High resolution anatomic and CSF flow sensitive MR imaging in diagnosis and management of patients with ventriculomegaly and dilated CSF spaces

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Aims and objectives

CSF spaces comprise all intracerebral ventricles, spinal and brain subarachnoid spaces, such as cisterns and sulci, and the central canal of the spinal cord. Research of CSF flow and its disorders began as early as 1913 by Dr. Walter Dandy of John Hopkins university.[1] First by experimental animals studies and then in 1919 more studies as pneumoventriculography yielded more information about CSF pathways and its abnormalities. Multiple congenital and acquired disorders can alter CSF flow dynamics and resulting in hydrocephalus.

The Dandy traditional classification of hydrocephalus still forms the basis of classification system used at this time. It includes:

- **Communicating hydrocephalus**: hydrocephalus with obstructive cisternal membrane only without accompanying intraventricular or fourth ventricular exit foramina obstruction.

- **Non communicating : Intraventricular membranous obstruction**: The membranous obstruction at the foramen of Monro, the cerebral aqueduct, foramen of Magendie, foramina of Luschka, and superior medullary velum.

The international classification of diseases, ninth revision codes for hydrocephalus use the same words in Dandy’s classification plus the new addition of idiopathic normal pressure hydrocephalus as a third category.[2]

**Types of CSF flow:**

- **Pulsatile**: a cyclic back and forth flows during every cardiac cycle. During systole, there is increased cerebral blood flow leading to brain tissue expansion and forcing caudal movement of CSF. While during diastole, decreased cerebral blood flow and associated brain tissue regression permits cranial movement of CSF. Average peak velocity of 5cm/sec.

- **Bulk**: Slow molecular motion by effect of gravity and Brownian motions. Average velocity of 0.2cm/sec.
· **Reflux**: turbulent back flow of CSF from the aqueduct to the third ventricle and from the third ventricle to the lateral ventricles.[3]

We aim to present a state of art imaging of CSF flow disorders and variants by combining high resolution anatomical images as 3D -constructive interference in steady state (3D-CISS) and CSF flow-sensitive imaging in correlation with clinical usefulness.
Methods and materials

Patients: Prospective study was conducted on 140 patients presented by ventriculomegaly or dilated CSF spaces. The patients were categorized into 7 groups according to the primary site of obstruction, type of the lesion or malformation. Conventional MRI imaging with 3D -CISS were included routinely as part of the examination followed by dynamic phase contrast sequence (magnitude and phase contrast cine images) that was tailored according to the suspected site of obstruction or malformation. Time-SLIP sequence was used in selected cases, mainly to enforce visualization of communication between examined ventricles or CSF spaces.

MR Imaging Technique:

- **Conventional study** including axial TSE T1, axial FLAIR and axial, sagittal, and coronal TSE T2.

- **3D-constructive interference in the steady state** applied in the sagittal plane to cover the entire ventricular region and the fourth ventricular exits.

It is a high resolution heavy T2 gradient-echo sequence providing a combination of high signal intensity levels and extremely high spatial resolution (compared to conventional images). This allows identification of fine anatomic details of CSF pathways. Patients with communicating hydrocephalus secondary to inflammation or haemorrhage have an obstructive component that may benefit from endoscopic division of these membranes. This technique could demonstrate the membranes within the prepontine and basal cisterns as well as its location, number, and extent. [4 on page ]

**Disadvantage:** poor tissue distinction within the brain parenchyma. However, this technique is aimed at tissue/fluid distinction for which it is highly sensitive and specific.

- **Cine- Phase contrast (PC) CSF flow imaging technique:** (Figure 1)

Cardiac gated (using pulse oximeter) flow sensitive sequence depending upon the application of two phase encoding pulses in opposite sensitization directions. When subtracting the acquired two data sets, the signal contribution from stationary nuclei is eliminated and only flowing nuclei are visible.

