Challenges in Measuring CSF Flow with MRI

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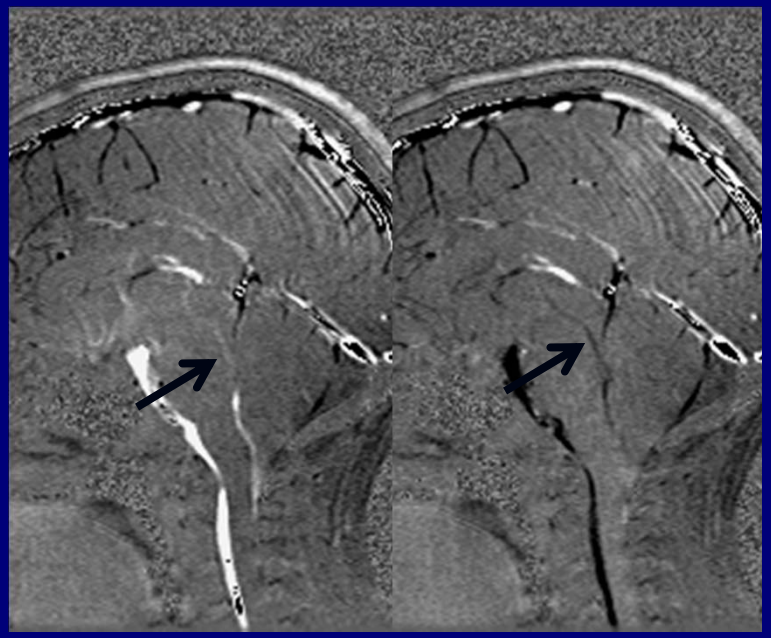
Background

