductal was 2.12 cm/s, which is low compared to normal. Quantitative assessment at foramen magnum for this patient was not possible, since there was severe hind brain herniation<sup>(11)</sup>.

In evaluation of Dandy-Walker malformations, one patient with Dandy-Walker variant was included in our study. He showed positive CSF flow at the aqueduct of Sylvius on cine images, with normal PSV of 6.06. There was normal CSF flow at the foramen magnum, yet it was not measured in this case because of a technical problem with the MRI machine. Yeldiz *et al.*<sup>(12)</sup> reported similar findings at foramen magnum of DWV patients in his study. Contrary to our study, he reported that his patients showed hypodynamic flow at the aqueduct of Sylvius. The discrepancy in the results may be attributed to the small sample size in our study and Yeldiz *et al.*<sup>(12)</sup> study, which included only 2 patients with DWV. A larger sample size may be

required to establish the pattern of CSF dynamics in DWV patients<sup>(12)</sup>.

Our study had several limitations. Appropriate history was not clear for some of the patients, because many parent had no insight on their child's disease. Also, our study included a small sample size, especially those representing congenital anomalies. A more thorough study on larger number of patients may be needed to observe and establish the CSF flow patterns in these types of pathologies.

## CONCLUSION

Phase contrast MR imaging is a rapid, simple and non-invasive technique which is sensitive to even small CSF flows, and can be used to evaluate CSF flow both qualitatively and quantitatively, and could be used in conjunction with conventional MRI in assessment of cases of hydrocephalus.

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