Challenges in Measuring CSF Flow with MRI

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Background

- MR imaging of CSF flow is difficult to use in clinical practice
- This is because:
  - Qualitative visual assessment is subjective and unreliable
  - Quantitative assessment although objective has wide variations in reported values to be definitive
Qualitative Analysis of CSF Flow

- Simple
- Subjective
- Can be performed on PACS workstation
CSF Flow in NPH: Qualitative Analysis

- Markedly increased flow is seen through aqueduct and 4th ventricle
CSF Flow in NPH: Sagittal

Normal Subject

NPH
CSF Flow in CMI: Qualitative Analysis

Normal Subject

Mild Flow abnormality

Severe Flow abnormality
Quantitative Analysis of CSF Flow

- Done off-line using flow software
  - All three major MR vendors have soft wares (need to be purchased)
- Objective
- A free software made available by Dr. Olivier Baledent can be downloaded from:
  http://www.tidam.fr/
Quantitative Analysis of CSF Flow

- **In-plane Analysis**: Velocity can be determined
- **Through plane Analysis**: Flow rate and stroke volume can be determined
Quantitative Analysis of CSF Flow in NPH

- Requires through-plane (axial) imaging of the aqueduct
- All images transferred to flow analysis program and aqueduct outlined on all cine-PC images
Quantitative Analysis of CSF Flow in NPH

- Volumetric CSF systolic and diastolic flow rate is calculated in micro liters
- CSF Stroke Volume = CSF flow rate in CC/2
- CSF stroke volume > 42 microliter *
  - Sensitivity=80% ; Specificity =100%

Bradley WG et al Radiology 1996; 198:523-529
Difficulties in Using Quantitative Analysis

- Wide variations
  - Different hardware and software
  - Variations in physiology and anatomy
    - Arterial inflow and venous outflow
    - Craniospinal compliance
    - CSF space size
How to Address the Variations?

- Using subject (patient) as their own control using a physiological challenge

- This will be similar to the use of infusion and jugular venous compression in CSF pressure studies
Problems of Using Physiological Challenge with Cine-PC

- Cine-PC sequence used for MR measurement of CSF flow takes 3-7 minutes depending on resolution employed and subject’s heart rate.
How to Use a Physiological Challenge with MR

- Decrease acquisition time of routine cine-PC sequence from 3-7 minutes to less than 15 seconds
- Use of real-time CSF flow imaging
- We have used both strategies to study CSF flow with a physiological challenge
Physiology-based Quantitative Assessment of CSF Flow with Valsalva Maneuver in Normal Subjects
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Hypothesis

- During Valsalva CSF flow across the foramen magnum decreases (compared to resting) and after Valsalva it increases to resting or higher value in normal subjects.
Post-Valsalva CSF Flow

Normal Subject  Chiari I Malformation
Valsalva Device

Figure 5
Imaging Methods

- Fast cine phase-contrast CSF flow imaging
  - Decreased acquisition time of routine cine-phase contrast (cine-PC) sequence from several minutes to <15 seconds using parallel imaging

- Pencil-beam Real Time CSF flow imaging
  - The pencil-beam velocity imaging works by excitation of a cylindrical RF pulse. The beam diameter and the length can vary
Fast Cine Phase-Contrast Imaging in Normal Subjects with Valsalva maneuver
Scanning Protocol

- Eight subjects
- CSF flow pulsations assessed just below the foramen magnum
  - Resting
  - During Valsalva maneuver
  - Immediately after Valsalva maneuver
    - Scanning starts 5-seconds after termination of Valsalva
  - The length of Valsalva was between 15-20 seconds
On all axial slices, thecal sac was outlined to calculate CSF flow during a cardiac cycle
CSF Flow Variables

- **CSF_OFV** = CSF Oscillatory Flow volume
  - sum of absolute volumes of CSF systolic and diastolic flows
- **CSF_Amp** = CSF flow waveform Amplitude
  - Height of the waveform from Maximum Systolic to Maximum Diastolic flow
- **CSF_Flow Rate** = **CSF_OFV** * HR
Results

CSF Oscillatory Flow volume: CSF_OFV

CSF_OFV decreased during Valsalva $P<0.003$

- Resting = $1.13 \pm 0.22$ ml
- During Valsalva = $0.77 \pm 0.14$ ml

CSF_OFV increased after Valsalva $P=0.001$

- During Valsalva = $0.77 \pm 0.14$ ml
- Immediately after Valsalva = $1.32 \pm 0.18$ ml
CSF Flow Waveform Amplitude: CSF_Amp

CSF_Amp decreased during Valsalva P=0.007
Resting=4.51 ± 1.64 ml/s
During Valsalva=3.69 ± 1.59 ml/s

CSF_Amp increased after Valsalva P=0.001
During Valsalva=3.69 ± 1.59 ml/s
Immediately after Valsalva =5.27 ± 1.49 ml/s
Heart Rate Changes

Heart Rate increased during Valsalva $P=0.002$

Resting=$67.8 \pm 10.4$ per minute
During Valsalva=$78.5 \pm 9.8$ per minute

Heart Rate decreased after Valsalva $P < 0.001$
During Valsalva=$78.5 \pm 9.8$ per minute
Immediately after Valsalva = $65.5 \pm 5$ per minute
CSF Flow Rate

Normalized for Heart Rate Differences

CSF Flow Rate decreased during Valsalva \( P = 0.005 \)

- Resting = \( 1.06 \pm 0.58 \) ml/s
- During Valsalva = \( 0.58 \pm 0.28 \) ml/s

Flow rate increased after Valsalva \( P < 0.001 \)

- During Valsalva = \( 0.58 \pm 0.28 \) ml/s
- Immediately after Valsalva = \( 1.3 \pm 0.37 \) ml/s
Pencil-beam CSF Flow Imaging in Normal Subjects with Valsalva maneuver
Pencil-beam CSF Flow Imaging

- Pencil beam technique is not a new technique but has been available since early 1990s

- It has never systematically used in clinical practice for CSF flow imaging
The pencil-beam velocity imaging works by excitation of a cylindrical RF pulse. The beam diameter and the length can vary but the one we tried in this preliminary experiment was 6-cm long and had a diameter of 2-cm.
Each pencil beam sequence was about 90-seconds long. Initially the subject was resting and then performed Valsalva for 15-20 seconds which was followed by post-Valsalva period.
Subject 1
Subject 2
Subject 2 (second attempt)
Correlation between Pressure and Flow Studies

CSF Flow with Pencil Beam

Lumbar – Ventricular Pressure
Conclusion

- It is possible to quantitatively assess CSF flow in response to Valsalva maneuver

- For now we intend to apply the technique in assessment of CSF flow obstruction in Chiari I malformation
Application to Chiari I Patients

- In Chiari I patients, immediately after Valsalva, CSF flow will not increase but may show further decrease compared to resting.
- In Chiari I patients, during Valsalva, CSF flow will decrease more than in normal subjects.
This technique can also potentially be used in assessment of aqueductal CSF flow in NPH.

Although early, we believe that this technique will open a new chapter in CSF flow imaging with MRI.
Thank You