- 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

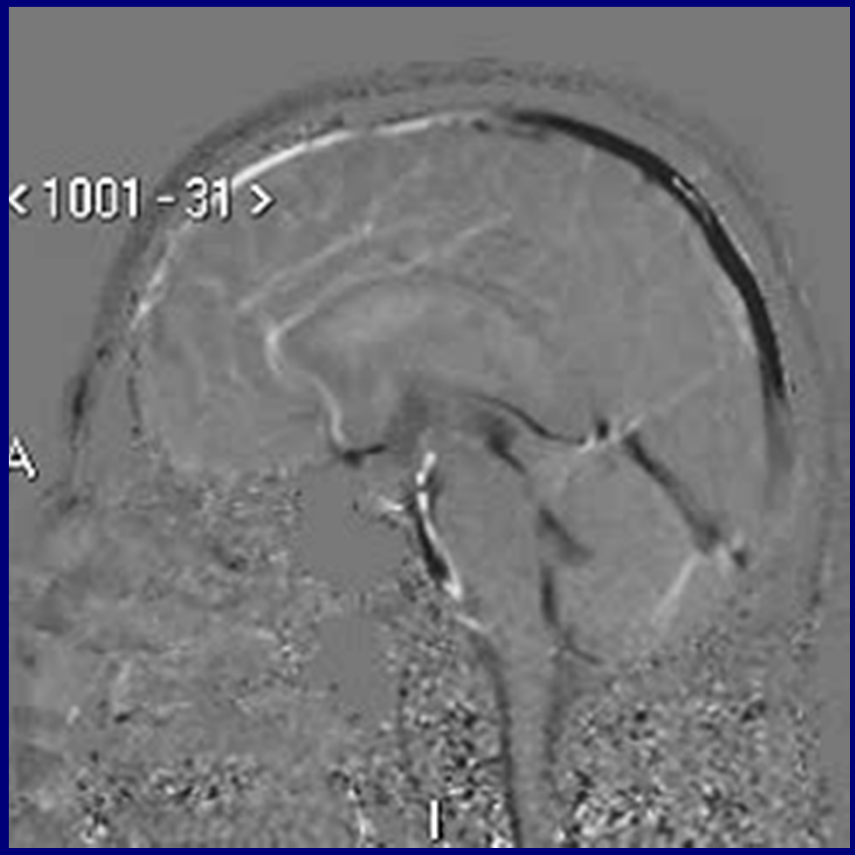
Qualitative Analysis of CSF Flow

- Simple
- Subjective
- Can be performed on PACS workstation

CSF Flow in NPH: Qualitative Analysis



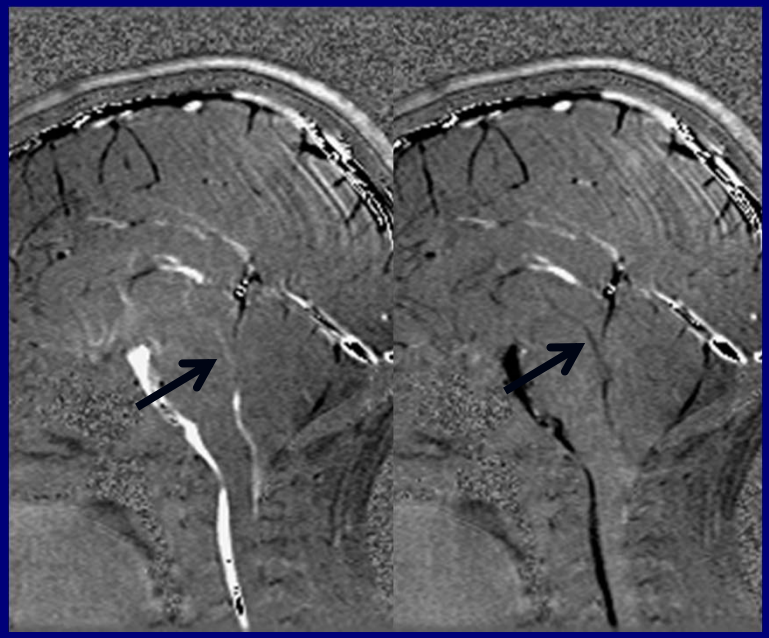
Normal Subject



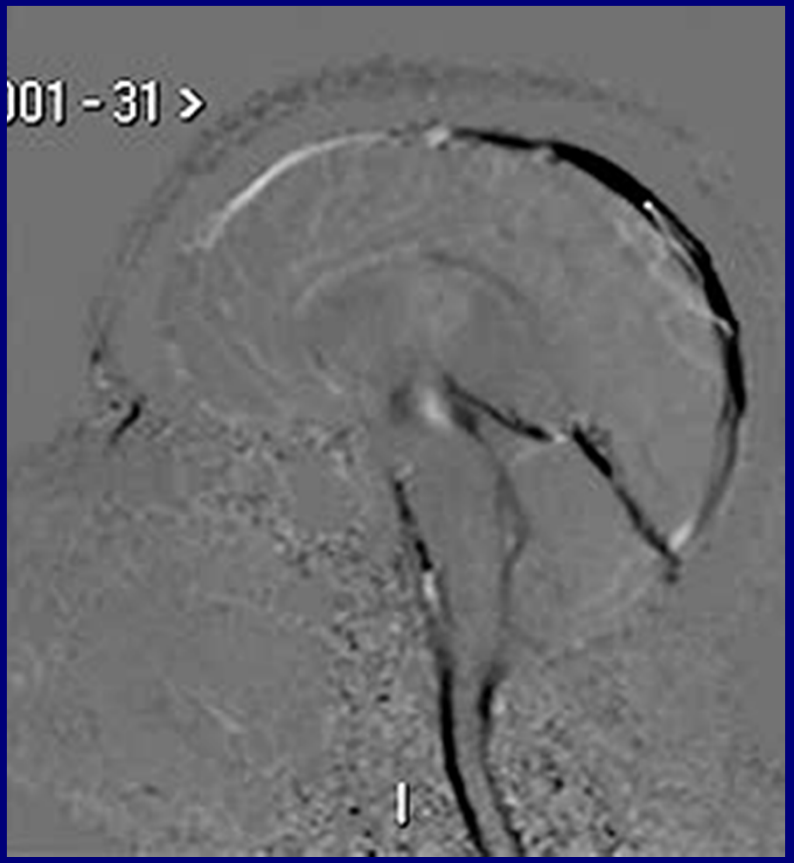
NPH

- 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

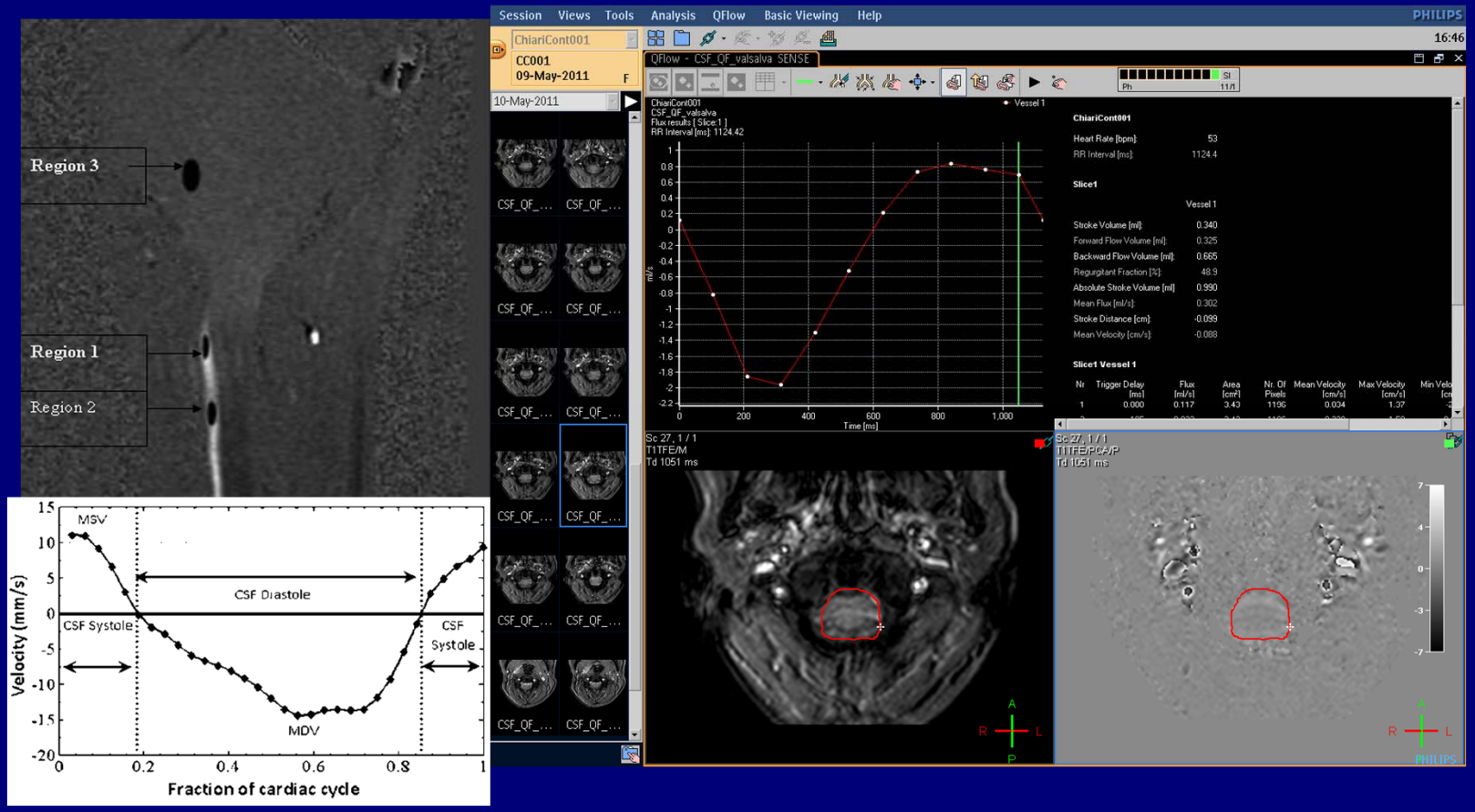
Severe Flow abnormality

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:

