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MRI CSF-Flowmetry: An innovative method in differentiation of normal pressure hydrocephalus and involutional cerebral atrophy

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Abstract

Background: MRI CSF-flowmetry imaging is a non-invasive and quick method, valuable for distinguishing between normal pressure hydrocephalus (NPH) and involutional cerebral atrophy (ICA). Aim of the Study: This study aimed to assess the value of phase-contrast MRI CSF-flowmetry in differentiating between NPH and ICA.

Patients and Methods: A descriptive case-control study was conducted at Martyr Ghazi Al-Hariri Specialized Surgical Hospital, Baghdad, Iraq, from April to December 2023. It included 28 patients and 25 control individuals. Conventional brain MRI was performed, followed by an assessment of CSF flow dynamics at the aqueduct of Sylvius.

Results: The 28 patients had an average age of 57.6 years (range: 50-87 years) and included 19 males and 9 females. MRI CSF-flowmetry differentiated NPH and ICA based on stroke volume, peak systolic velocity, peak diastolic velocity, and mean flux (flow). Control group mean values were 19.40 µL, 3.83 cm/sec, 3.49 cm/sec, and 0.03 ml/sec, respectively. ICA cases showed significantly lower mean values (9.42 µL, 1.72 cm/sec, 1.45 cm/sec, and 0.01 ml/sec). Conversely, NPH cases exhibited significantly elevated mean values (69.33 µL, 7.92 cm/sec, 6.66 cm/sec, and 0.05 ml/sec), indicating hyperdynamic CSF flow in NPH and hypodynamic flow in ICA.

Conclusion: Phase-contrast MRI CSF-flowmetry is a beneficial tool for distinguishing between normal pressure hydrocephalus and involutional cerebral atrophy.

Keywords: P-Normal Pressure Hydrocephalus, Involutional cerebral atrophy, stroke volume, peak systolic velocity, peak diastolic velocity, mean flux (flow)

Introduction

Cerebrospinal fluid (CSF) is a clear, colorless fluid with a density of 1.003-1.008 g/cm³, produced at ~500 mL/day. The body contains 125-150 mL of CSF at any time, replenished every 7.5 hours. CSF is distributed between the ventricular system (~35 mL), spinal canal (~30-70 mL), and subarachnoid spaces. CSF has lower glucose, protein, and potassium levels and higher chloride content than plasma. Normal CSF pressure in adult's ranges from 6-25 cmH_2O (mean: 18 cmH_2O) [1, 2]. Most CSF (70-80%) is produced by the choroid plexus (CP), with the remainder derived from brain capillaries. CSF absorption occurs in the brain parenchyma and lymphatics near the cribriform plate and cranial nerves [3, 4]. CSF Circulation: CSF flows via convective and pulsatile movements. Convective flow is unidirectional, driven by pressure gradients from the choroid plexus to arachnoid granulations. Pulsatile flow oscillates with the cardiac cycle, regulated by the Monro-Kellie hypothesis, which balances brain, CSF, and blood volumes [5, 6]. MRI techniques such as phase-contrast MRI (PC-MRI) and heavily T2-weighted sequences enable detailed evaluation of CSF circulation, aiding in diagnosing hydrocephalus, CSF leaks, arachnoid cysts, and other CSF-related disorders [7]. Phase-Contrast MRI CSF-Flowmetry: PC-MRI, introduced in 1986, uses bipolar gradients to differentiate between flowing and stationary hydrogen nuclei, providing quantitative CSF flow data. Parameters include stroke volume, peak systolic/diastolic velocity, mean flux, and flow direction. Low VENC values (2-4 cm/s) are useful for non-communicating hydrocephalus, while higher values (20-25 cm/s) are applied in hyperdynamic CSF conditions like normal pressure hydrocephalus [8]. Quantitative flow information, such as stroke volume and mean velocity, is derived from PC-MRI, supporting diagnoses and surgical planning [9].

