The role of magnetic resonance imaging cerebrospinal fluid flowmetry in differentiation between normal flow hydrocephalus and involutional brain atrophy

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Abstract

Objective: To assess the value of phase contrast magnetic resonance imaging cerebrospinal fluid flowmetry in differentiating between normal pressure hydrocephalus and involutional atrophy.

Methods: The descriptive case-control study was conducted at the Al-Yarmouk Teaching Hospital, Baghdad, Iraq, from April to December 2017, and comprised patients with normal pressure hydrocephalus and involutional brain changes. Healthy volunteers were included as controls. Demographic data was recorded and the patients were divided according to age. Conventional magnetic resonance imaging of the brain was performed followed by the assessment of cerebrospinal fluid flow dynamics, was done at the level of the aqueduct of Sylvius. Data was analysed using SPSS 25.

Results: Of the 23 subjects with a mean age of 52.3±16.8 years (range: 25-75 years), There were 13(56.5%) males and 10(43.5%) were females. Also, there were 17(74%) patients and 6(26%) controls. Among the patients, 8(47%) had brain atrophic changes based on magnetic resonance imaging, and 9(53%) had normal pressure hydrocephalus signs clinically and scanning criteria. Flowmetry showed mean systolic velocity 1.5±0.3 cm/sec, peak systolic velocity 1.5±0.3 cm/sec and systolic stroke volume 28.5±4.7μL in the control group which was significantly different from the patients (p<0.001).

Conclusion: Phase-contrast magnetic resonance imaging was found to be a useful tool to differentiate between normal pressure hydrocephalus and age-related brain atrophy.

Keywords: Hydrocephalus, MRI-CSF flowmetry. (JPMA 69: S-78 (Suppl. 3); 2019)

Introduction

The cerebrospinal fluid (CSF) compromises all spaces including ventricles, spinal and subarachnoid spaces, such as sulci and cistern as well as the central canal of the spinal cord. The rate of CSF formation in humans is about 0.3-0.4 ml min⁻¹. The portion of the fluid formed in the lateral ventricles escapes by the foramen of Monro into the third ventricle and then via the aqueduct into the fourth ventricle. Two components can be distinguished in CSF circulation; bulk flow which is circulation, and pulsatile flow which is back-and-forth motion. In bulk flow, CSF is produced by choroid plexus and absorbed by arachnoid granulations. The force which provides CSF movement from the ventricular system to arachnoid granulation and CSF absorption is caused by a hydrostatic pressure gradient between the site of its formation (slightly high pressure) and its site of absorption (slightly low pressure). In pulsatile flow, the CSF movement is pulsatile and results from pulsations related to the cardiac cycle of the choroid plexus and the subarachnoid portion of the cerebral arteries. Because very little CSF truly circulates through the subarachnoid space, pulsatile flow, rather than bulk flow, can be measured and demonstrated by phase contrast (PC) magnetic resonance imaging (MRI). MRI of CSF flow began with the qualitative observation of the degree of flow void in the aqueduct of Sylvius and the adjacent third and fourth ventricles, but it was not used commonly because it is influenced by many acquisition parameters and often may be difficult to quantify. Phase contrast MRI generates signal contrast between flowing and stationary nuclei by sensitising the phase of the transverse magnetisations of the velocity of motion. Two data-sets are acquired with opposite sensitisations, yielding opposite phases for the moving nuclei, and identical phases for the stationary nuclei. Because the phase varies with position in the field, the net phase after subtraction of the two data-sets is non-zero, and there is residual signal from the flowing CSF. When the two data-sets are subtracted, the signal contribution from the stationary nuclei is eliminated and only the flowing nuclei are seen. Pre-PC-MRI data is acquired and, the anticipated maximum CSF flow velocity must be entered into the pulse sequence protocol called velocity encoding (VENC). To obtain the optimal signal, the CSF flow velocity should be the same as, or slightly less than, the selected VENC. CSF flow velocities >VENC can produce...
Gait disturbance is typically the initial and most prominent symptom of the triad and may be progressive.13,14 NPH is caused by an increase in intracranial pressure (ICP) due to an abnormal accumulation of CSF in the ventricles of the brain, leading to ventriculomegaly. The ICP gradually falls but still remains slightly elevated, and the CSF pressure reaches a high normal level of 150-200 mmH2O. ICP values, therefore, are not usually elevated, and because of that the patients do not exhibit the classic signs that accompany increased ICP such as headache, nausea, vomiting, or altered consciousness. Although some studies have shown pressure elevations to occur intermittently, enlarged ventricles put increased pressure on the adjacent cortical tissue and cause myriad effects in such patients. The diagnosis of NPH is usually first led by brain imaging, either computed tomography (CT) or MRI, to rule out any mass lesions in the brain. This is then followed by lumbarpuncture and the evaluation of clinical response to CSF removal. This can be followed by continuous external lumbar CSF drainage over 3-4 days. MRI may show some degree of trans-ependymal migration of CSF surrounding the ventricles on T2/fluid attenuated inversion recovery (FLAIR) sequence. Imaging, however, it cannot differentiate between pathologies with similar clinical picture, like Alzheimer’s dementia, vascular dementia or Parkinson’s disease. Involutional brain atrophy is the morphological presentation of brain parenchymal volume loss that is frequently seen on cross-sectional imaging in elderly population.