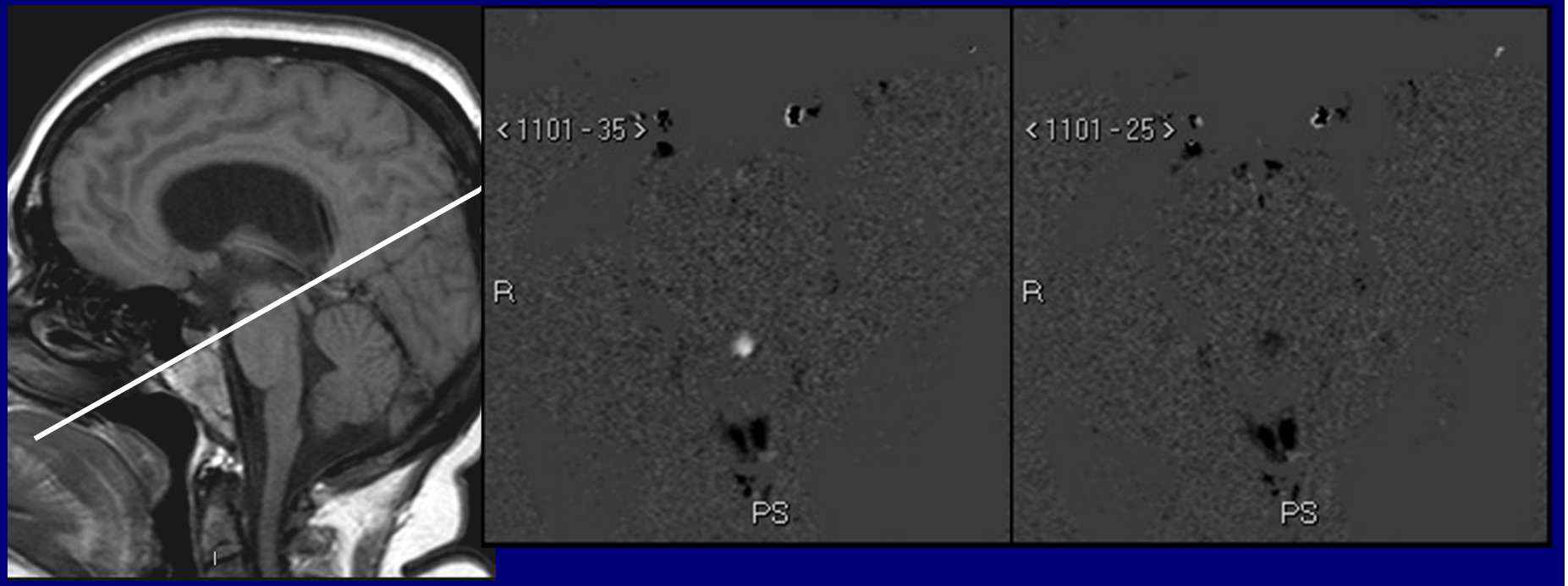
http://www.tidam.fr/

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

Contributors

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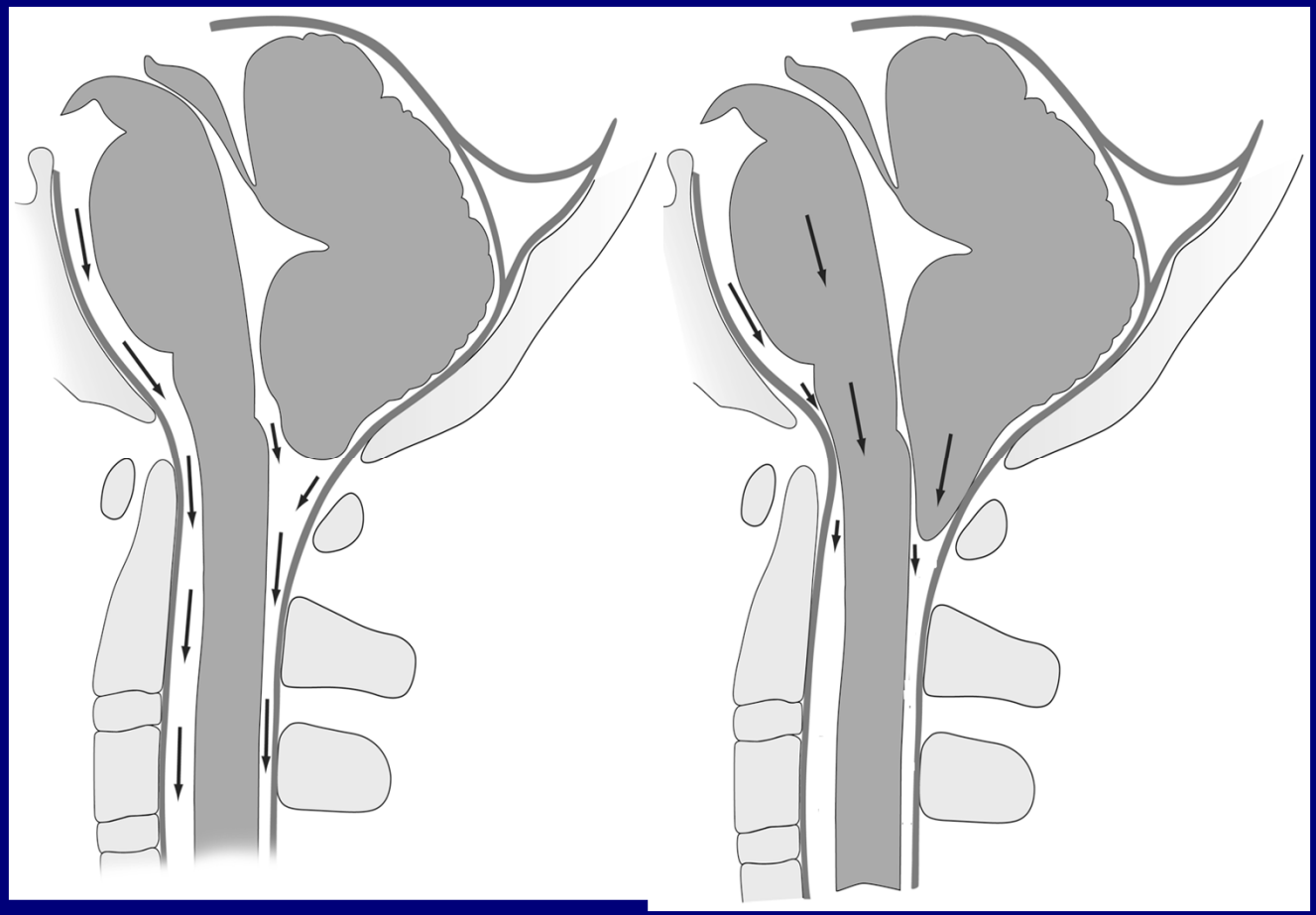
Hypothesis