For qualitative and quantitative assessment of CSF flow, two PC sequences in two planes were acquired:

- Midline high-resolution sagittal.
According to the anatomic region, the axial-oblique, coronal oblique, or sagittal-oblique cine PC was obtained with the same parameters except for the velocity encoding (VENC), which is set to the through plane taking into account the expected velocity of flow in every case in order to avoid aliasing artifact. It should always be chosen to exceed the expected maximum velocity within the selected region of interest (ROI).

**N.B** Velocity encoding (V_{enc}) is given in centimeters per second. It determines the highest and lowest detectable velocity encoded by a PC sequence.

Two sets of images for each plane are then evaluated:

1- Magnitude image (magnitude of difference signal)
   - The background is totally suppressed (dark color).
   - Flow appears as bright signal (regardless of its direction).

2- Phase image (phase of difference signal)
   - The background is mid-grey.
   - Flow has different signal according to its direction (forward diastolic flow is bright, while backward systolic flow is dark).

**Time-spatial labeling inversion pulse (time-SLIP) imaging technique:**[3 on page ] (Figure 2)

An application of spin-labeling methods to CSF flow. Spin-labeling methods were introduced in the late 1980s, it has been used for vascular imaging by selectively saturating the spins of the blood in vessels to a given region. A similar but unique approach can be used to visualize the bulk and turbulent flow of CSF in the CNS over several cardiac cycles using CSF as an internal tracer.

A series of single-shot images with incremental inversion recovery delay times are acquired using a 2D Fast Advanced Spin Echo (FASE) sequences. A nonselective inversion recovery was applied to null the background signals and a labeling-selective pulse was then applied to observe the movement of labeled "tagged" CSF. Tagged CSF will appear bright in contrast to dark "untagged" CSF and background.

Time-SLIP technique enables the labeling of a variable volume of CSF in any orientation and in any place in the central nervous system.

Time-SLIP CSF imaging is purely qualitative; it allows visualization of the linear and turbulent movement of CSF, communication between two CSF spaces and flow through the aqueduct or surgically created stoma.[5 on page ]
Images for this section:

**Fig. 1:** Sagittal phase contrast (PC) images. A, magnitude image shows flow as bright signal. B & C phase contrast images, bright CSF flow signal during diastole (B), and dark CSF flow signal during systole (C).

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Fig. 2: Sagittal Time-SLIP image with tagged CSF at the aqueduct and 4th ventricle region showing CSF reflux flow (arrow) from the aqueduct into the third ventricle.

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Results

The study included 140 patients.

Group 1: Obstructed ventricular foramina. (Fig. 3,4,5,6)

Nine patients were presented by headache. Seven of them showed thin webs obstructing foramen of Monro. While, two patients showed fourth ventricle outlet obstruction by webs and subarachnoid synechiae at the basal CSF cisterns with obliteration of the foramina of Luschka.

If one of the fourth ventricular outlets appeared obstructed, the hydrocephalus was categorized as non-communicating.

Identification of obstructive pathologic processes at any level through the CSF pathway is of significant importance because it can change the mode of management in patients with hydrocephalus, avoiding shunt insertion.

Advantage of 3D-CISS has been not only demonstrating the membranes within the prepontine cistern, but also guiding the neuroendoscopic procedure, showing the location, number, and the extent of the membranes.

Group 2: CSF obstruction at the aqueduct of Sylvius. (Fig. 7,8,9,10)

This group includes eighteen patients. All patients showed dilated ventricles (lateral, third) and foramina of Monro proximal to obstruction, and normal fourth ventricle and foramina (Luschka, Magendie) distal to obstruction.

Fifteen of them showed total aqueduct obstruction by web (post intracranial infection or hemorrhage or idiopathic) and by tectal plate compression by a large quadrigeminal cistern arachnoid cyst.

The other three patients showed partial aqueduct obstruction with weak CSF flow demonstrated in PC sequence.
Group 3: Communicating hydrocephalus. (Fig. 11,12,13,14)

Fifteen patients demonstrated diffuse hydrocephalus with no obstructing point detected at either the aqueduct or ventricular foramina. Eight of these patients had history of intracranial hemorrhage or infection and showed thin membranes traversing the basal CSF cisterns in 3D CISS images.