Clinical Applications

MRI CSF-flowmetry distinguishes NPH from involutional cerebral atrophy (ICA). Hyperdynamic CSF flow (elevated indices) in NPH predicts better outcomes with ventriculoperitoneal shunting, while hypodynamic flow (reduced indices) characterizes ICA [10]. The technique aids in identifying obstructive hydrocephalus, arachnoid cyst communication, Chiari malformations, and post-surgical CSF dynamics in endoscopic third ventriculostomy or VP shunt procedures [8]. Normal Pressure Hydrocephalus (NPH): NPH is a reversible syndrome of cognitive impairment, gait apraxia, and urinary incontinence. It features ventriculomegaly with resistance to CSF outflow, often associated with cerebral hypoperfusion and Alzheimer's disease. Imaging findings include a callosal angle < 90°, temporal horn width > 5.5 mm, and periventricular edema. Evan's index (> 0.3) and other indices guide diagnosis and management [11, 12]. Involutional Cerebral Atrophy (ICA): ICA is characterized by compensatory CSF space enlargement due to reduced brain parenchyma. Imaging alone may not differentiate ICA from NPH or other dementias. Features favoring NPH include ventriculomegaly, peri-ventricular edema, and upward displacement of the corpus callosum. Temporal horn width > 5.5 mm and reduced mammillopontine distance (< 9 mm) further support NPH diagnosis [13]. MRI CSF-flowmetry is an essential tool for diagnosing and managing CSF-related disorders, offering non-invasive insights into dynamic flow patterns crucial for patient care. The aim of study is to assess the value of PC MRI CSF-flowmetry in differentiating between normal pressure hydrocephalus and involutional cerebral atrophy.

Methods

This descriptive case-control study was conducted from April to December 2023 at Martyr Ghazi Al-Hariri Specialized Surgical Hospital, Baghdad, Iraq. A total of 28 patients (19 males, 9 females; age range 50-87 years) with clinical suspicion of idiopathic normal pressure hydrocephalus (iNPH) and 25 control individuals (age range 50-80 years) were enrolled. Patients were referred by neurologists based on clinical features of iNPH (gait apraxia, dementia, or urinary incontinence) and MRI evidence of ventriculomegaly. External lumbar CSF drainage (25-39 mL) was performed, with clinical improvement assessed at 1, 2, and 4 hours. Patients with improvement were classified as the NPH group, while those without improvement were classified as the ICA group. Controls were individuals undergoing non-brain MRI who consented to additional brain MRI.

Inclusion Criteria

- **NPH Group:** Clinical suspicion of iNPH with improvement after CSF drainage and ventriculomegaly on MRI.
- **ICA Group:** No clinical improvement after CSF drainage with ventriculomegaly on MRI.
- **Control Group:** Comparable age and no brain pathology undergoing non-brain MRI.

Exclusion Criteria

- Neurodegenerative disorders (e.g., Alzheimer's disease, leukomalacia).
- History of major trauma or brain surgery.

MRI Studies

1. **Conventional MRI:** T1 axial, T2 axial, and FLAIR coronal sequences evaluated for ventriculomegaly indices (e.g., Evan's index, temporal horn width, callosal angle).
2. **PC-MRI CSF Flowmetry:** Axial plane perpendicular to the aqueduct with cardiac gating using parameters (TR=21ms, TE=10ms, flip angle=15°, VENC=5-20 cm/s). Circular ROI included pixels reflecting CSF flow signals.

CSF Flowmetry Parameters

- Systolic stroke volume (SV).
- Peak systolic and diastolic velocities (cm/s).
- Mean flux (ml/sec).

Statistical Analysis: Data were presented as mean ± SD or median (range). Differences between groups were analyzed using Student's t-test (significance at $p \leq 0.05$) via SPSS v25.0 and GraphPad Prism v6.

