Original Research Article

MRI CSF Flowmetry in Differentiation Between Normal Pressure Hydrocephalus and Involutional Brain Atrophy

Abstract

Background: Phase contrast (PC) cine magnetic resonance imaging (MRI) is a valuable imaging method in estimating cerebrospinal fluid (CSF) dynamics that concerns several disease processes. The aim of this work was to estimate the usefulness of cine- PC MRI CSF flowmetry in patients with normal pressure hydrocephalus (NPH) and to differentiate them from involutional brain atrophy.

Methods: This prospective study included 30 patients with overlapping symptoms of NPH with involutional brain changes and 10 healthy volunteers as controls with no clinical symptoms and normal imaging results. Two imaging planes were applied: one in the sagittal plane with plane velocity encoded in the caudo-cranial direction for a qualitative assessment & one in the axial plane with through-plane velocity encoded in the caudo-cranial direction for quantitative measurements.

Results: Pathological CSF flow dynamics in NPH, peak systolic velocity and systolic SV values were greater than controls; these findings imply that cases with NPH had hyper dynamic aqueductal CSF flow. In cerebral atrophy, blood flow to the brain is reduced; we reported lower peak systolic velocity and lower SV values compared to healthy participants, suggesting hypo dynamic CSF circulation.

Conclusion: PC MRI CSF flowmetry is shown to be a valuable method especially in the elderly, in diagnosing NPH & differentiating it from age associated brain atrophy where differentiation based on conventional and clinical radiological basis may be complicated.

Keywords: Normal Pressure Hydrocephalus, Involutional Brain Atrophy, MRI, CSF

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Introduction:

Cerebrospinal fluid (CSF) is generated at a rate of 500 mL per day predominantly in the choroid plexus in the ventricles. Through the foramina of Lushka and Magendie, it exits the ventricular system and enters the subarachnoid space (SAS). Once inside the SAS, the CSF either travels down around the spinal cord or up across the cerebral convexities.(1) Typically, the components of the central nervous system are regarded to be static structures. There is movement of the brain and spinal cord, as well as significant movement of the CSF. CSF flow in ordered manner throughout the skull and spinal canal as a consequence of heart pulsations. Cardiac systole creates a pressure wave transferred to intracranial arteries and capillaries, resulting in caudal flow of CSF (CSF systole) via the ventricular system, basal cisterns, and foramen magnum into the cervical SAS. After cardiac diastole, a flow reversal with cephalic migration of CSF occurred. (2) As CSF is critical in intracranial homeostasis, disruptions in CSF flow may result in a range of disorders, including hydrocephalus and Alzheimer's disease.(3)

The hydrocephalus term is taken from the Greek word "hydro" indicating water and "Cephalus" indicating head. Formerly known as "water on the brain," hydrocephalus is the accumulation of an abnormally high volume of CSF in the ventricles. (4)

Normal pressure hydrocephalus (NPH), also known as idiopathic hydrocephalus, comprises of dementia, gait incoordination, and urine incontinence in a patient with a radiographical dilated ventricles that are inappropriate to any sulcal enlargement. (5)

Phase-contrast magnetic resonance imaging (MRI) may be used to evaluate the CSF flow quantitatively, where measures volume besides flow velocity are used to identify diseases and provide therapy for the relevant cases. Additionally, Phase contrast (PC) MRI permits CSF circulation to be evaluated qualitatively (i.e., bulk flow) and back and forth movement (i.e., pulsatile flow).(6) Imaging patients suspected with NPH utilising retrospective cardiac

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gating, phase-contrast plane perpendicular to the cerebral aqueduct requires precise positioning of the plane perpendicular to the flow human being assessed. The PC approach is a very sensitive indicator of flow and has the ability to quantify flow noninvasively.(7)

The functional evaluation of NPH is a common usage of MRI CSF flow imaging. Hyperdynamic CSF flow is seen when the ventricular system enlarges with sulcal enlargement absence (ventriculosulcal disproportion). Patients with NPH whose CSF flow is hyperdynamic respond more to ventriculoperitoneal shunt (VPS) installation than patients whose flow is normal or reduced.(7) Hyperdynamic CSF circulation is characterised by an increase in the mean systolic flow with the absolute stroke volume (SV) in NPH patients (SV > 42 µl). Clinically, these cases displayed what is known as HAKIM'S TRIAD (magnetic gait, urinary incontinence and dementia).(8)

Our study objective was to evaluate the efficacy of cine-phase contrast MRI CSF flowmetry in patient with NPH and to distinguish them from involutional brain atrophy.

Patients and Methods:

This prospective study enrolled 40 persons, 30 patients with overlapping symptoms of NPH and involutional brain changes (Hakims triad); 20 men and 10 women, with ranged age from 35 to74 years and 10 healthy volunteers ;6 men and 4 women; between the age of 18–48 years with no clinical signs and normal imaging data. The enrolled cases were referred from neurology outpatient clinics to Radiodiagnosis and Medical Imaging department at Tanta university hospital. The study was performed over a period of one year from April 2021 to May 2022 after being approved from the Ethical Committee Tanta University. Informed written consent was obtained from all patients.