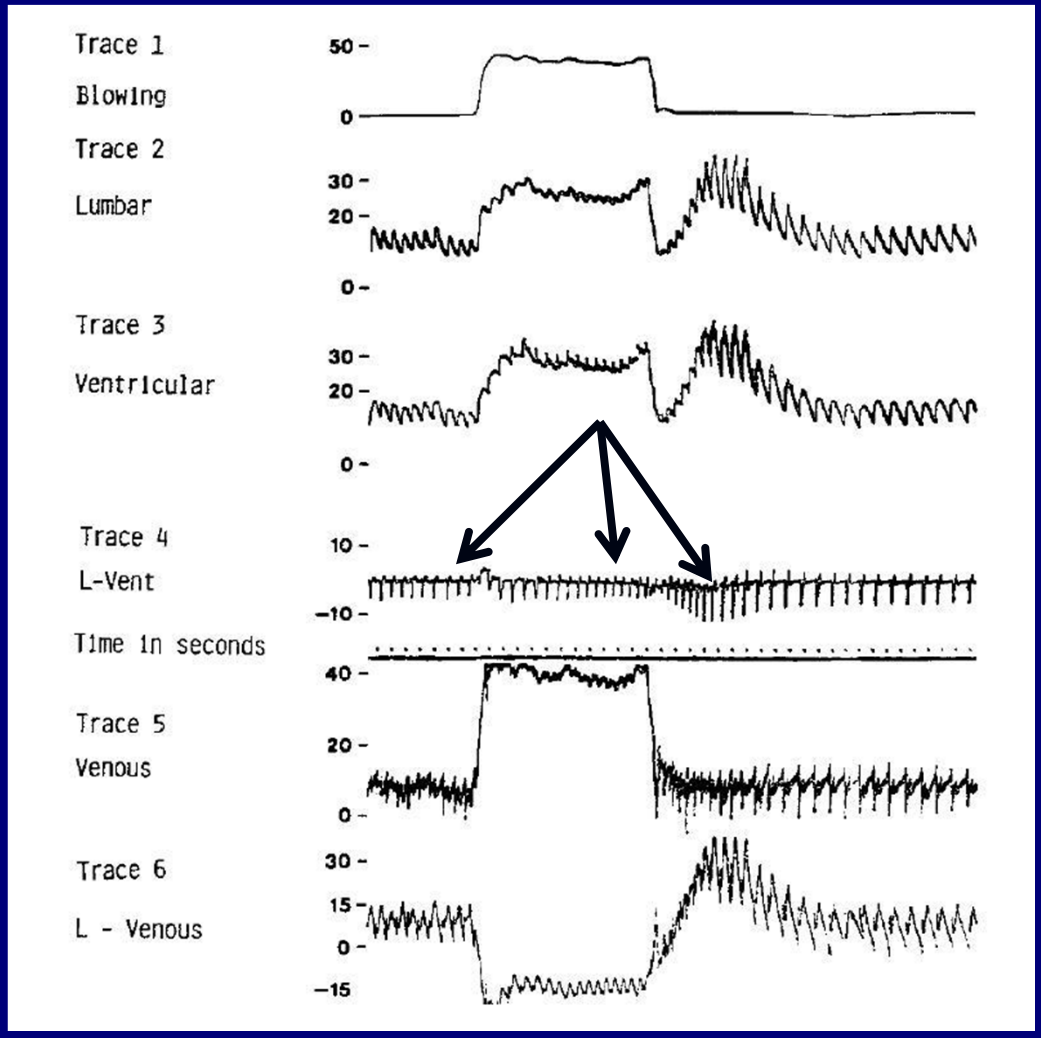
- During Valsalva CSF flow across the foramen magnum decreases (compared to resting) and after Valsalva it increases to resting or higher value in normal subjects

Post-Valsalva CSF Flow



Normal Subject

Chiari I Malformation



Williams B. Simultaneous cerebral and spinal fluid pressure recordings. I. Technique, physiology, and normal results. Acta Neurochir (Wien) 1981; 58:167-185.

