Measuring Brain Stiffness In Chronically Shunted Hydrocephalus Patients Using MR Elastography

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Introduction

- Ultrasound elastography used clinically but limited because of
  - 1) penetrate through bone (e.g. skull)
  - 2) high frequencies limit the penetration depth
- External applicators vibrate the tissue
  - synchronized to the MRI sequences
  - sensitized to microscopic tissue motion
- Use MRE to understand hydrocephalus
- Hypothesis: changes in brain elastance with hydrocephalus related to symptoms, e.g., chronic headaches [1].
- Changes in elastance association with disease onset or in development overtime with shunting
- Causes headaches with a functioning shunt [2, 3]
- Goal: MRE use to investigate brain elastance role in pathophysiology and symptoms of pediatric hydrocephalus

Methods

- 27 shunt-dependent hydrocephalus patients (age 14-35, median age 19), shunted as infants were selected
- 20 healthy controls (age 8-46, median age 22)
- Excluded Patients: abnormally large ventricles
- 3T Philips MRI used
- MRE data acquired, inducing vibration via MRI-compatible pneumatic pistons at 30Hz, transmitted through the zygomatic arches
- Clinical measures: The Headache Disability Index (HDI), Hydrocephalus Outcome Questionnaire (HOQ), and other clinical data collected e.g., Beck Depression Inventory (BDI), clinical history and outcome, and shunt revision
- Brain elastance averaged across white and grey matter masks and within lobar regions
- Investigate linear associations with ventricular size, HDI and HOQ

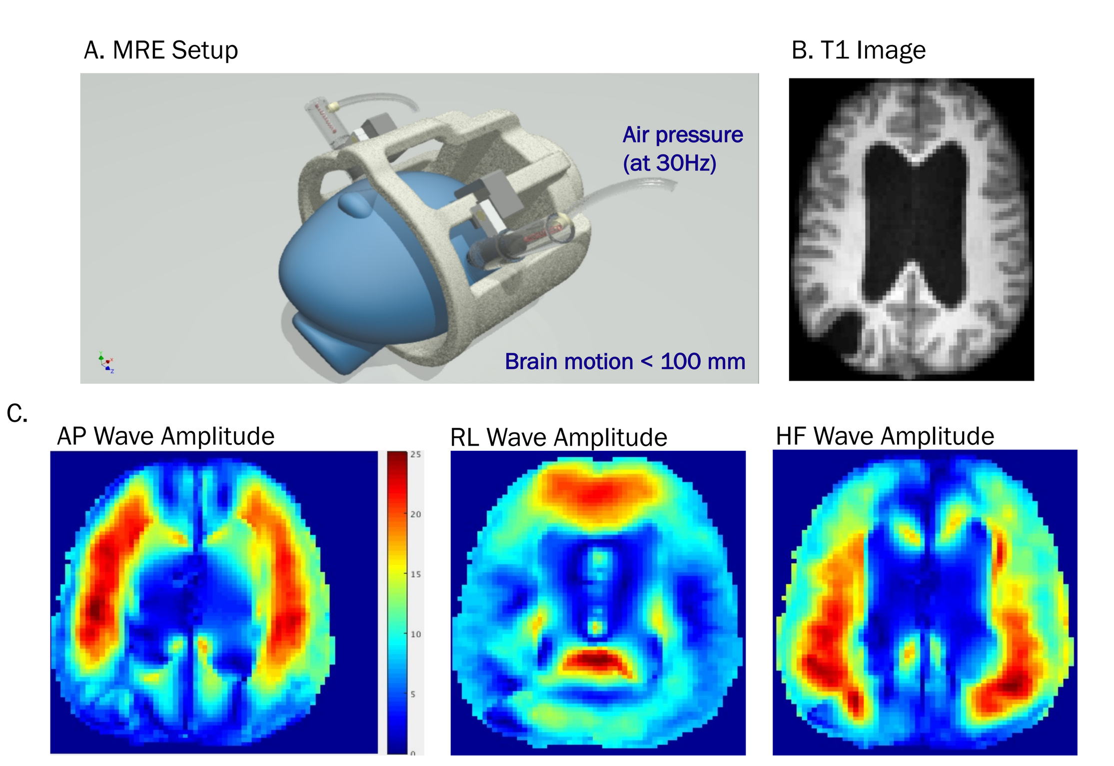


Figure 1: A. MRE vibrations are induced through spring loaded, air activated pistons, and fits inside the standard MRI head coil. It presses gently against cheekbone after the patient has been positioned in the coil. Simple 1-2 minutes to set up.
B. An anatomical T1 image. C. Examples of wave amplitude maps; AP = Anterior Posterior, RL = Right Left, HF = Head Foot.