The Inclusion criteria were patients clinically suspected to have NPH and brain atrophy based on clinical symptoms and conventional MRI findings. All patients either male or female. The exclusion criteria were patients with a relevant neurological disease (tumor, any obstructive

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lesion along CSF pathway) or cerebrovascular risk factors (except for leukoaraiosis). Patients presented with symptoms similar to Hakim triad, but their conventional MRI findings were normal and CSF parameters were within normal ranges. Cardiac patients with arrhythmia. Patients who had general contraindications for MRI as the presence of cardiac pacemaker or those who had electrically or magnetically activated implants (cochlear implants). Claustrophobic patients.

All patients were evaluated by complete history taking including: Personal history: as regards the name, age and sex. Present history: as regards the presenting symptoms as headache, dementia, gait disturbance and urine incontinence. Past history: as regards any previous surgical intervention, neurological disease, stroke, or cranial trauma.

General examination: Conventional MRI using MRI machine (GE 1.5T SIGNA Explorer) by using head coil in neutral supine position without any case preparation at MRI unit at radio diagnosis and medical imaging department, Tanta University Hospital.

Routine conventional MRI sequences including Axial T1WI (TR/TE= 400-600/10-20 ms). Axial and sagittal T2WI (TR/TE=2000-4000/100-120 ms). Axial FLAIR images (TR/TE/Inversion time (TI) = 4000-6000/140/1200). Diffusion weighted images (TR=3.6s, TE=93ms, Angle=90 degree). Midsagittal FIESTA image with thin cuts for better evaluation of CSF flow void sign along the aqueduct of Sylvius (TR=5.4s, TE=2.1s).

In all cases, peripheral cardiac gating was performed (used for cardiac synchronization) with MR compatible electrodes. A localizer was positioned on cerebral aqueduct, perpendicular to ampullar region of the aqueduct on midsagittal FIESTA image.

Two-dimensional cine PC MRI (2D cine PC-MRI) which is cardiac gated for detection of CSF flow during systole and diastole with the following imaging parameters included the following: (Repetition time TR=25, echo time TE=4.3, Flip angle = 10º, Number of acquisitions = 2, Field of view: 180 mm Matrix: 128x512, Scan thickness: 1mm, Phase

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encoding velocity VENC: 5 -20 cm/sec Measurement time according to patient heart rate was approximately 2.25 minutes.)

Protocol that was done for examination: At the level of the sylvian aqueduct, CSF flow parameters were analysed. Two imaging modalities were used: one in the axial plane with through-plane velocity encoded in the cranio-caudal direction for flow measurement and one in the sagittal plane within-plane velocity encoded in the cranio-caudal direction for qualitative evaluation. Velocity encoding VENC (=5-20 cm/sec) determines the highest and lowest detectable velocity encoded by a PC sequence and it should exceed the expected maximum velocity within selected ROI to avoid aliasing.

Post processing calculation including the following: All conventional MRI images and CSF flow parameters were transferred to workstation (GE advantage AW 4.7). On these phase pictures, CSF flow was quantified using the ROI data, and a CSF flow wave form was constructed. On the phase pictures, a circle ROI was formed to encompass pixels that exhibited CSF flow signals from the cerebral aqueduct. Because the phase pictures did not depict the actual anatomical lumen of the aqueduct, but just the CSF flow, the ROI was put in the aqueduct depicted on a magnified image with the use of a mouse-driven pointer and was replaced for the aqueduct's diameter. On the CSF flow wave form, the time of the cardiac cycle was plotted on the x axis and the velocity on the y axis. During CSF diastole, CSF passages in caudo-cranial direction (positive velocity), whereas through CSF systole, CSF flows in the cranio-caudal direction (negative velocity). Each curve has a corresponding table showing the CSF velocity and flow values for each time frame.

Parameters that were measured include the following: Peak systolic velocity (cm/s), the greatest CSF velocity measured throughout systole. End diastolic velocity (cm/s), the maximum CSF velocity measured throughout diastole. Mean (average) velocity in both systole and diastole (cm/s). Forward flow volume (ml) indicates CSF flow volume in the

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forward direction, and backward flow volume (ml) reflects CSF flow volume going in the opposite direction. SV (µl) defined the mean volume or the CSF passing the aqueduct during the systole = mean flow x CSF duration during the systole.

Case (1)

Clinical history: Male patient aged seventy-three years old presented with classic triad of gait disturbance, urine incontinence and dementia.