Table 1: MRI findings of NPH and ICA patient groups (*Chisquare test*)

		Groups		P-Value
		ICA (N=15)	NPH (N=13)	
Evans ratio >0.3	N	15	13	1.00
	%	100.0%	100.0%	
Mean temporal horn width > 7 mm	N	10	10	*p*>0.05
	%	66.7%	76.9%	
Collosal angle <90°	N	2	9	*p*<0.05
	%	13.3%	69.2%	
Disproportionately enlarged subarachnoid space (DESH)	N	1	9	*p*<0.05
	%	6.7%	69.2%	
Upward bowing of corpus callosum (callosal height >25 mm)	N	3	10	*p*<0.05
	%	20.0%	76.9%	
Cingulate sulcus sign	N	1	4	*p*>0.05
	%	6.7%	30.8%	
Aqueductal flow void	N	3	5	*p*>0.05
	%	20.0%	39.2%	
Subependymal edema	N	5	9	*p*<0.05
	%	33.3%	69.2%	

P-Value < 0.05 is statistically significant. P-Value > 0.05 is statistically non-significant

Results

Evans ratio > 0.3: All patients of NPH and ICA had positive Evans ratio > 0.3 (100%). Mean temporal horn width >7 mm: ten of thirteen patients with NPH had enlarged temporal horns of lateral ventricles (76.9%) while ten of fifteen patients with ICA had the same finding (66.7%). Callosal angle < 90°: nine of thirteen patients with NPH had decreased callosal angle (69.2%) while two of fifteen patients with ICA had the same finding (13.3%). Disproportionally enlarged subarachnoid space (DESH): nine of thirteen patients with NPH had DESH (69.2%) while one of fifteen patients with ICA had the same finding (6.7%). Upward bowing of corpus callosum: ten of thirteen patients with NPH had upward bowing of corpus callosum (76.9%) while three of fifteen patients with ICA had the same finding (20.0%). Cingulate sulcus signs: four of thirteen patients with NPH had cingulate sulcus sign (30.8%) while one of fifteen patients with ICA had the same finding (6.7%). Aqueductal flow void: five of thirteen patients with NPH had aqueductal flow void (39.2%) while three of fifteen patients with ICA had the same finding (20.0%). Subependymal edema: nine of thirteen patients with NPH had subependymal edema (69.2%) while five of fifteen patients with ICA had the same finding (33.3%).

Regarding MRI CSF-flowmetry parameters among the control group: Results of our study revealed the mean values of systolic stroke volume, PSV, PDV and mean flux in the control group (19.40 microL, 3.83 cm/sec, 3.49 cm/sec and 0.03 ml/sec respectively), (Table 2).

Table 2: Analysis of MRI CSF-flowmetry parameters among the control group (*student t test*).

	N	**Median (range)**	Mean	**Std. Deviation**
Systolic stroke volume (microL)	25	19.40 (11.50-30.10)	19.88	5.42
PSV(cm/sec)	25	3.83 (2.78-4.39)	3.74	1.18
PDV(cm/sec)	25	3.49 (2.36-4.88)	3.40	0.77
Mean flux(ml/sec)	25	0.03(0.01-0.05)	0.03	0.01

Peak Systolic Velocity (PSV), Peak Diastolic Velocity (PDV)

Regarding MRI CSF-flowmetry parameters among NPH and ICA patient groups versus control group: Results of our study revealed the mean values of systolic stroke volume, PSV, PDV and mean flux in the NPH group (69.33 microL, 7.92 cm/sec, 6.66 cm/sec and 0.05 ml/sec respectively) (table 3) and in the ICA group (9.42 microL, 1.72 cm/sec, 1.45 cm/sec and 0.01 ml/sec respectively), (Table 3).

Table 3: Analysis of MR CSF-flowmetry parameters among NPH and ICA patient groups versus control group (*F test*)

