Intraaqueductal dynamic phase-contrast MRI CSF flow quantification in the communicative hydrocephalus

Poster No.: C-1130
Congress: ECR 2013
Type: Scientific Exhibit
Authors: M. A. Lucic, M. Bjelan, A. Ragaji, K. Koprivsek, S. Lucic, D. Kozarski, M. Spirovski, V. Njagulj, D. Kozic; Sremska Kamenica/ RS
Keywords: Hemodynamics / Flow dynamics, Diagnostic procedure, MR, Neuroradiology brain, CNS
DOI: 10.1594/ecr2013/C-1130

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Purpose

Though we have achieved a tremendous improvement in our knowledge of the cerebrospinal fluid (CSF) creation, circulation, and absorption during the last decades, there is still a waste inanity in our understanding of the CSF basic physiology and pathology\(^1\). The fact that some uncertainties regarding the CSF circulation are still present is enhancing the certainty that our understanding of pathological deviations and/or variations from normal CSF flow pathways may still be confined by our insufficient understanding of the fundamental physical and physiological postulates of this phenomenon\(^2-5\). Having in mind that majority of nowadays available diagnostic imaging tools in examination of the patients with CSF flow disorder is usually conditioned by limited technological capabilities of existing equipment\(^6\), radiologists traditional reliance on classical signs of increased volume of CSF compartments leaves the broad space for the question is it possible to establish an accurate radiological diagnosis based on morphometric parameters solely, or is it founded at the preconceptions derived mostly from the clinical symptomatology of the patient. As an inevitable consequence, we are facing the major obstacles in the reliability of diagnosis and the adequacy of treatment in the patients with CSF flow disorders\(^7\), including the patients with communicant hydrocephalus in our daily radiological practice. In a strong believe that the key of accuracy lies within the concept of hydrodynamics\(^1,8\) rather than morphometrics and hydrostatics, and using the dynamic phase-contrast MRI with the possibility to display the pulsatile CSF flow, allowing the assessment of the CSF flow amplitudes\(^9-12\), we started on the idea that the quantification of CSF hydrodynamics parameters by use of appropriate post-processing software tools may additionally contribute in differentiation of communicant hydrocephalus. Therefore, as the purpose of this investigation we defined to establish the differences in CSF net flow, average and maximal CSF velocities within the cerebral aqueduct (CA) in the patients with communicant hydrocephalus (CH) in comparison to the group of healthy volunteers without the hydrodynamic disorder (WHD).

Methods and Materials

The study included one hundred patients (59 males and 41 females, age range 29 to 74 years), divided into the experimental group consisted of 52 patients with CH, and the control group consisted of 48 age-matching healthy volunteers without the hydrodynamic disorder (WHD).

In all patients we performed brain MRI on 1.5T imager (Avanto TIM, Siemens, Erlangen) by use of ECG retrospectively gated phase-contrast FLASH (Fast Low-Angle Shot) through-plane sequence with following technical parameters (TR 36.2 ms, TE 10.4
ms, FA 10°, VE 10cm/s, FOV 200, slab 4mm, matrix 256x256, acq 1) positioned perpendicularly to the cerebral aqueduct, later displayed and evaluated by multiple gated images in a closed-loop cinematographic (CINE) format (Fig. 1).

In order to quantify CSF flow parameters, the acquired images were analyzed by the use of "Segment" (v. 1.8 R0931), a comprehensive freely available software package for medical image analysis and cardiac image analysis. The region of interest (ROI) has been manually defined at the level of cerebral aqueduct (Fig. 2).

The obtained numerical values in the CH group were statistically processed in comparison with the values in the age-related group of healthy volunteers without the CSF hydrodynamic disorder (WHD).

Images for this section:

![Fig. 1: Six of 16 MRI images in total obtained by phase-contrast FLASH through-plane sequence positioned perpendicularly to the cerebral aqueduct. A different signal within the aqueduct dependent on the cardiac cycle phase is observable.](image-url)
Fig. 2: Acquired images were analyzed by use of Segment v. 1.8 R0931, a comprehensive freely available software package for medical image analysis and cardiac image analysis (http://segment.heiberg.se).
Results

The cross-sectional area of cerebral aqueduct has been larger in CH group than in WHD group, due to the generally wider aqueductal diameter in communicating hydrocephalus patients (Table 1), and statistically significant difference between the groups has been found (p<0.05).