The membranes that obscured only the cisterns (ie, interpeduncular, prepontine, and premedullary) were defined as communicating hydrocephalus with cisternal obstruction.[4]

In the other seven patients no obstructing point or pathological subarachnoid membranes could be detected.

Group 4: Arachnoid cyst (communicating vs non communicating). (Fig. 15,16,17,18,19)

Arachnoid cysts are classified as communicating or non-communicating according to their relation to the subarachnoid space. There has been considerable controversy regarding the indications for the surgical treatment of asymptomatic ACs. However, there is a consensus that patients with symptomatic cysts causing seizures, hydrocephalus, increased intracranial pressure, or neurologic impairment should be managed surgically. Two surgical approaches are encountered; the first is cyst excision or fenestration into the subarachnoid space, basilar cisterns, or ventricles. The second is cystoperitoneal shunt placement.

Determination of communication between the arachnoid cyst to the CSF space is important in the preoperative evaluation. CT cisternography (CTC) was the most widely used diagnostic method to show such communication. But this method is considered invasive and using contrast material injected intrathecal. Flow-sensitive cine MR imaging techniques have been increasingly used to investigate the flow characteristics of CSF and its use is also increasing as a reasonable noninvasive diagnostic method alternative to CTC for the functional evaluation of ACs.[6]

PC MRI may improve the diagnostic confidence in differentiating communicating and non-communicating arachnoid cysts and posterior fossa cystic malformations from each other.
Twelve patients had arachnoid cysts communicating with the subarachnoid space. Ten patients had non-communicating arachnoid cysts.

Group 5: hydrocephalus in elderly with dementia. (Fig 20,21,22,23,24,25)

Classic symptom of normal pressure hydrocephalus: triad of gait disturbance, urinary incontinence and dementia. Ventriculomegaly with altered CSF dynamics and normal CSF pressure, but a slight pressure gradient persists between the ventricles and the brain parenchyma. In properly selected patients, ventricular shunting results in resolution of symptoms and slows progressive deterioration.

The aim of ventriculoperitoneal shunting is not to decrease mean pressure, but to dampen the pulse pressure by providing extra capacitance to the ventricular system.

**Radiological findings:**

- Ventricles and Sylvian fissures symmetrically dilated out of proportion to sulcal enlargement.

- Normal hippocampus (which distinguishes NPH from atrophy).

- Upward bowing of corpus callosum.

- Increased or normal CSF flow void.

- Periventricular high signal, primarily anterior to frontal horns or posterior to occipital horns of lateral ventricles (transependymal CSF flow).

Twenty five patients were presented by gait disturbance and clinical suspicion of iNPH. By evaluating the conventional and CSF flow imaging, twenty patients showed radiological findings of iNPH and presented by hyperdynamic CSF flow across the aqueduct, while five patients were matching with vascular dementia and brain atrophic changes. These patients showed significantly decreased CSF flow and low stroke volume through the aqueduct as compared with NPH patients.
Group 6: posterior fossa malformations with CSF flow disorders.

Cystic posterior cranial fossa malformation as Dandy Walker malformation, Dandy Walker variant, Blake’s pouch cyst and mega cistern magna have different distinct CSF flow patterns which are different from that of arachnoid cyst. [7]

Nineteen patients showed variable posterior cranial fossa cystic malformation. Two patients had DWM, three had DWV, three patients had Blake’s pouch cyst, seven patients had MCM and four patients had non-communicating posterior fossa arachnoid cyst.

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Posterior fossa arachnoid cyst: (Fig. 26,27)

- Could be communicating or non-communicating.

Blake pouch cyst: (Fig. 28,29,30)

- Failure of regression of the normally transient Blake’s pouch which is itself secondary to imperforation of the foramen of Magendi.

- BPC communicates with the 4th ventricle and separate from the subarachnoid space (not communicating with the posterior cervical subarachnoid space).

- Normal position of tentorium.

- Normal sized posterior fossa.

- Tetra ventricular hydrocephalus.