It is a common finding in the elderly, and so there is some controversy as to when imaging changes are labelled as cerebral atrophy, rather than simply involutional or age-related when the patient has normal cognition. Cerebral atrophy is simply the compensatory enlargement of the CSF spaces from reducing brain parenchymal volume, representing idiopathic generalised changes seen with age. As it is not a distinct disease on its own, there is no uniform mode of presentation and the finding of atrophy is often incidental when imaging is taken for some other indication. Features that favour hydrocephalus include dilatation of the temporal horns; lack of dilatation of para-hippocampal fissures; increased frontal horn radius; acute ventricular angles; peri-ventricular interstitial oedema from trans-ependymal flow; intra-ventricular flow void from CSF movement on MRI; widening of the third ventricular recesses (midsagittalplane); upward displacement of the corpus callosum (midsagittalplane); depression of the posterior fornix (midsagittalplane); decreased mamillo-pontine distance (midsagittalplane); narrow callosal angle; and cingulate sulcussign.

The current study was planned to assess the value of PC-MRI CSF flowmetry in differentiating between NPH and involutional atrophy.
Patients and Methods
The descriptive case-control study was conducted at Al-Yarmouk Teaching Hospital, Baghdad, Iraq, from April to December 2017, and comprised patients with NPH and involutional atrophy patients as well as healthy controls. The protocol study was approved by the Ethical Committee of Scientific Researches of Diagnostic Radiology at Al-Yarmouk Teaching Hospital.

Patients of either gender, aged 25-75 years, were included on the basis of presenting clinical features of NPH and MRI criteria which included prominent cerebral sulci (cortical atrophy); and Ventriculomegaly (central atrophy) without bulging of the third ventricular recesses.

Demographic data was recorded and additional data was collected from the patients' case sheet and clinical evaluation reports. Normal pressure hydrocephalus diagnosis was made on the basis of clinical symptoms and MRI criteria which included Ventriculomegaly; frontal and temporal horns of the lateral ventricles; upward bowing of the corpus callosum; peri-ventricular high signal on T2-weighted sequences; narrow callosal angle; changes in sulcal size; a line parallel to the floor of the 4th ventricle; and Sylvian fissures out of proportion to the sulcal enlargement, which was minimal, and hippocampal and mesial temporal lobe volumes, which were near-normal.

Imaging features of cerebral atrophic changes in old patients included prominent cerebral sulci (cortical atrophy); and Ventriculomegaly (central atrophy) without bulging of the third ventricular recesses.

CSF flowmetry protocol depends on the analysis of the CSF flow properties at the level of the aqueduct in all patients. All MRI scans were done using a single unit (Philips Achieva 1.5 Tesla SE), and a circular polarized neurovascular coil was chosen.

Conventional MRI of the brain was performed, standard axial T1-weighted image (T1W1), axial and sagittal T2WI and axial FLAIR images were obtained before CSF flow measurements were made.

In PC-MRI, CSF flow dynamics study and electrocardiogram (ECG) gated protocol was used with a high-resolution axial PC protocol and an imaging plane perpendicular to the cerebral aqueduct. PC images were displayed on a gray scale, where low signal intensity indicated caudal flow and bright signal intensity represented cranial flow, while CSF flow quantification was performed on the images using the region of interest (ROI) measurements and a CSF flow wave form was generated. A circular ROI was drawn to include the pixels that reflected the CSF flow signals of the cerebral aqueduct on the phase images. The ROI was placed in the aqueduct shown on a magnified image with the aid of a mouse driven cursor and was substituted for the diameter of the aqueduct.

Because the phase images only showed the CSF flow and not the real anatomical lumen of the aqueduct, the area of the circular ROI was controlled at 1-5mm which contains no stationary brain tissue and is slightly smaller than the diameter of the aqueduct. Following the acquisition of the CSF flow velocity curves, CSF hydrodynamics were analysed in terms of the peak systolic velocity and mean systolic velocity. The mean flow was calculated from the equation: mean flow (cm³/sec) = mean systolic velocity (cm/sec) x area of ROI (cm²), where the mean systolic velocity was automatically determined from the mean value of the measured velocities of each cardiac phase, and the selection of ROI was measured with the aid of a mouse-driven cursor.

Finally, systolic stroke volume was calculated using the equation: systolic stroke volume = mean systolic flow x duration of CSF systole.