Bidirectional intraaqueductal CSF net flow has been significantly higher in CH group in comparison to WHD group (p<0.001); also the summary net flow values were significantly higher in CH than in WHD group (p<0.05), whereas in CH group net CSF flow has been found to be of predominately caudo-cranial direction (+0.053 ± 0.175ml/s), and in WHD group predominantly of cranio-caudal direction (-0.018 ± 0.047ml/s) (Table 2). The characteristic curves of CSF net flow through the single cardiac cycle are shown on figure 3.

Average CSF velocities were significantly higher in CH group in comparison to WHD group (p<0.05 in cranio-caudal direction and p<0.001 in caudo-cranial direction) (Table 3). Specific curves of average CSF velocities through the single cardiac cycle are presented on figure 4.

Bidirectional maximal CSF velocities were significantly higher in CH group compared to WHD group (p<0.001) (Table 4), and the maximal velocities values in both cranio-caudal and caudo-cranial directions through the single cardiac cycle are graphically presented by characteristically shaped curves (Fig. 5).

Images for this section:

<table>
<thead>
<tr>
<th>Group</th>
<th>ROI (cm² ± SD)</th>
<th>Span (cm²)</th>
<th>Significance (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHD</td>
<td>0.117 ± 0.047</td>
<td>0.1, 0.3</td>
<td></td>
</tr>
<tr>
<td>CH</td>
<td>0.196 ± 0.097</td>
<td>0.1, 0.4</td>
<td>p&lt;0.05</td>
</tr>
</tbody>
</table>

Table 1: The cross-sectional area of CA has been significantly larger in CH group than in WHD group, due to obviously larger diameter of cerebral aqueduct in communicating hydrocephalus patients.
Table 2: Net CSF flow through the cerebral aqueduct values in both CH and WHD groups.

<table>
<thead>
<tr>
<th>CSF flow (mL/s)</th>
<th>WHD (mL/s ± SD)</th>
<th>CH (mL/s ± SD)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranio-caudal direction</td>
<td>-0.083 ± 0.066</td>
<td>-0.164 ± 0.120</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Caudo-cranial direction</td>
<td>0.065 ± 0.061</td>
<td>0.221 ± 0.178</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Net flow</td>
<td>-0.018 ± 0.047</td>
<td>+0.053 ± 0.175</td>
<td>p&lt;0.05</td>
</tr>
</tbody>
</table>

Fig. 3: Graphical display of intraaqueductal CSF net flow through the single cardiac cycle in both CH and WHD groups obtained by Segment software.

Table 3: Average CSF velocities through the cerebral aqueduct in both CH and WHD groups.

<table>
<thead>
<tr>
<th>Average velocity (cm/s)</th>
<th>WHD (cm/s ± SD)</th>
<th>CH (cm/s ± SD)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranio-caudal direction</td>
<td>-2.961 ± 1.528</td>
<td>-3.831 ± 1.134</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Caudo-cranial direction</td>
<td>2.320 ± 1.125</td>
<td>3.686 ± 1.349</td>
<td>p&lt;0.001</td>
</tr>
</tbody>
</table>
**Fig. 4:** Graphical display of average CSF velocities through the cerebral aqueduct during the single cardiac cycle in both CH and WHD groups.

**Table 4:** Maximal CSF velocities through the cerebral aqueduct in both CH and WHD groups.
**Fig. 5:** Graphical display of maximal intraaqueductal CSF velocities in cranio-caudal (upper row) and caudo-cranial (lower row) directions during the single cardiac cycle in both CH (left) and WHD (right) groups.
Conclusion

Dynamic phase-contrast MRI techniques by use of implemented FLASH through-plane sequence, positioned perpendicularly to the cerebral aqueduct enables the precise measurement of CSF flow parameters by "Segment" software in both experimental and control groups. Phase-contrast MRI CSF flow quantification within cerebral aqueduct may facilitate the establishing of the communicant hydrocephalus diagnosis, but also may enable to accurately differentiate communicant hydrocephalus from other entities, which correlates with the results of some other similar investigations\textsuperscript{14,15}.

Shapes of characteristic curves of net flow, average and maximal velocity were distinctively different between the observed groups, providing the easier distinction of the communicant hydrocephalus.

The evidently larger cross-sectional area of cerebral aqueduct in communicant hydrocephalus may appear as a predictive feature in a future, leaving the space to be potentially proven by some novel CSF flow measurement techniques\textsuperscript{16}.

References


**Personal Information**

Milos A. Lucic  
Diagnostic Imaging Center  
Institute of Oncology of Vojvodina  

University School of Medicine, University of Novi Sad  
Institutski put 4  
21204 Sremska Kamenica  
Serbia  

e-mail: milos.a.lucic@gmail.com