Conventional MRI Imaging:

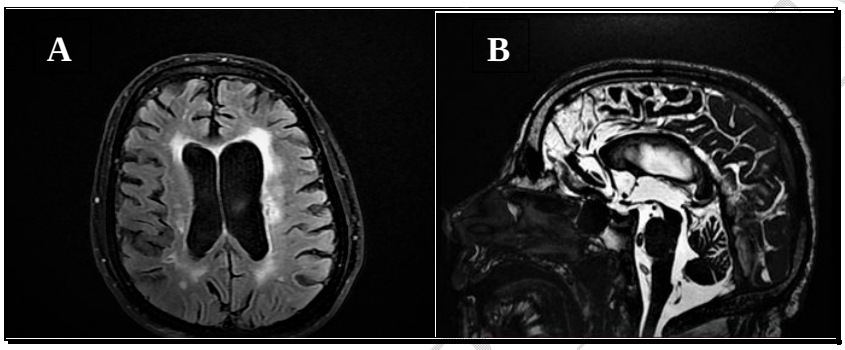

Image 1 : (A) Axial FLAIR and (B) Midsagittal FIESTA images show: dilated ventricular system, peripheral involutional brain changes and leukoariosis.

MRI CSF Flowmetry Study:

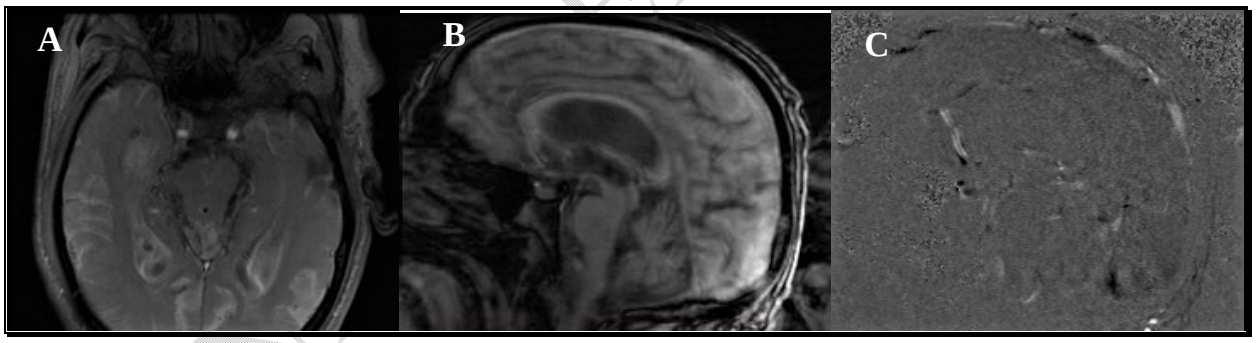

Image 2: showing in-plane (A) & (B) rephased and (C) phase images of CSF flow MRI scans.

Graph 1 :CSF Flow Curve:

List 1 : Parameters of CSF Flowmetry:

Peak Positive Velocity (cm/s)	7.64
Peak Negative Velocity (cm...	−9.33
Flow (ml/beat)	−0.06
Positive Pixel Flow (ml/beat)	0.052
Negative Pixel Flow (ml/bea...	−0.113

Quantitative assessment by CSF flow parameters: Peak systolic velocity = 9.33cm/s. End diastolic velocity = 7.64 cm/s. Mean systolic flow = 0.2ml/s. Systolic duration = 500 msec. SV = 100 microliter. CSF flowmetry study showing increased velocity, flow as well as SV of the Sylvius Aqueduct indicating hyperdynamic circulation.

Conclusion: The findings are impressive for hyperdynamic CSF circulation, in view of patient history, routine conventional MRI findings and CSF Flowmetry study result, the diagnosis is: NPH with very high SV.

Case (2)

Clinical history: Male patient aged sixty years old presented with urine incontinence.

Conventional MRI Imaging:

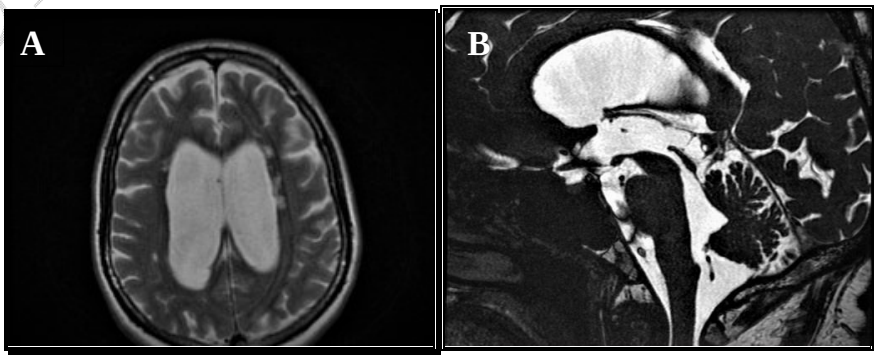

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Image 3 : (A) Axial T2 and (B) Midsagittal FIESTA images show: dilated ventricular system out of proportion of peripheral atrophic brain changes.