Valsalva Device

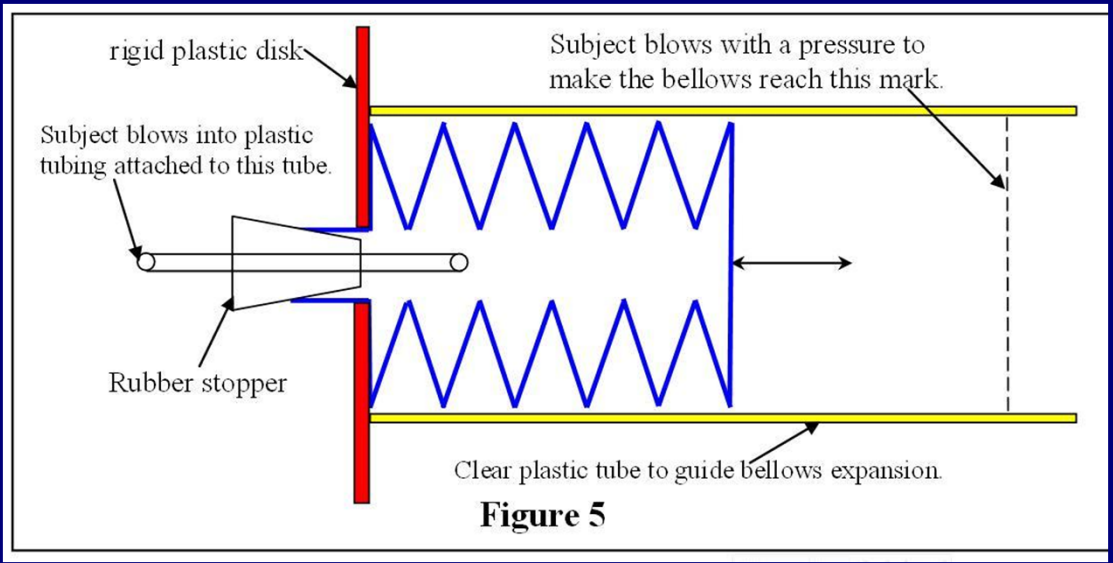


Figure 5

Imaging Methods

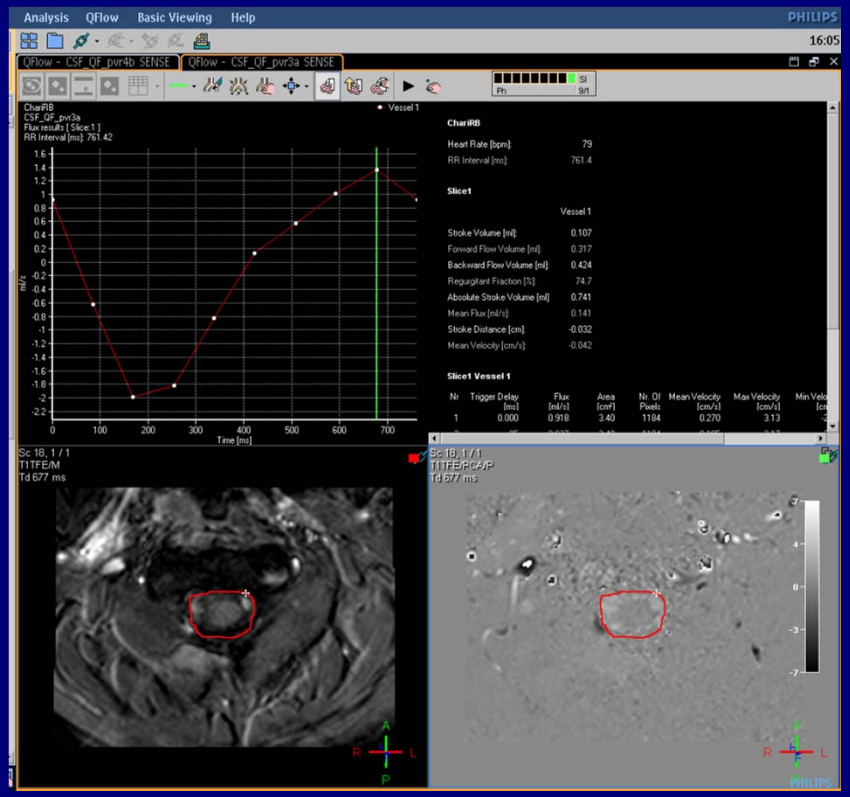
- Fast cine phase-contrast CSF flow imaging
  - Decreased acquisition time of routine cine-phase contrast (cine-PC) sequence from several minutes to <15 seconds using parallel imaging
- Pencil-beam Real Time CSF flow imaging
  - The pencil-beam velocity imaging works by excitation of a cylindrical RF pulse. The beam diameter and the length can vary

Fast Cine Phase-Contrast Imaging in Normal Subjects with Valsalva maneuver

Scanning Protocol

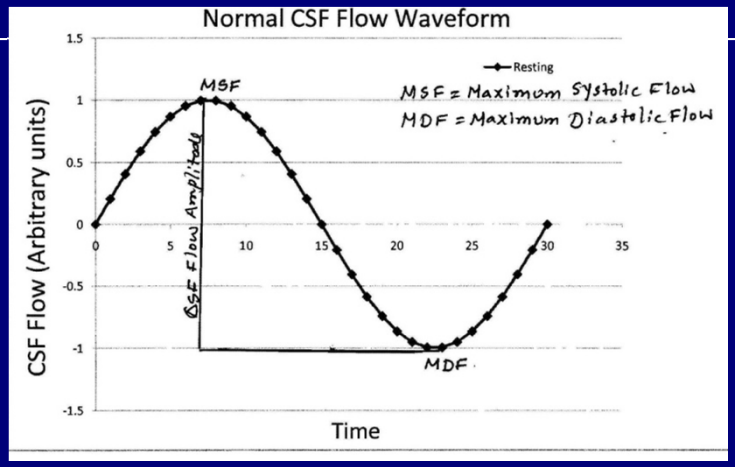
- Eight subjects
- CSF flow pulsations assessed just below the foramen magnum
  - Resting
  - During Valsalva maneuver
  - Immediately after Valsalva maneuver
    - Scanning starts 5-seconds after termination of Valsalva
  - The length of Valsalva was between 15-20 seconds

Image Analysis



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 $\pm$ 1.64 ml/s

During Valsalva=3.69 $\pm$ 1.59 ml/s

CSF_Amp increased after Valsalva P=0.001

During Valsalva=3.69 $\pm$ 1.59 ml/s

Immediately after Valsalva =5.27 $\pm$ 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

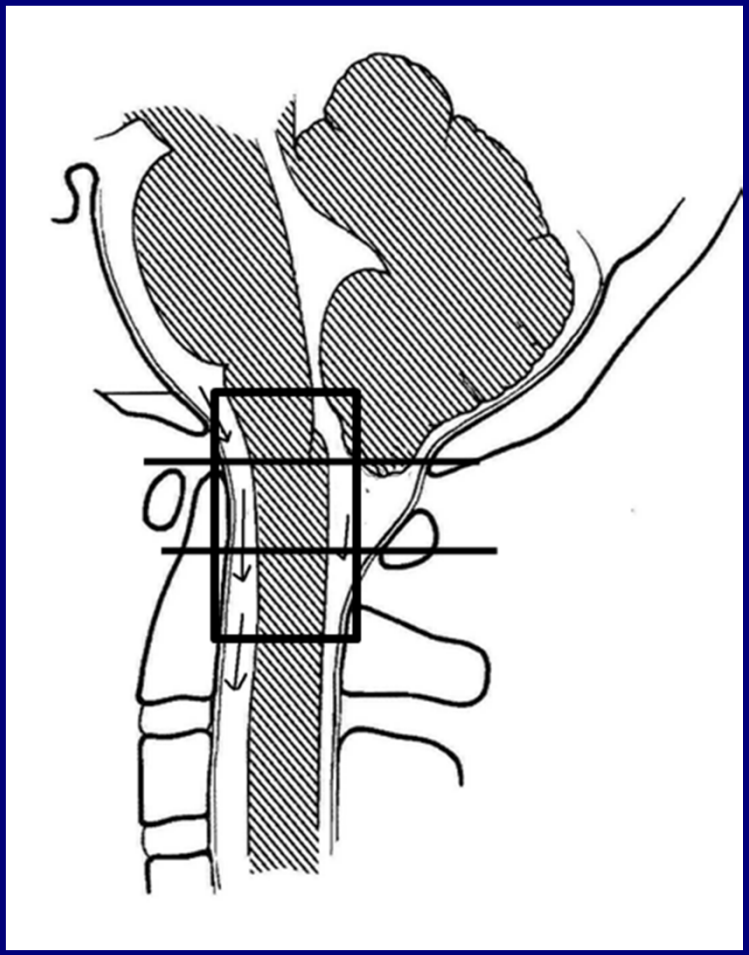
Immediately after Valsalva =1.3 $\pm$ 0.37 ml/s