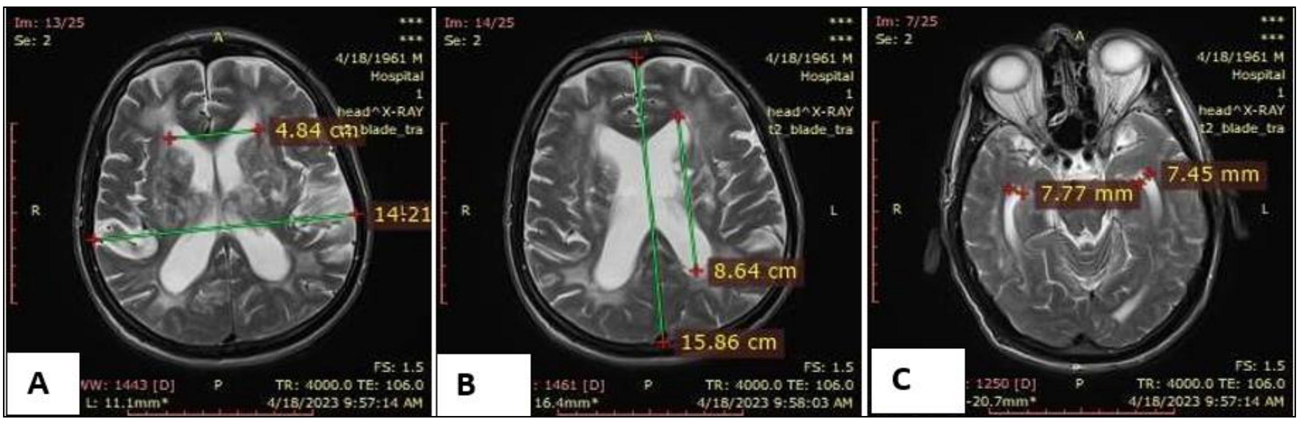
		N	**Median (range)**	**Mean**	**Std. Deviation**	**P-Value**
Systolic stroke volume (microL)	Control	25	19.40 (11.50-30.10)	19.88	5.42	p<0.05
	NPH	13	65.00 (34.00-140.00)	69.33	36.72	
	ICA	15	9.00 (3.00-15.00)	9.42	3.50	
PSV (cm/sec)	Control	25	3.83 (2.78-4.39)	3.74	1.18	p<0.05
	NPH	13	8.27 (4.39-11.91)	7.92	2.42	
	ICA	15	2.34 (1.07-5.68)	1.72	0.67	
PDV (cm/sec)	Control	25	3.49 (2.36-4.88)	3.40	0.77	p<0.05
	NPH	13	5.08 (3.92-13.64)	6.66	2.90	
	ICA	15	2.15 (1.23-3.83)	1.45	0.54	
Mean flux	Control	25	0.03(0.01-0.05)	0.03	0.01	p<0.05
	NPH	13	0.05(0.03-0.07)	0.05	0.01	
	ICA	15	0.01 (0.001-0.03)	0.01	0.003	

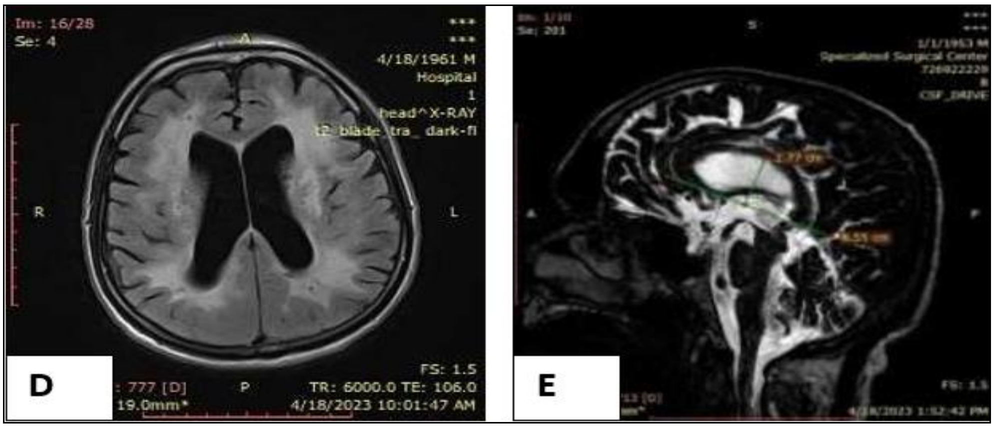
Peak Systolic Velocity (PSV), Peak Diastolic Velocity (PDV) P-Value < 0.05 is statistically significant. P-Value > 0.05 is statistically non-significant

Case 1

Clinical presentation: 70 years old male patient presented with dementia and gait ataxia