MRI CSF Flowmetry Study:

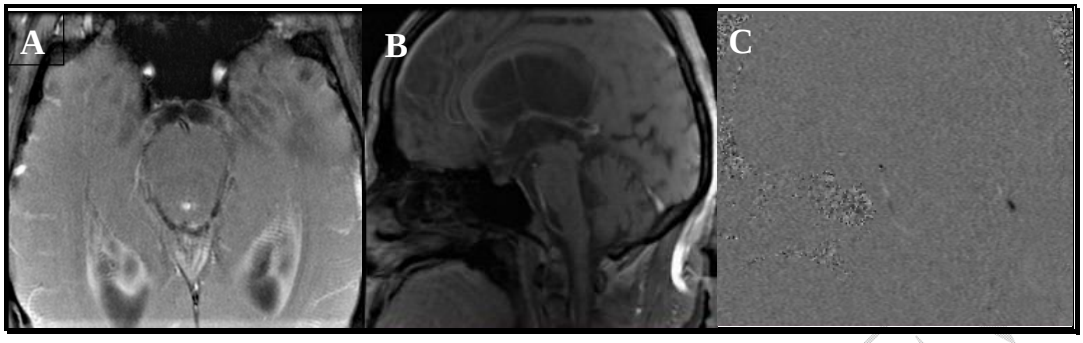
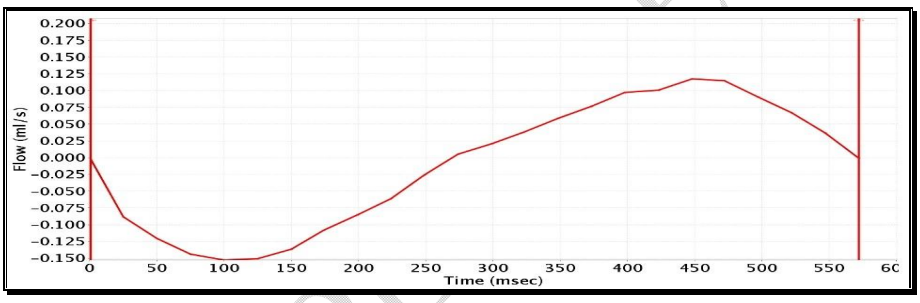


Image 4 : showing in-plane (A) & (B) rephased and (C) phase images of CSF flow MRI scans.

Graph 2 : CSF Flow Curve:



List 2 : Parameters of CSF Flowmetry:

Peak Positive Velocity (cm/s)	4.79
Peak Negative Velocity (cm/s)	-7.43
Flow (ml/beat)	-0.006
Positive Pixel Flow (ml/beat)	0.022
Negative Pixel Flow (ml/beat)	-0.028

Quantitative assessment by CSF flow parameters: Peak systolic velocity = 7.43cm/s. End diastolic velocity = 4.79 cm/s. Mean systolic flow = 0.13 ml/s. Systolic duration = 250 msec. SV = 32.5 microlitre. CSF flowmetry study showing increased velocity, flow as well as SV inside the Sylvius Aqueduct indicating hyperdynamic circulation.

Conclusion: The findings are impressive for hyperdynamic CSF circulation, in view of routine conventional MRI findings and CSF Flowmetry study result, the diagnosis is: NPH with high SV.

Case (3)

Clinical history: Male patient aged fifty-nine years old presented with gait disturbance and urine incontinence.

Conventional MRI Imaging:

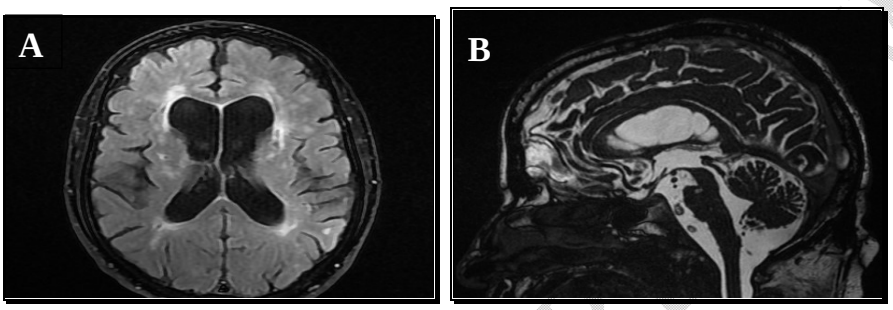


Image 5 : (A) Axial FLAIR and (B) Midsagittal FIESTA images show: dilated ventricular system, leukoariosis and peripheral involutional brain changes.