Pencil-beam CSF Flow Imaging in Normal Subjects with Valsalva maneuver

Pencil-beam CSF Flow Imaging

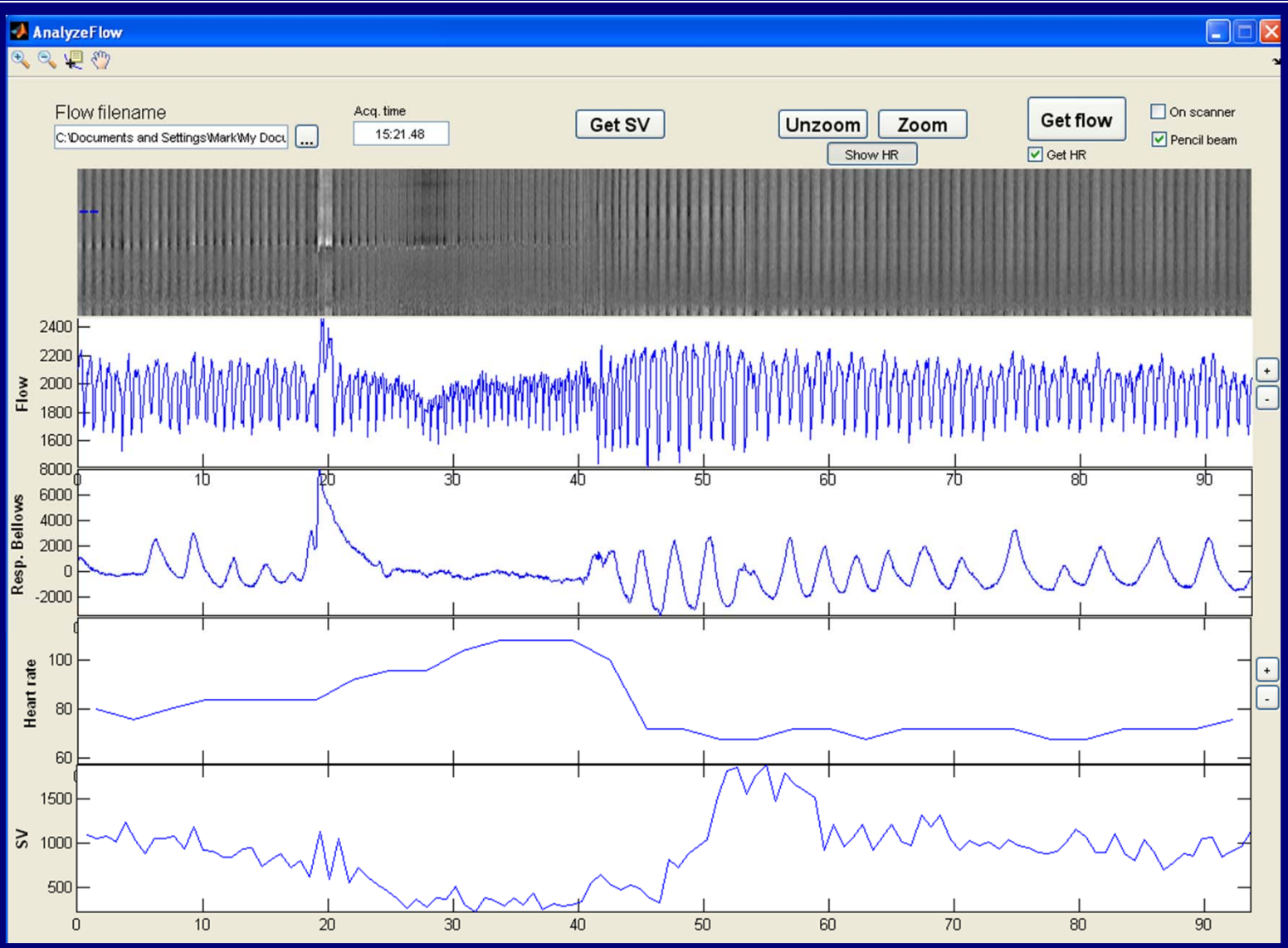
- Pencil beam technique is not a new technique but has been available since early 1990s
- It has never systematically used in clinical practice for CSF flow imaging