- Displaces 4th ventricle choroid plexus into the superior cyst wall.
o Consistently associated with hydrocephalus.

**DWV: (Fig. 31,32)**

o Less vermian hypoplasia and cystic dilation of the 4\textsuperscript{th} ventricle.

o No enlargement of the posterior fossa.

o Prominent retrocerebellar CSF space that communicates freely with a normal or dilated 4\textsuperscript{th} ventricle.

o CSF flow communicating between the large retrocerebellar cistern and the posterior cervical subarachnoid space.

o CSF flow through the aqueduct is slow.

o Hyperdynamic flow along the aqueduct and 4\textsuperscript{th} ventricle. (unlike arachnoid cyst).

**DWM: (Fig. 33,34)**

o Large posterior fossa and superiorly displaced tentorium.

o Cystic dilated fourth ventricle. The dilated fourth ventricle fills the posterior fossa and extends into the cisterna magna which is compressed between the dilated 4\textsuperscript{th} ventricle and the dura.

o Complete or partial vermian agenesis.

o The cystic CSF collection is not communicating freely with the basal cisterns.

o No flow between the cistern magna and posterior cervical subarachnoid space.
o Hydrocephalus is present in 90% of cases.

o Posterior fossa cyst can be shunted directly.

o If aqueduct stenosis or occlusion present, separate ventriculoperitoneal shunt is also placed.

o Preoperative MRI CSF flow is required to assess aqueduct patency.

Patent aqueduct with CSF flow from the aqueduct to the posterior fossa cyst.

Chiari 1 malformation: (Fig. 35,36)

Small sized posterior cranial fossa associated with pointed cerebellar tonsil herniated through the foramen magnum and consequently compromise or alter the normal CSF flow dynamic at the foramen magnum. Symptomatic patients may present with headaches, dizziness, ataxia, fainting with a cough, weakness or numbness, episodic aural fullness, tinnitus and vertigo.

Selection criteria for surgery depends on patient symptoms and the degree of tonsillar ectopia and CSF flow obstruction. The degree of CSF flow obstruction rather than the degree of tonsillar herniation can better select patients who are most responsive to surgery. Improved CSF velocity profile following surgery in such patients is useful in anticipation of symptomatic improvement.[8]

Eight patients in our study had Chiari 1 malforamation. All patients were presented by headache mainly occipital. Five patients had syringomyelia.

Group 7: post management of hydrocephalus

ETV:

Successful technique in treating occlusive hydrocephalus caused by primary or secondary aqueductal stenosis and space-occupying lesions of the midbrain, the pineal region or the posterior fossa. But it is thought to be less effective in patients with hydrocephalus caused by intraventricular or subarachnoid hemorrhage, in patients with meningitis, in pediatric patients with associated spinal dysraphism and in normal pressure hydrocephalus.[9, 10]
A range of image parameters have been assessed to evaluate the permeability of the ETV including:

• Ventricular size changes. But it is not a good indicator of ventriculostomy patency.

• Flow void signal intensity.

• Stroke volume measurements by using cine phase-contrast MR.

PC CSF flow sensitive MRI imaging offers more physiologic data than structural MR images and qualitative assessment of the patency of ventriculostomy.

**Sagittal Technique**: For qualitative assessment of CSF flow.

**Axial Technique**: For quantitative assessment with an imaging plane perpendicular to the ventriculostomy.

A decrease in stroke volume during the follow-up was associated with ventriculostomy failure and clinical deterioration.[9]

In this study, sixteen patients evaluated for ETV function:

- Twelve patients showed fair to good functioning ETV. *(Fig. 37,38)*

- Four patients showed non-functioning ETV and no clinical improvement. *(Fig. 39)*

**Ventriculoperitoneal shunt**: *(Fig. 40)*

Clinical assessment is the primary method for assessment of the VP shunt functioning.

PC MRI can also be used to evaluate VP shunt patency. In shunt catheters, because of the one-way valve mechanism, normal flow is unidirectional and rhythmic.

No signal means no flow in PC imaging.