MRI CSF Flowmetry Study:

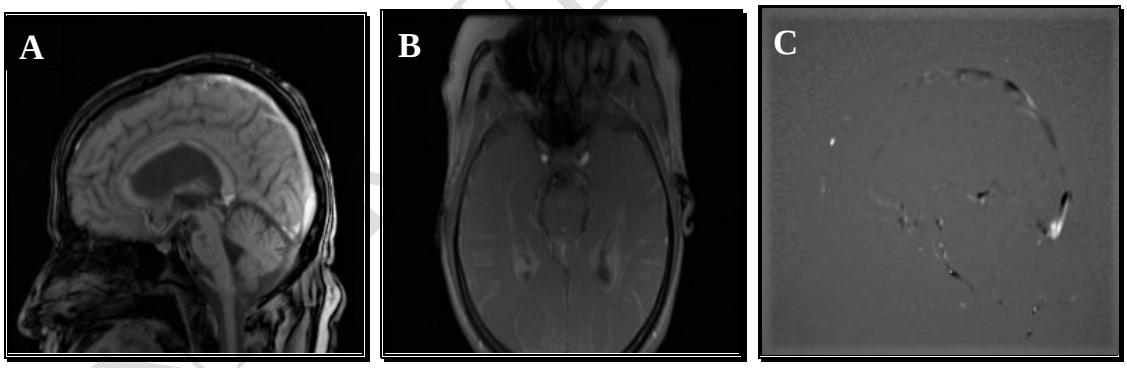
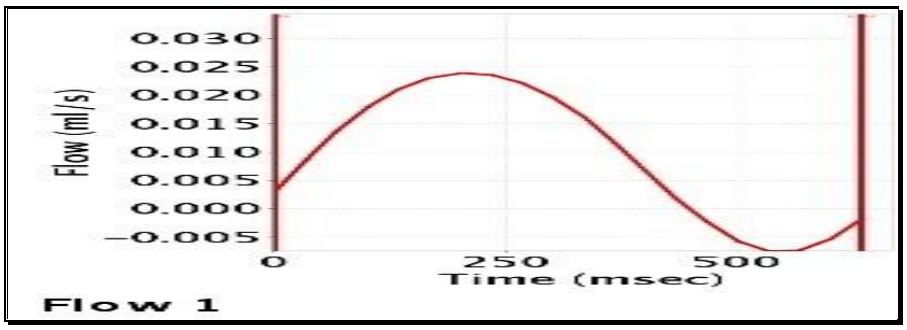


Image 6 : showing in-plane (A) & (B) rephased and (C) phase images of CSF flow MRI scans.

Graph 3 : CSF Flow Curve:



List 3 : Parameters of CSF Flowmetry:

Peak Positive Velocity (cm/s)	3.24
Peak Negative Velocity (cm...	−1
Flow (ml/beat)	0.006
Positive Pixel Flow (ml/beat)	0.007
Negative Pixel Flow (ml/bea...	−0.001

Quantitative assessment by CSF flow parameters: Peak systolic velocity = 1 cm/s. End diastolic velocity = 3.24 cm/s. Mean systolic flow = 0.015 ml/s. Systolic duration = 250 msec. SV = 3.7 microliter.

CSF flowmetric study revealing reduced velocity, flow, and SV within the Sylvius aqueduct indicating hypo-dynamic circulation (atrophy).

Conclusion: The findings are impressive for hypo-dynamic CSF circulation, in view of routine conventional MRI findings and CSF Flowmetry study result, the diagnosis is: brain atrophy.

Statistical analysis

Statistical analysis was done by SPSS v27 (IBM©, Chicago, IL, USA). Quantitative parametric data were described as mean and standard deviation (SD) and were analysed by ANOVA (F) test with post hoc test (Tukey). Qualitative variables were shown as frequency and percentage (%) and were analysed utilizing the Chi-square test. A two tailed P value < 0.05 was exhibited statistically significant.

Results:

Socio-demographic characteristics (age and sex) of studied groups. Table 1

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Table 1: Socio-demographic characteristics (age and sex) of studied groups

Age	Diagnosis			ANOVA		TUKEY'S Test		
	NPH	Atrophy	Control	F	P-value	N&A	N&C	A&C
Range	35- 74	52- 70	18 - 48	23.368	<0.001 *	0.531	<0.001 *	<0.001 *
Mean ±SD	56.700 ± 10.815	60.700 ± 5.736	34.500 ± 9.744					

Gender	Diagnosis						Chi-Square	
	NPH		Atrophy		Control			
	N	%	N	%	N	%	X^2	P-value
Male	13	65.00	7	70.00	6	60.00	0.220	0.896
Female	7	35.00	3	30.00	4	40.00		
Total	20	100.00	10	100.00	10	100.00		

Descriptive Statistics of Aqueductal CSF Parameters of aqueductal CSF flow in control group. Table 2

Table 2: Descriptive Statistics of Aqueductal CSF Parameters in control group

		Control		
Systolic peak velocity" PSV" (cm/s)	Range	2.38	-	4
	Mean ±SD	3.045	±	0.535
End diastolic peak velocity " PDV" (cm/s)	Range	1.12	-	2.88
	Mean ±SD	2.161	±	0.536
Peak systolic flow " PSF"(ml/s)	Range	0.048	-	0.064
	Mean ±SD	0.053	±	0.005
Peak diastolic flow "PDF" (ml/s)	Range	0.01	-	0.04
	Mean ±SD	0.021	±	0.010
Mean systolic flow (ml/s)	Range	0.028	-	0.044
	Mean ±SD	0.033	±	0.005
Systolic duration (mm/s)	Range	150	-	250
	Mean ±SD	193.000	±	37.133
Systolic SV (µl/s)	Range	5.2	-	7
	Mean ±SD	6.230	±	0.589
Aqueductal area (cm2)	Range	0.03	-	0.05
	Mean ±SD	0.039	±	0.009