- 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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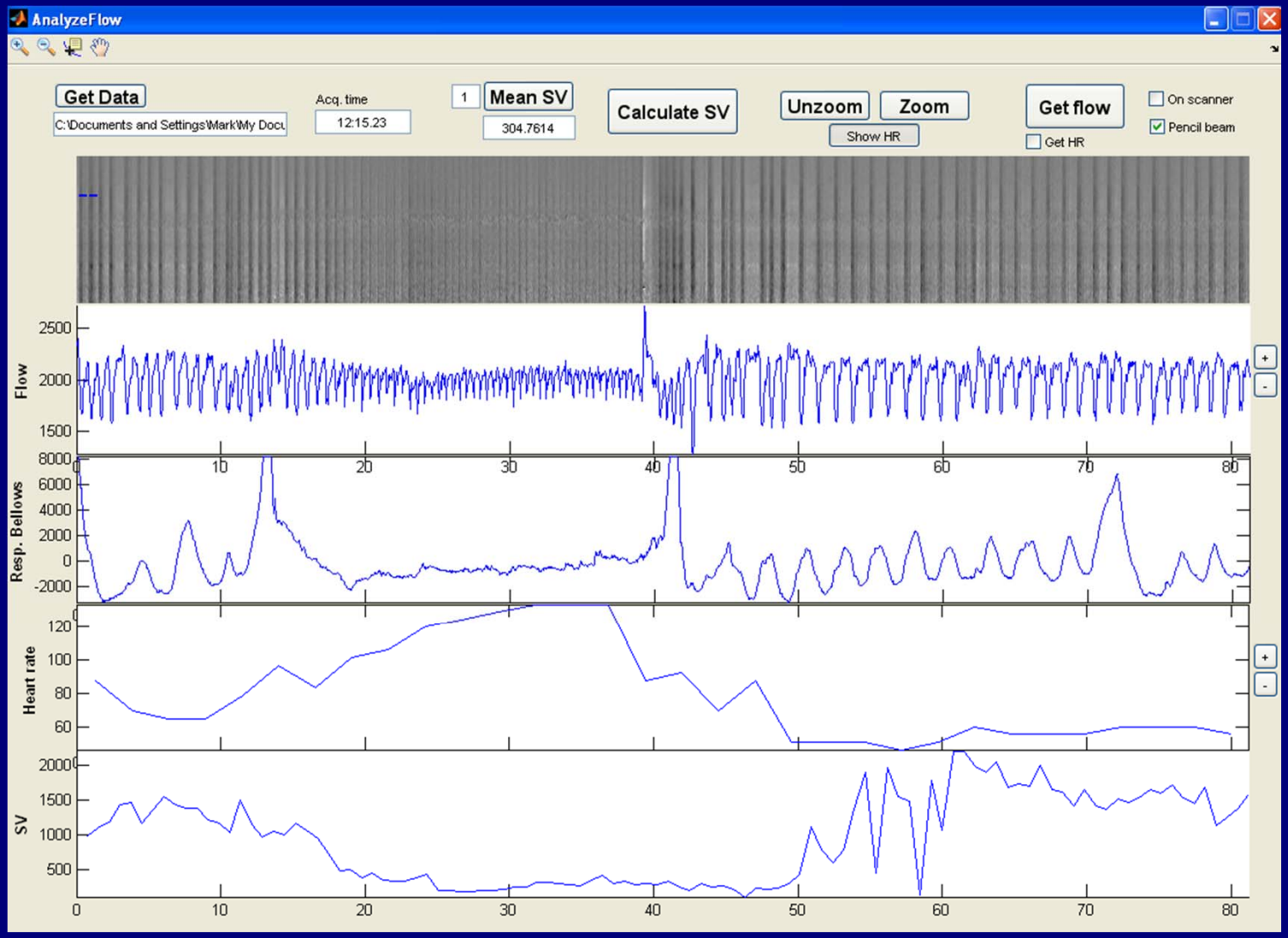
Subject 2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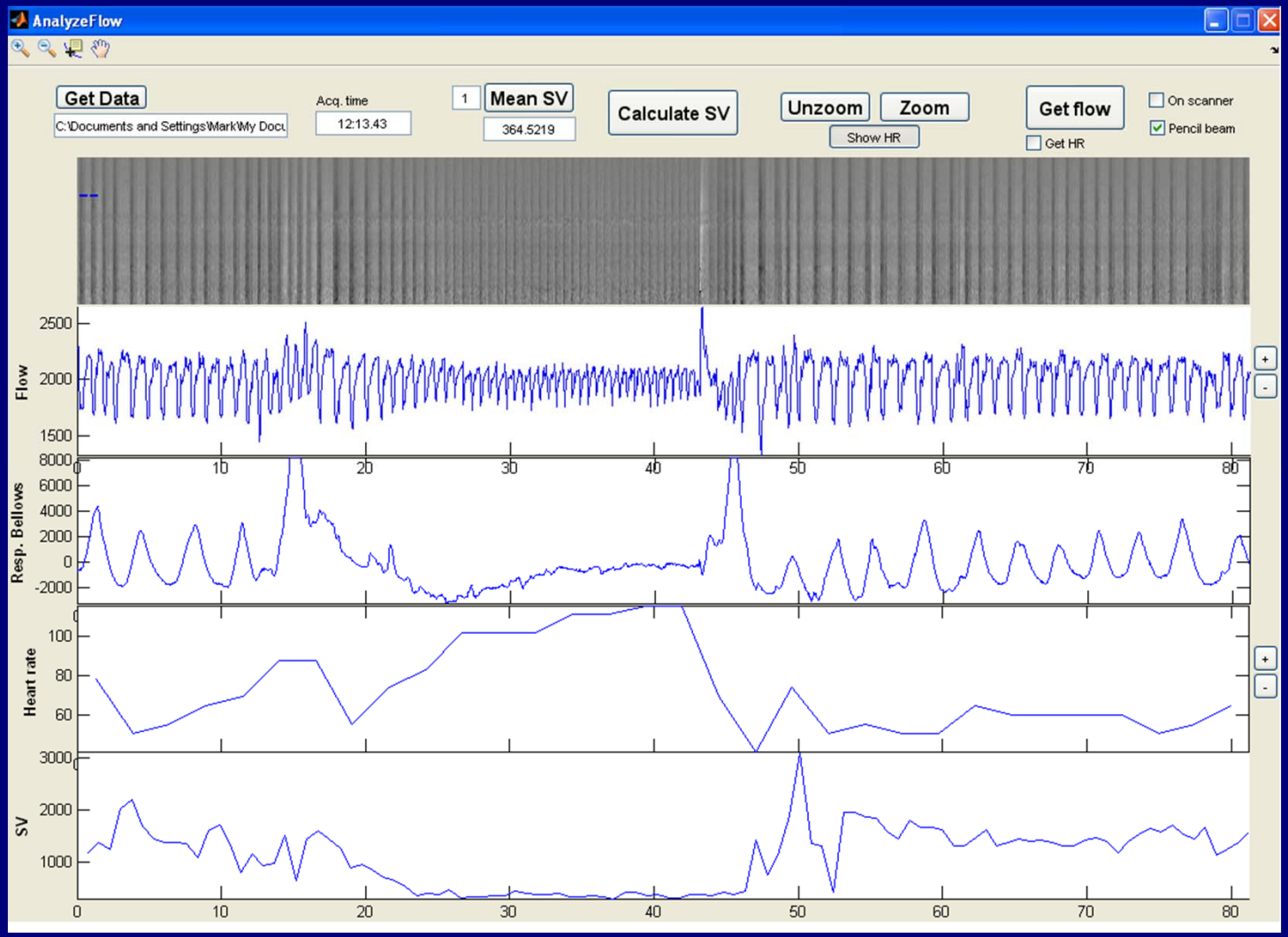
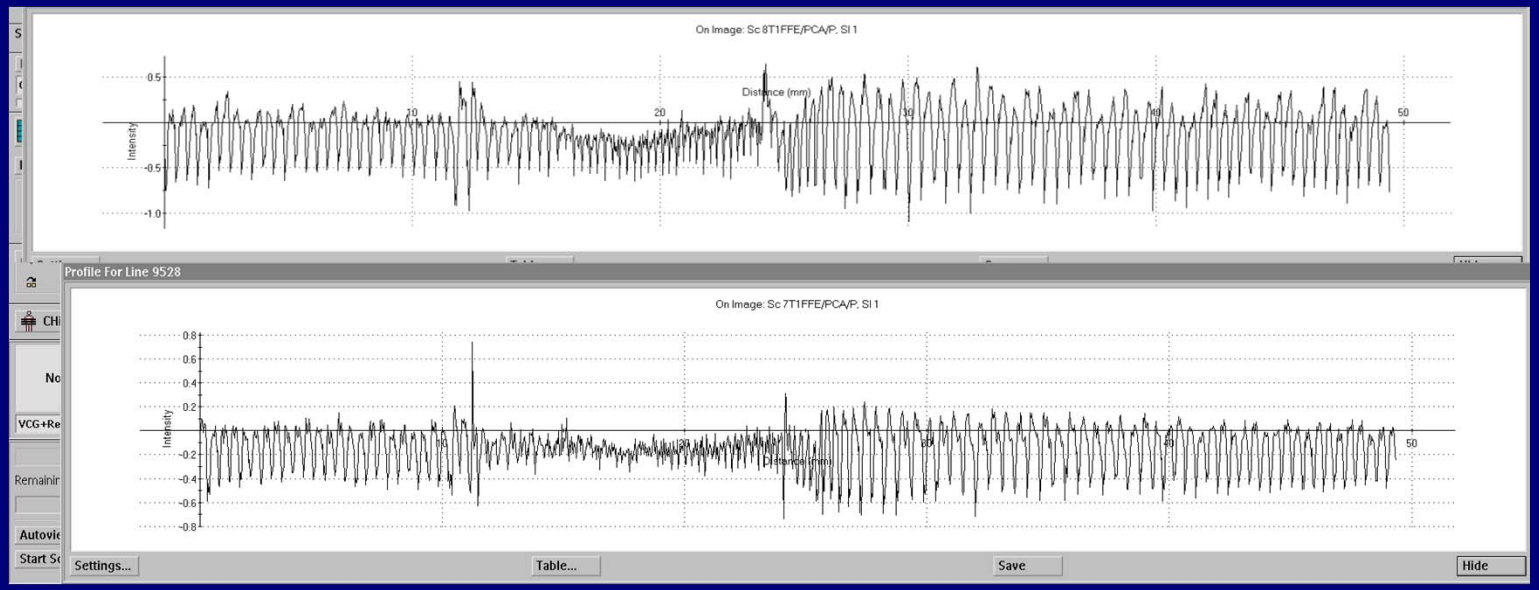
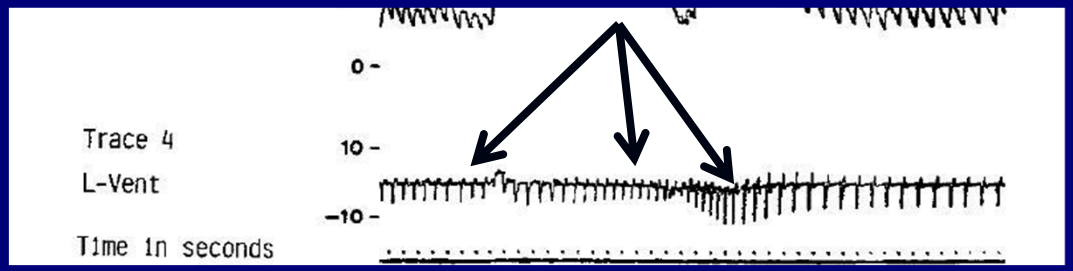
Subject 2 (second attempt)