Because of very low CSF flow rates in shunt catheters, minimum VENC values (2-5 cm/s) should be used for assessing VP shunts.

Eight patients were assessed for a non-functioning ventricular shunt device, none shows CSF flow signal at the shunt tip in PC MRI, this was clinically correlated.
Fig. 3: A, Bilaterally dilated lateral ventricles in axial T2 WI. B, 3D CISS sagittal and reformatted multiplanar images shows dilated lateral ventricles, small 3rd and 4th ventricles. Obstructing web is seen at foramen of Monro on both sides. C and D Phase, and E, magnitude sagittal images of PCMRI show normal CSF flow signal through the aqueduct and basal cisterns.

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Fig. 4: A, Axial T2WI shows Unilateral left lateral ventricle dilatation. B, Coronal reformatted CISS image shows web obstructing the left foramen of Monro. C, Sagittal CISS images shows obstructed left foramen of Monro (red arrow) and patent aqueduct of sylvius (blue arrow). D, Sagittal CISS images shows patent right foramen of Monro (black arrow). E, Coronal Time-SLIP image shows CSF flow between the right lateral ventricle and third ventricle (arrow head) while no flow at the left lateral ventricle. ( video 1)

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**Fig. 5:** Coronal Time-SLIP of patient in Fig.4 showing normal CSF flow reflux from the third ventricle into the right lateral ventricle and absent reflux on the left side.

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Fig. 6: A, axial FLAIR shows diffuse ventricular dilatation with intraventricular hemorrhage. B, Axial T2WI at the 4th ventricle foramina shows no definite obstructing lesion. C, Axial and coronal, D, sagittal reformatted CISS images are better depicting thin synechiae (arrows) obstructing the lateral 4th ventricle foramina. Also noted different CSF signal intensity inside and outside the 4th ventricle. E, Magnitude and phase images of PC sequence show free CSF flow across the aqueduct, basal cisterns and upper cervical subarachnoid space.

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**Fig. 7:** A, Axial T2 WI shows moderate symmetric supratentorial ventricular dilatation. B, Sagittal CISS image shows thin web (arrow) within the lower 1/3 of aqueduct. C, phase image and D, magnitude image of PC sequence hardly show minimal CSF flow (arrows) across the aqueduct.
Fig. 8: Axial PC sequence across the mid-portion of aqueduct for quantitative CSF flow measurement showing irregular biphasic flow with decreased stroke volume.

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**Fig. 9:** A, Axial T2WI shows marked supratentorial ventricular dilatation. B, Sagittal CISS image shows web obstructing the superior opening of aqueduct (arrow). C, phase images and D, magnitude image of PC sequence show no CSF flow across the aqueduct.

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**Fig. 10:** Cine-magnitude PC sequence of patient in Fig.9 shows no CSF flow across the aqueduct.

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Fig. 11: A, Axial T2WI in an infant (3month age), shows lateral ventricular dilatation. B, Sagittal CISS image shows patent aqueduct (blue arrow). C, Sagittal CISS images show multiple thin septae at the prepontine cistern (red arrows).

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**Fig. 12:** Axial PC image across the aqueduct show free CSF flow with average stroke volume in quantitative CSF flow measurement at the midportion of the aqueduct.

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**Fig. 13:** A, Axial T2WI shows lateral ventricles dilatation. B, Sagittal CISS image shows patent aqueduct with internal signal void flow. C, Sagittal magnitude and D, phase images of PC sequence show biphasic CSF flow across the aqueduct. Relative limited or diminished flow at the prepontine cistern.

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**Fig. 14:** Cine-PC sequence of patient in Fig.13 shows CSF flow across the aqueduct and relative limited or diminished flow at the prepontine cistern.

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Fig. 15: A, Axial and B, coronal T2WIs show a large right hemispheric arachnoid cyst. C, Coronal reformatted CISS image shows thin infero-medial cyst's wall this is possibly communicating with the right parasellar cistern. D, Axial magnitude and E, phase images of PC sequence at the level of supra sellar cistern show CSF flow communication (arrows) between the arachnoid cyst and right parasellar cistern.