Clinical presentation and Conventional MRI findings of NPH patients. Table 3

Table 3: Clinical presentation and Conventional MRI findings of NPH patients

Hakims triad		NPH	
		N	%
Gait disturbance	Yes	16	80.00
	No	4	20.00
Urinary incontinence	Yes	17	85.00
	No	3	15.00
Dementia	Yes	14	70.00
	No	6	30.00
Conventional MRI finding			
Ventricular enlargement	Yes	20	100.00
	No	0	0.00
Periventricular Leukoariosis	Yes	14	70.00
	No	6	30.00

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Prominent sulci, fissures, and cisterns	**Yes**	11	55.00
	No	9	45.00
Brain Mantle (mm) Anterior	**Range**	26 - 37	
	Mean ±SD	30.250 ± 2.633	
Brain Mantle (mm) Posterior	**Range**	18 - 30	
	Mean ±SD	24.200 ± 3.302	
Others (Headache, blurring of vision)	**Yes**	2	10.00
	No	18	90.00

Descriptive Statistics of Aqueductal CSF Parameters in NPH group. Table 4

Table 4: Descriptive Statistics of Aqueductal CSF Parameters in NPH group

		NPH		
Systolic peak velocity" PSV" (cm/s)	**Range**	6	-	15.2
	Mean ±SD	9.064	±	2.404
End diastolic peak velocity " PDV" (cm/s)	**Range**	2.5	-	13
	Mean ±SD	7.055	±	2.726
Peak systolic flow " PSF"(ml/s)	**Range**	0.05	-	0.55
	Mean ±SD	0.182	±	0.135
Peak diastolic flow "PDF" (ml/s)	**Range**	0.04	-	0.4
	Mean ±SD	0.173	±	0.106
Mean systolic flow (ml/s)	**Range**	0.04	-	0.38
	Mean ±SD	0.150	±	0.110
Systolic duration (mm/s)	**Range**	250	-	700
	Mean ±SD	407.500	±	101.664
Systolic SV (µl/s)	**Range**	24	-	159
	Mean ±SD	58.250	±	40.048
Aqueductal area(cm2)	**Range**	0.04	-	0.13
	Mean ±SD	0.077	±	0.024

Classification of NPH Patients According to SV. Figure 1

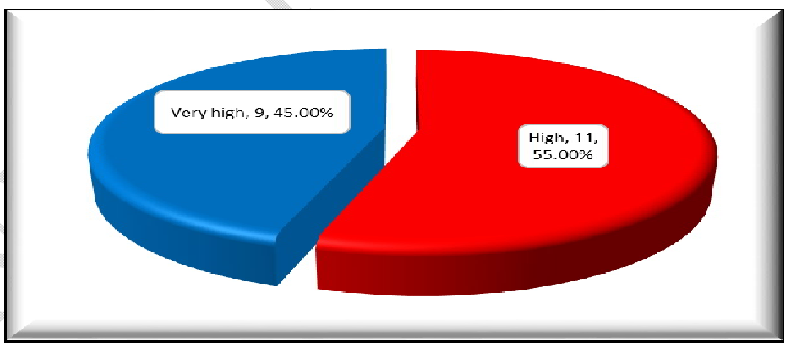

Figure 1: Classification of NPH according to systolic SV.

Clinical presentation and Conventional MRI findings of (Brain atrophy) patients. Table 5

Table 5: Clinical presentation and Conventional MRI findings of (Brain atrophy) patients

Hakims triad		**Atrophy**	
		N	**%**
Gait disturbance	**Yes**	6	60.00
	No	4	40.00

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Urinary incontinence	**Yes**	7		70.00
	No	3		30.00
Dementia	**Yes**	9		90.00
	No	1		10.00
Conventional MRI findings		**Atrophy**		
		N		**%**
Ventricular enlargement	**Yes**	9		90.00
	No	1		10.00
Periventricular Leukoariosis	**Yes**	9		90.00
	No	1		10.00
Prominent sulci, fissures, and cisterns	**Yes**	10		100.00
	No	0		0.00
Brain Mantle (mm) Anterior	**Range**	26	-	32
	Mean ±SD	29.500	±	2.121
Brain Mantle (mm) Posterior	**Range**	18	-	28
	Mean ±SD	24.800	±	3.120
Others (Headache, blurring of vision)	**Yes**	0		0.00
	No	10		100.00

Descriptive Statistics of Aqueductal CSF Parameters in Brain atrophy group. Table 6

