O-301 – Pressure Maps of Normal and Variant Dural Sinuses derived from 4D Flow MRI Velocity Measurements
Disclosures

Speaker Name: Prateek Sanan

I have no financial interests or relationships to disclose with regard to the subject matter of this presentation.
Motivation

- Dural arteriovenous fistulas (DAVFs) are vascular malformations that can present aggressively with seizure, hypertensive encephalopathy, and intracranial hemorrhage.

- Intraoperative ultrasound studies have shown that dural venous pressure is elevated in spinal DAVF patients with myelopathy. [1]

- However, venous pressure measurements of intracranial DAVFs have not been reported.

- 4D Flow MRI is a powerful tool that has been used to measure hemodynamic parameters and velocity fields.

Illustrations demonstrate different types of arteriovenous fistulas. The types listed above represent increasing risk of neurologic injury and bleeding. (Image courtesy of http://www.cvsection.org)

Study Objectives

- Classify dural venous sinuses anatomy from PC angiograms.
  - Dural venous drainage was classified based on common torcular herophili anatomy: type 1 = true confluence, type 2 = partial confluence, and type 3 = isolated drainage of the deep venous system into one transverse sinus. [2]

- Hemodynamic analysis in the transverse sinuses (TS):
  - cross-section area in healthy normal
  - mean blood flow rates
  - blood flow directionality
  - relative pressure change in the transverse sinuses

Methods

• Subjects
  – 60 healthy volunteers (age range 45-75y, mean=64y, 32F)
  – 7 subjects diagnosed with unilateral DAVFs affecting the transverse/sigmoid sinus (age range 33-72y, mean =52y, 2F).

• Acquisition: 4D flow MRI with Radial Sampling (PCVIPR) followed by an offline reconstruction.

• Post-processing
  – Background phase correction was performed in Matlab (The Mathworks, Natick, MA) on the PC angiograms.
  – Vessel segmentation was performed in MIMICs (Materialize, Leuven, Belgium).
  – Flow quantification and visualization were carried out in Ensight (CEI, Apex, NC).
Acquisition: 4D Flow MRI- PCVIPR

Scanner

3T system (MR750, GE Healthcare, Waukesha, WI)
8 channel head coil (Excite HD Brain Coil, GE Healthcare, Waukesha, WI)

PCVIPR [6,7]
Sample center of k-space with every TR
Whole-brain coverage with high isotropic spatial resolution

Scan parameters
FOV = 22 x 22 x 10 cm³
(0.7 mm)³ isotropic spatial resolution
scan time = 7 min
Venc = 80 cm/s for healthy subjects
Venc = 100 cm/s for DAVF patients
20 reconstructed cardiac time frames using temporal interpolation [8]

Anterograde blood flow in the right TS throughout the cardiac cycle

Retrograde blood flow in left TS throughout the cardiac cycle
coronal/anterior view

coronal/posterior view
Type 1

Type 2

Type 2

Type 3

Higher relative pressure
### Results: flow, area, anatomy in normal subjects

**$T_S^{\text{proximal}}$**

<table>
<thead>
<tr>
<th></th>
<th>Flow (mL/s) (n=60)</th>
<th>Area (mm$^2$) (n=60)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Left TS</strong></td>
<td></td>
<td></td>
<td>Right TS</td>
<td></td>
</tr>
<tr>
<td>Type 1 (n=10)</td>
<td>2.06 ± 1.24</td>
<td>17.8 ± 5.04</td>
<td>4.68 ± 2.20</td>
<td>30.5 ± 9.10</td>
</tr>
<tr>
<td>Type 2 (n=35)</td>
<td>2.80 ± 1.58</td>
<td>19.30 ± 8.64</td>
<td>4.20 ± 1.63</td>
<td>27.40 ± 8.29</td>
</tr>
<tr>
<td>Type 3 (n=15)</td>
<td>1.22 ± 0.52</td>
<td>9.26 ± 2.62</td>
<td>5.74 ± 1.3</td>
<td>35.0 ± 5.62</td>
</tr>
<tr>
<td></td>
<td>TS with deep</td>
<td>TS with deep</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>venous system</td>
<td>venous system</td>
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<tr>
<td></td>
<td>drainage</td>
<td>drainage</td>
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</tbody>
</table>

**Anatomy count:**

- Healthy subjects: 10 type 1, 35 type 2, 15 type 3
- DAVF subjects: 5 type 1, 2 type 2

*Significant difference P < 0.05*
Results: blood flow rates

<table>
<thead>
<tr>
<th></th>
<th>TS DAVF side</th>
<th>TS contralateral to DAVF</th>
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<tbody>
<tr>
<td>DAVF patients (n=7)</td>
<td>-1.72 ± 6.12</td>
<td>6.70 ± 2.18</td>
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<tr>
<td>Left TS</td>
<td></td>
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<tr>
<td>Right TS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthy subjects (n = 60)</td>
<td>2.32 ± 1.51</td>
<td>4.63 ± 1.83</td>
</tr>
</tbody>
</table>

Significant difference P < 0.05
Results: pressure changes

\[ \Delta P = TS_{\text{distal}} - TS_{\text{proximal}} \]

where:

- \( TS_{\text{distal}} = 50 \text{ mm from torcular herophili} \)
- \( TS_{\text{proximal}} = 25 \text{ mm from torcular herophili} \)

<table>
<thead>
<tr>
<th>( \Delta P ) (mmHg)</th>
<th>TS DAVF side</th>
<th>TS contralateral to DAVF</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAVF patients (n=7)</td>
<td>0.06 ± 0.49</td>
<td>-0.27 ± 0.47</td>
</tr>
<tr>
<td></td>
<td>Left TS</td>
<td>Right TS</td>
</tr>
<tr>
<td>Healthy subjects</td>
<td>-0.13 ± 0.09</td>
<td>-0.12 ± 0.09</td>
</tr>
<tr>
<td>(n = 60)</td>
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Significant difference P < 0.05
Discussion

• Anatomical variants of the dural venous sinuses are quite common, with 58% of healthy individuals demonstrating a partial confluence at the torcular herophili.

• Significantly, the right TS drains more blood flow than the left TS for the 3 anatomy types.

• 93% of subjects with type 3 anatomy had deep venous system drained into the left TS.

• Even though pressure changes were small, a positive gradient downstream was found in DAVFs patients. Initial findings support the hypothesis that DAVFs result in venous hypertension which may be the mechanism ultimately leading to aggressive presentation.
Discussion cont.

• 4D flow MRI allows blood flow directionality assessment along the dural venous sinuses, which helps detecting retrograde flow and in the classification of DAVFs severity.

• This study demonstrates:
  
  • The large volume coverage and high spatial/temporal resolution of 4D flow MRI can provide pathophysiological insight and help clinicians in the characterization of DAVFs.
  
  • Feasibility of noninvasive relative pressure measurements in the dural venous sinuses with 4D flow MRI in the context of DAVF.
Acknowledgements

In memory of Zachary J Clark, MD
January 25, 1986 – March 6, 2017
Acknowledgements

- Jacob Macdonald
- Dahan Kim
- Carson Hoffman
- Philip Corrado
- UW-Madison MR Flow Group
- GE Healthcare for research support

Funding

- NIA grant P50-AG033514
- NIHHLBI R01HL072260
- NIGMS R25GM083252
- ASNR Alzheimer’s Grant Award

MRI Technicians:
- Kelli Hellenbrand
- Sara John
- Jenelle Fuller