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**Fig. 16:** Axial cine-PC sequence at the level of supra sellar cistern (of patient in Fig.15), shows CSF flow between the arachnoid cyst and the right parasellar cistern.

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**Fig. 17:** A, Sagittal CISS image shows a large quadrigeminal cistern arachnoid cyst mildly compressing the tectal plate and aqueduct. B, Sagittal magnitude and C, phase images of PC sequence show CSF flow across the aqueduct (blue arrow) and no flow.
detected within the cyst. Also seen CSF flow through endoscopic third ventriculostomy defect (arrow head).

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Fig. 18: Sagittal Cine-PC sequence of patient in Fig.17 shows CSF flow across the aqueduct and no flow detected within the quadrigeminal cistern arachnoid cyst. Also there is CSF flow through endoscopic third ventriculostomy.

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Fig. 19: another case of non communicating quadrigeminal cistern arachnoid cyst. A, Axial T2WI shows mild lateral ventricle dilatation and quadrigeminal cistern arachnoid cyst. B, Coronal reformatted and C, Sagittal CISS images show the cyst is totally compressing the aqueduct of Sylvius. D, Sagittal magnitude and E, phase images of PC sequence show no CSF flow across the aqueduct and no flow detected within the cyst.

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**Fig. 20:** 50y old Female patient with clinical triad of NPH A, Axial and B, Coronal T2WIs show moderate lateral ventricle dilatation, dilated sylvian fissures out of proportion to medial cortical sulci. C, Sagittal CISS image shows patent aqueduct with internal signal void denoting hyperdynamic CSF flow. D, Sagittal magnitude image of PC sequence shows CSF flow across the aqueduct.

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**Fig. 21:** The same patient in fig. 20 Axial quantitative PC image across the mid portion of the aqueduct, shows hyperdynamic biphasic CSF flow with measured stroke volume = 150 µl

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**Fig. 22:** 55Y old female patient with clinical suspicion of NPH. A, Axial and B, Coronal T2WIs show mild lateral ventricle dilatation out of proportion to the medial cortical sulci. C, Sagittal CISS image shows patent aqueduct with internal signal void (arrow) denoting hyperdynamic CSF flow. D, Sagittal magnitude image of PC sequence shows CSF flow across the aqueduct.

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Fig. 23: The same patient in fig. 22 Axial quantitative PC image across the mid portion of aqueduct, shows hyperdynamic biphasic CSF flow with measured stroke volume = 84 µl

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**Fig. 24**: 65 Y old female patient with vascular dementia. A, Axial and B, Coronal T2WIs show dilated lateral ventricles and cortical sulci, also noted right temporal encephalomalacic changes. C, Sagittal T2 WI shows patent aqueduct. D, Sagittal magnitude image of PC sequence shows CSF flow across the aqueduct.

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Fig. 25: The same patient in fig. 24 Axial quantitative PC image across the mid portion of aqueduct, showing biphasic CSF flow and the stroke volume = 39 µl

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**Fig. 26:** Non communicating retrocerebellar arachnoid cyst. A, Axial T2WI and B, Sagittal T1 WI show a large retrocerebellar cyst with no associated hydrocephalus. C, Sagittal CISS image shows a thin septum (arrow head) separating the retrocerebellar cyst from the cisterna magna. D, Sagittal magnitude and E, phase images of PC sequence show absence of definite CSF flow between the cyst and cisterna magna and also between the cyst and the 4th ventricle.

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**Fig. 27:** Sagittal Cine-PC sequence of patient in Fig.26 shows absent CSF flow between the retrocerebellar arachnoid cyst and cisterna magna and also between the cyst and the 4th ventricle.

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**Fig. 28:** Blake's pouch cyst. A and B, Sagittal 3D-CISS images reveal a large retrocerebellar cyst with patent aqueduct. A choroid plexus is noted at the entry zone of
the cyst (arrow). C, Sagittal phase contrast image shows absence of definite flow between the cyst and the posterior cervical subarachnoid space.