Correlation between Pressure and Flow Studies



CSF Flow with Pencil Beam

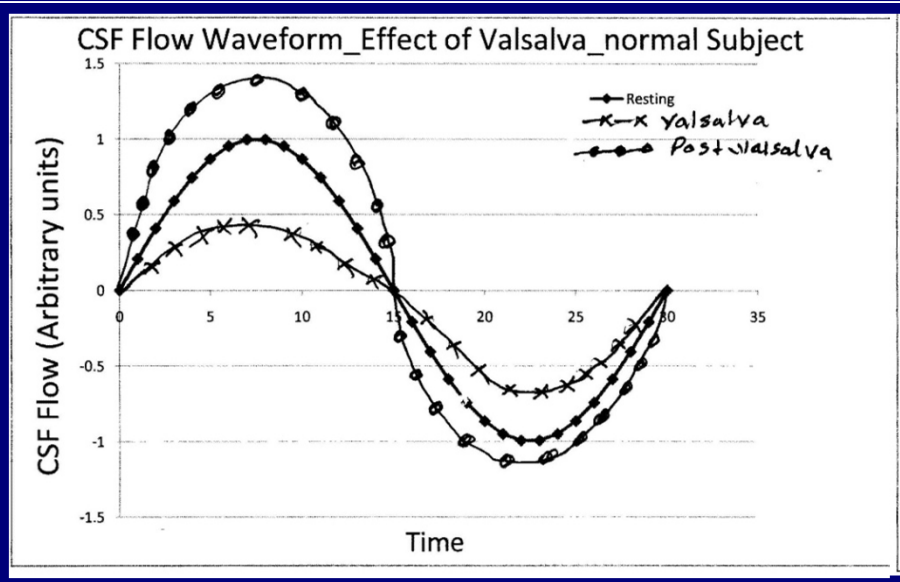


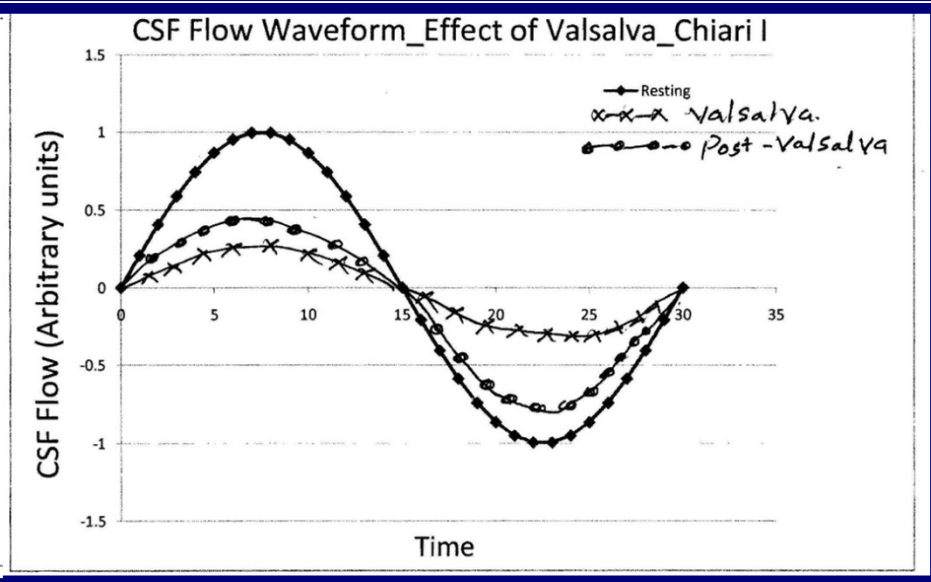
Lumbar –Ventricular Pressure

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 iNPH
- Although early, we believe that this technique will open a new chapter in CSF flow imaging with MRI

Thank You

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