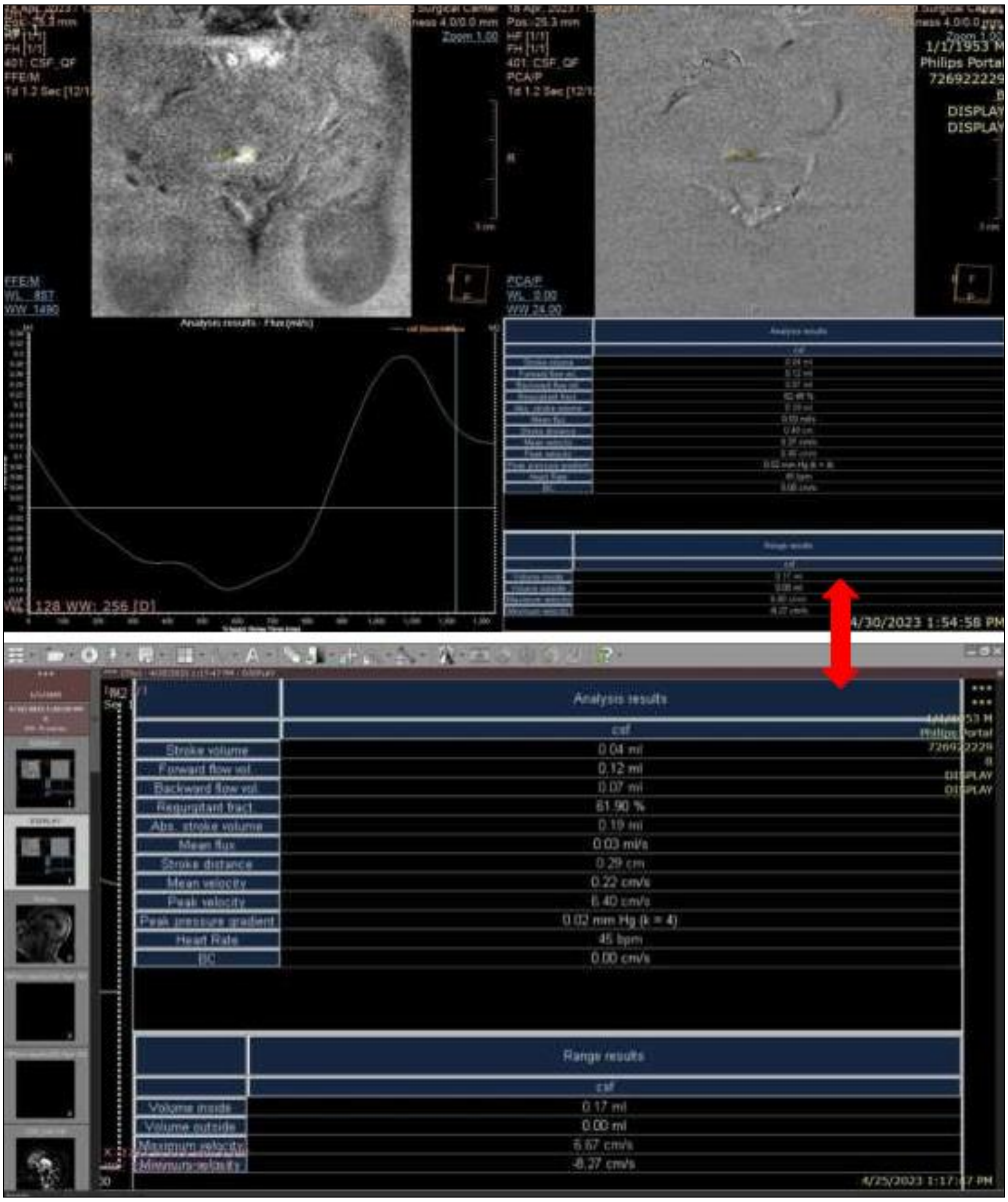
Conventional MRI findings





On axial T_2 WI, axial FLAIR WI and 3D constructive interference in steady stats (CISS), there is dilated ventricular system in form of increased Evans ratio of 0.36(A), anterioposterior diameter of lateral ventricle index of 0.58 (B) and increased mean width of temporal horns of 7.3 mm (C) associated with subependymal edema (D), upward bowing of corpus callosum with callosal height measured 27.7 mm and aqueductal signal flow void (E).