Data was analysed using SPSS25, and was presented as mean, standard deviation (SD) and range. Independent t-test and two-tailed analysis of variance (ANOVA) were used to compare the continuous variables between the groups and the least square difference (LSD) post-hoc test was used to sort out significant values. Pearson’s Chi-square test was used to assess statistical association between the patients’ gender and diagnosis. P<0.05 was considered significant.

Results
Of the 23 subjects with a mean age of 52.3±16.8 years (range: 25-75 years), There were 13(56.5%) males and 10(43.5%) females. Also, there were 17(74%) patients and 6(26%) controls. Among the patients, 8(47%) had brain

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Overall</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>4 (30.8%)</td>
<td>2 (20%)</td>
<td>6 (26.1%)</td>
<td>0.637</td>
<td>not significant</td>
</tr>
<tr>
<td>Atrophy</td>
<td>5 (38.5%)</td>
<td>3 (30%)</td>
<td>8 (34.8%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal pressure hydrocephalus</td>
<td>4 (30.8%)</td>
<td>3 (30%)</td>
<td>7 (39.1%)</td>
<td>0.391</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>13 (100%)</td>
<td>10 (100%)</td>
<td>23 (100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
atrophic changes based on magnetic resonance imaging, and 9(53%) had normal pressure hydrocephalus signs clinically and scanning criteria (Table-1).

There was no significant difference between patients’ age and MRI findings (p>0.05).

Table-2: comparison of magnetic resonance imaging (MRI) parameters, according to diagnosis (n=23).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Normal</th>
<th>Atrophy</th>
<th>NPH</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean±SD</td>
<td>Normal pressure hydrocephalus</td>
<td>Normal pressure hydrocephalus</td>
<td>Normal pressure hydrocephalus</td>
<td></td>
</tr>
<tr>
<td>Mean±SD</td>
<td>1.5 ± 0.3</td>
<td>0.7 ± 0.3</td>
<td>3.1 ± 0.9</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Peak systolic velocity (cm/Sec.)</td>
<td>1.5 ± 0.3</td>
<td>0.9 ± 0.3</td>
<td>5.8 ± 1</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Systolic stroke volume (Microliter)</td>
<td>28.5 ± 4.7</td>
<td>9.1 ± 2.8</td>
<td>85.3 ± 13.9</td>
<td>&lt;0.0001*</td>
</tr>
</tbody>
</table>

*Significant at 0.05 level by ANOVA test.
SD: Standard Deviation.

Stroke volume of >42 microliters has been shown to predict good response from shunting. Upper limit of stroke volume is variable from institution to institution, and is related to intrinsic scanner differences with the suggested upper limit being two times the normal value.

Table-3: Least square difference(LSD) post-hoc test of magnetic resonance imaging (MRI) parameters, according to diagnosis (n=23).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean difference</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean systolic velocity (cm/Sec.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>0.8</td>
<td>0.023*</td>
</tr>
<tr>
<td>Atrophy</td>
<td>-1.7</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Normal pressure hydrocephalus</td>
<td>-2.5</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Atrophy</td>
<td>-3.6</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Peak systolic velocity (cm/Sec.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>1.3</td>
<td>0.006*</td>
</tr>
<tr>
<td>Atrophy</td>
<td>-4.9</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Normal pressure hydrocephalus</td>
<td>-5.6</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Atrophy</td>
<td>-76.2</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

Peak systolic velocity, mean systolic velocity and systolic stroke volume values were significantly higher in NPH patients, and markedly lower in cerebral atrophy compared to healthy controls (Tables-2, 3).

Discussion

The study found consistent MRI flow patterns in healthy controls compared to involutional brain atrophy and NPH patients. There were no statistically significant differences in mean velocity, cranial and caudal volume, net volume, gender, and mean flow parameters among different age groups. This is in accordance with an earlier study.22

In pathological CSF flow dynamics in NPH patients, the systolic peak velocity and the systolic stroke volume were significantly higher than the controls, which means NPH patients had hyper-dynamic aqueduct CSF flow.

In cerebral atrophy, blood flow to the brain is decreased, and there was markedly lower systolic peak velocity, systolic mean velocity and stroke volume values compared to the controls which reflect a hypodynamic CSF circulation in the former.

In the current study there was a significant difference between specific MRI flowmetry parameters and patients diagnosis, which was in agreement with a study.23

A relatively wide range of normal aqueduct CSF velocity values measured by the cine-phase contrast MRI technique has been reported in literature and this may be attributed to the different gradient strengths and parameters used by different groups according.24

Conclusion

PC-MRI was found to be a useful tool in the diagnosis of NPH noninvasively, especially in the elderly, to differentiate it from age-related brain atrophy where differentiation based on clinical and conventional radiological basis may be difficult. PC-MRI provides the potential for non-invasive CSF flow quantification and this should allow for the exclusion of patients with similar symptomatology resulting in dementia caused by vascular, toxic or other causes.

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Conflicts of Interest: None.

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References