Fig. 29: another patient with Blake’s pouch cyst. A, Sagittal T2WI shows a large retrocerebellar cyst opening at the inferior aspect of 4th ventricle and associated with hydrocephalus. B, Sagittal magnitude and C & D, phase images of phase contrast sequence show CSF flow across the aqueduct (red arrow), visible flow between the 4th ventricle and the cyst (blue arrow) and no flow is seen between the cyst and the upper posterior cervical subarachnoid space (arrow head).
**Fig. 30:** Cine-PC sequence of patient in Fig. 29 shows CSF flow across the aqueduct, visible flow between the 4th ventricle and the Blake’s pouch cyst and no flow is seen between the cyst and the upper posterior cervical subarachnoid space.
Fig. 31: Patient of Dandy Walker Variant. A, Sagittal T1WI shows a large posterior fossa cyst with hypoplastic vermis. B &C, Phase contrast sagittal images show evidence of CSF flow communication between the cyst and the posterior cervical subarachnoid space (arrow head) and between the cyst and 4th ventricle (arrow).

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Fig. 32: Cine-PC sequence of patient in Fig. 31 shows CSF flow communication between the cyst and 4th ventricle and between the cyst and the posterior cervical subarachnoid space.

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**Fig. 33:** Patient of Dandy Walker Malformation. A, Sagittal 3D-CISS image shows hypoplastic vermis with ballooned 4th ventricle directly opening into a large posterior fossa cyst. B, Sagittal magnitude and C&D, phase images of PC sequence show CSF flow (arrow) across the aqueduct and absence of flow (arrow head) between the posterior fossa cyst and the posterior cervical subarachnoid space.

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Fig. 34: Cine-PC sequence of patient in Fig. 33 shows CSF flow across the aqueduct and absence of flow between the posterior fossa cyst and the posterior cervical subarachnoid space. Patient with DWM.

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Fig. 35: 30 Y old female patient with symptomatic Chiari 1 malformation. A, Sagittal 3D-CISS image shows herniation of the cerebellar tonsil with near total obstruction of the
foramen magnum and cervical cord syrinx. B, Sagittal magnitude and C, phase images of PC sequence show turbulent flow along the foramen magnum and prominent CSF flow within the syrinx.

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Fig. 36: The same patient in figure 26 with Chiari 1 malformation. Axial quantitative PC image across the foramen magnum shows turbulent CSF flow with flow jets in opposite direction at the anterior subarachnoid space, increased CSF inside the syrinx and different CSF flow velocities.

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Fig. 37: Patient with Functioning ETV. A, Sagittal CISS image shows a defect at the floor of the third ventricle with CSF signal void flow between the third ventricle and preptontine cistern. B, Sagittal magnitude and C&D, phase images of PC sequence show evident CSF flow across the endoscopic third ventriculostomy defect.

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Fig. 38: Cine-PC sequence of patient in Fig.37 with functioning endoscopic third ventriculostomy (ETV) shows evident CSF flow through ETV.

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Fig. 39: Patient with aqueductal obstruction and nonfunctioning ETV. Moderate supratentorial ventricular dilatation in axial (A) and coronal (B) T2WIs. C, Sagittal CISS image shows obstructed aqueduct and ETV defect is not well defined. D, Sagittal magnitude and E, phase images of PC sequence show absent CSF flow at the ETV and aqueduct.

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Fig. 40: 20Y old male patient with inserted lateral ventricle shunt device for management of aqueduct obstruction. The patient developed recent onset headache. A, Axial T2WI shows lateral ventricles dilatation and tube of shunt device. B, Sagittal CISS image shows obstructed aqueduct by webs. C & D coronal oblique rephased (c) and phase (D) images of PC sequence at the tip of the shunt in perpendicular plane showing absent flow signal reflecting obstructed or nonfunctioning shunt.

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Conclusion

3D-CISS sequence and CSF flow sensitive MR imaging are useful non-invasive techniques in the setting of routine MR imaging for comprehensive diagnosis and management of patients with ventriculomegaly and dilated CSF spaces.
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