CSF flowmetry results, quantitative evaluation



SSV=95 microL, PSV=8.27 cm/sec
PDV=6.80 cm/sec, mean flux=0.03 ml/sec
Elevated CSF flowmetry parameters indicating hyperdynamic CSF flow consistent with normal pressure hydrocephalus

Discussion

This study evaluated conventional MRI and CSF flowmetry findings to differentiate between normal pressure Hydrocephalus (NPH) and involutional cerebral atrophy (ICA). Among conventional MRI indices, the callosal angle proved significant for diagnosing NPH, observed in 69.2% of NPH cases compared to 13.3% in ICA. This aligns with Cagnin A's findings, where the callosal angle averaged 109±9° in NPH versus 136.9±8.2° in ICA [14]. Disproportionately enlarged subarachnoid space Hydrocephalus (DESH) was present in 69.2% of NPH patients versus 6.7% in ICA, supporting Hashimoto M's conclusion that DESH is characteristic of NPH and not attributable to generalized brain atrophy [15]. Increased callosal height, indicating upward bowing of the corpus callosum, was observed in 76.9% of NPH cases versus 20% of ICA cases. Yoram Segev similarly noted significant differences, with callosal height averaging 39.2 mm in NPH versus 21.6 mm in ICA [16]. Subependymal edema was also more prevalent in NPH (69.2%) than ICA (33.3%), though comparable studies are lacking. The flow void phenomenon was not reliable for differentiating NPH and ICA, consistent with findings by Jang YH *et al*., who reported inconsistent visualization on routine MRI [17]. CSF flowmetry findings highlighted hyperdynamic circulation in NPH and hypodynamic flow in ICA. Among controls, mean Systolic Stroke Volume (SSV), Peak Systolic Velocity (PSV), peak diastolic velocity (PDV), and mean flux were 19.40 µL, 3.83 cm/s, 3.49 cm/s, and 0.03 mL/s, respectively. These findings align with Senger KPS, Abdallah A.E.A., and Mohamed S. Abdulla, who reported similar baseline values [10, 18, 19]. NPH patients exhibited significantly higher CSF flow indices (SSV: 69.33 µL, PSV: 7.92 cm/s, PDV: 6.66 cm/s, mean flux: 0.05 mL/s) compared to controls. These findings are consistent with Kahlon B and Abdallah A.E.A., who demonstrated elevated SSV and PSV values in NPH [20]. Youssef *et al*. also reported significantly higher SSV (46-259 µL) and PDV (5.6-17 cm/s) in NPH compared to controls (30 ± 9.8 µL and 4.9-5.8 cm/s) (47). Similarly, Mohamed S. Abdulla showed elevated PDV (7.29 cm/s) and mean flux (0.17 mL/s) in NPH patients [10]. In ICA, CSF flow indices were significantly reduced (SSV: 9.42 µL, PSV: 1.72 cm/s, PDV: 1.45 cm/s, mean flux: 0.01 mL/s) compared to controls. Abdallah A.E.A. and Youssef *et al*. similarly reported decreased SSV and PSV in ICA, reflecting hypodynamic circulation [18, 21]. Mohamed S. Abdulla also observed reduced PDV (2.97 cm/s) and mean flux (0.012 mL/s) in ICA [10]. The study's limitations include a small sample size and the availability of phase-contrast MRI only at one hospital, with other facilities requiring software upgrades for this technique. Overall, MRI CSF-flowmetry and conventional imaging indices provide valuable tools for distinguishing NPH from ICA and guide clinical management effectively.

Conclusion

The study showed usefulness of MR CSF-flowmetry technique in the differentiation between NPH and ICA. MR CSF- flowmetry findings, however, should be interpreted in conjunction with the clinical manifestations and the conventional MRI findings. The phase-contrast technique enables measuring aqueductal flow parameters in a reliable and reproducible way that is useful in discrimination of NPH and involutional brain changes.

Conflict of Interest
Not available

Financial Support
Not available

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