Table 6: Descriptive Statistics of Aqueductal CSF Parameters in Brain atrophy group

		Atrophy		
Systolic peak velocity" PSV" (cm/s)	**Range**	1	-	2.8
	Mean ±SD	1.770	±	0.637
End diastolic peak velocity " PDV" (cm/s)	**Range**	1	-	3.24
	Mean ±SD	1.537	±	0.653
Peak systolic flow " PSF"(ml/s)	**Range**	0.005	-	0.03
	Mean ±SD	0.016	±	0.008
Peak diastolic flow "PDF" (ml/s)	**Range**	0.01	-	0.03
	Mean ±SD	0.015	±	0.007
Mean systolic flow (ml/s)	**Range**	0.005	-	0.015
	Mean ±SD	0.009	±	0.003
Systolic duration (mm/s)	**Range**	250	-	500
	Mean ±SD	346.500	±	70.002
Systolic SV (µl/s)	**Range**	1.75	-	4
	Mean ±SD	3.079	±	0.805
Aqueductal area(cm2)	**Range**	0.02	-	0.11
	Mean ±SD	0.059	±	0.029

Regarding Comparison between the three groups regarding, there was significantly increased in NPH with statistically significant difference as regards PSV. Regarding Atrophy versus Control, there was statistically non-significant difference. Regarding NPH versus Atrophy, there was statistically significant difference. As regards Aqueductal SV, NPH versus Control, there was significantly increased in NPH with statistically significant difference. Atrophy versus Control, there was statistically non-significant difference. NPH versus Atrophy, there

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was significantly increased in NPH with statistically significant difference. The PSV and SV were observed to be significantly elevated in NPH group than in atrophy group. Table 7

Table 7: Comparison between the three groups regarding PSV, EDV, PSF, PDF, Mean Systolic Flow, Systolic Duration, Systolic SV, Aqueductal area and brain mantle.

		Diagnosis			ANOVA		TUKEY'S Test		
		NPH	Atrophy	Control	F	P-value	N, A	N, C	A, C
Systolic peak velocity " PSV" (cm/s)	Range	6 - 15.2	1 - 2.8	2.38 - 4	71.973	<0.001*	<0.001*	<0.001*	0.254
	Mean ±SD	9.064 ± 2.404	1.770 ± 0.637	3.045 ± 0.535					
End diastolic peak velocity " PDV" (cm/s)	Range	2.5 - 13	1 - 3.24	1.12 - 2.88	34.192	<0.001*	<0.001*	<0.001*	0.766
	Mean ±SD	7.055 ± 2.726	1.537 ± 0.653	2.161 ± 0.536					
Peak systolic flow " PSF"(ml/s)	Range	0.05 - 0.55	0.005 - 0.03	0.048 - 0.064	11.881	<0.001*	<0.001*	0.004*	0.678
	Mean ±SD	0.182 ± 0.135	0.016 ± 0.008	0.053 ± 0.005					
Peak diastolic flow "PDF" (ml/s)	Range	0.04 - 0.4	0.01 - 0.03	0.01 - 0.04	20.687	<0.001*	<0.001*	<0.001*	0.987
	Mean ±SD	0.173 ± 0.106	0.015 ± 0.007	0.021 ± 0.010					
Mean systolic flow (ml/s)	Range	0.04 - 0.38	0.005 - 0.015	0.028 - 0.044	13.514	<0.001*	<0.001*	0.001*	0.774
	Mean ±SD	0.150 ± 0.110	0.009 ± 0.003	0.033 ± 0.005					
Systolic duration (mm/s)	Range	250 - 700	250 - 500	150 - 250	22.500	<0.001*	0.151	<0.001*	0.001*
	Mean ±SD	407.500± 101.664	346.500 ± 70.002	193.000 ± 37.133					
Systolic Stroke volume (µl/s)	Range	24 - 159	1.75 - 4	5.2 - 7	17.464	<0.001*	<0.001*	<0.001*	0.967
	Mean ±SD	58.250 ± 40.048	3.079 ± 0.805	6.230 ± 0.589					
Aqueductal diameter(cm^2)	Range	0.04 - 0.13	0.02 - 0.11	0.03 - 0.05	9.197	0.001*	0.131	<0.001*	0.136
	Mean ±SD	0.077 ± 0.024	0.059 ± 0.029	0.039 ± 0.009					

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Different methods of treatment. Figure 2

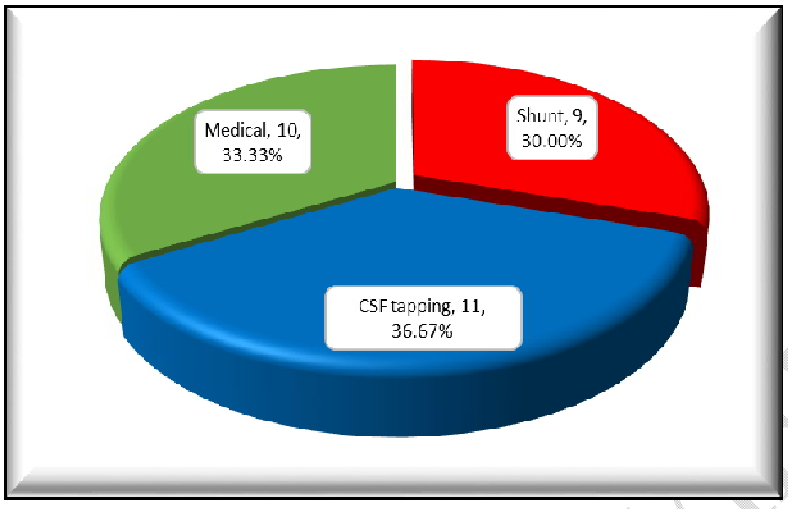

Figure 2: Different methods of treatment

Discussion:

Magnetic resonance imaging has generated a substantial amount of data about the dynamics of CSF. MR CSF assessment has progressed from a qualitative visual method during the previous decade.(9) The qualitative and quantitative study of CSF dynamics using flow-sensitive cardiac gated PC MR imaging methods has increased in frequency throughout the last decade.(10) When directly confronted with an aged patient exhibiting signs of dementia, disorientation, gait difficulties, and urinary incontinence, determining whether this patient has shunt-responsive NPH or atrophy is a major challenge.(7)

As previously indicated, the clinical manifestation is very overlapping, and standard neuroradiology may not be precise. The following is a significant application of CSF flow investigations.[7]

Our study was not found to be matched with the study performed by **Youssef et al. (11)** that exhibited that, the mean age of NPH group was about (63.7 ± 7.2), in the cerebral atrophy group was about (71.0 ± 3.2) & for the control group was about (55.8 ± 3.3). This may be due to different studied sample. Our results are not matched with **Youssef et al. (11)** who reported

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that dementia was the most common presenting symptom in NPH group and was found in 89.5 % while urine incontinence was 47.4 % and gait disturbance was 78.9 %. Ventricular dilatation results are compatible with **Youssef et al. (11)** who reported that ventricular dilatation was in 100 % but the associated brain ischemic changes are not matched with our results as it was in 15.3%.

This method enabled evaluation of CSF flow quantitatively and qualitatively. Qualitative assessment included cardiac-cycle-related direction of CSF flow as well as homogeneity of flow. Several quantitative parameters of CSF flow were reported; these are conventionally grouped into velocity, volumetric flow parameters and SV. (12)

Our findings are consistent with the existing understanding of CSF circulation that was described by **Youssef et al. (11)** the variations in cerebral blood volume caused by the cardiac cycle induce oscillatory bidirectional CSF flow along the craniospinal axis.

Our results correlate with a study carried out by **Abbey et al. (13)** who reported SV (17.41±10.11 µl/s) in their control group.

Comparable to our findings, **Yousef et al. (7)** reported that PSV varied between 0.64 and 3.24 cm/s with a mean value of (2.27 ± 0.94 cm/s).

Our results correlate with a study presented by **Youssef et al. (11)** on 30 cases (25 patients with NPH & 5 controls), reported markedly elevated peak systolic velocity and SV values with statistically significant difference compared to healthy volunteers representing hyper dynamic CSF flow in the NPH group.

Our results correlate also with **Ihab et al. (14)** which demonstrated marked elevation of peak systolic velocity & SV in comparison with healthy volunteers with mean values about (9.1 ± 3.1 cm/s) & (141 ± 83 µl/s) respectively.

The current findings correlate also with a study performed by **Senger et al. (15)** who studied 72 patients (36 control and 36 NPH cases) and reported elevation peak systolic velocity & SV

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with mean values of about (8.12 ± 2.53 cm/s) & (152 ± 49 µl/s) respectively compared to (3.99 ± 1.56 cm/s) & (32.1 ± 12.3 µl/s) in normal control.

As proved by study done by **Scollato et al. (16)** on Nine patients with clinical and radiographic signs of NPH but declined VPS therapy were reviewed every 6 months for a period of two years for progression of their clinical signs and changes in their SV, as determined via PC MRI.

Conclusions:

Phase contrast MRI CSF flowmetry was found to be a useful tool especially in the elderly, in diagnosing NPH & differentiating it from age related brain atrophy where differentiation based on clinical and conventional radiological basis may be difficult. It is simple, fast and non-invasive effective method that adds more to the total accuracy of the conventional MRI examination as it provides valuable additional information, increasing the confidence of the diagnosis, reducing rate of unnecessary previously used invasive techniques so reducing rates of complications and predicting shunt responsiveness.

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List of abbreviation

PC	Phase contrast
CSF	cerebrospinal fluid
MRI	Magnetic resonance imaging
NPH	normal pressure hydrocephalus
SV	Stroke volume
subarachnoid space	SAS

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