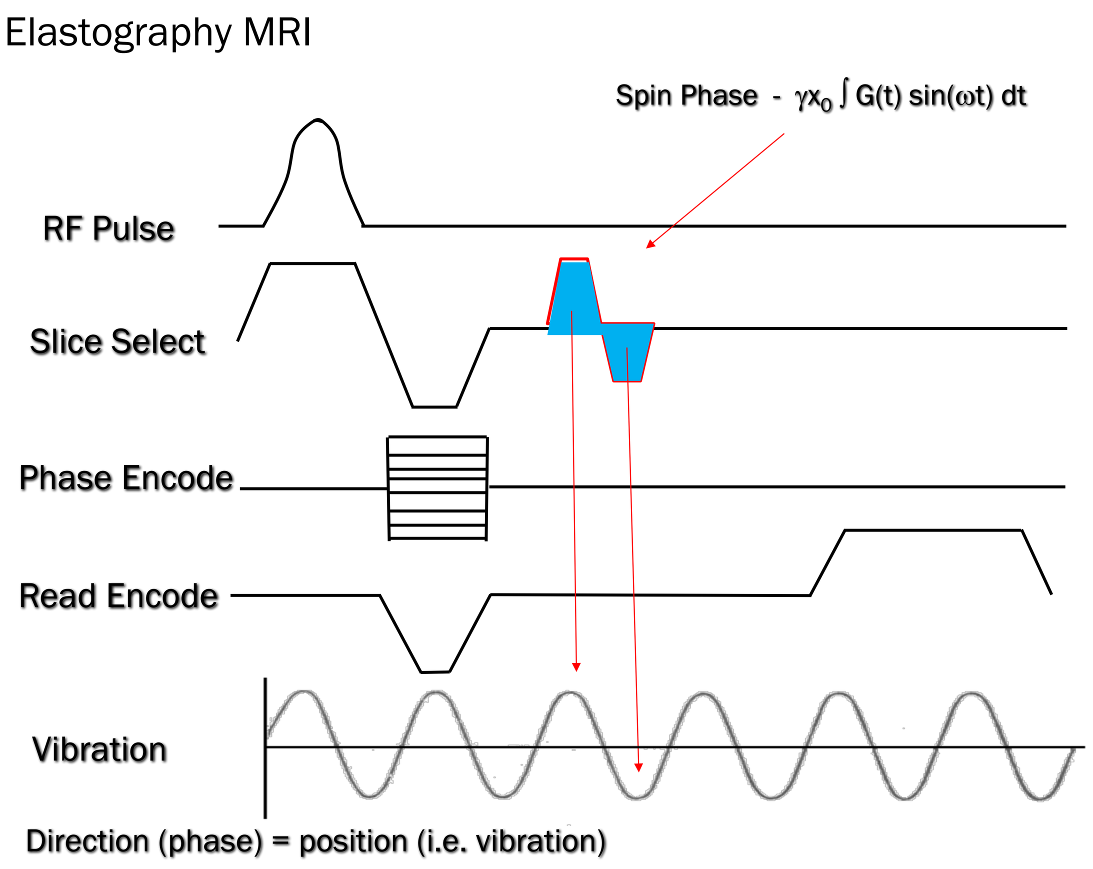


Figure 2: MRE uses a cine phase contrast sequence. Multiple phase are acquired separately to reconstruct image across one vibration cycle. Typical phase sensitivity ~ 2 μm/radian.

Results

- Brain stiffness was reduced in patients compared to controls
- **Whole brain WM:** G* = 1.71 ± 0.20 kPa vs. 1.93 ± 0.13 kPa, $p < 0.001$
- **Frontal GM:** G* = 1.48± 0.14 kPa vs. 1.34 ± 0.16 kPa, p=0.00133
- **Occipital GM:** G* = 1.28± 0.11 kPa vs. 1.11 ± 0.20 kPa, p<0.001
- Parietal GM: G* = 1.30 ± 0.14 kPa vs. 1.23 ± 0.21 kPa, p=0.395
- **WM** and **Occipital GM** stiffness was negatively correlated with ventricular size
  - **R^2 = 0.11; 0.23, p = 0.006; 0.003** respectively
- Weak negative correlation between parietal lobe grey matter stiffness and Headache Disability Index HDI, **R^2 = 0.17, p = 0.028**
- Decreased stiffness with more HDI score, **R^2 = 0.17, p = 0.028**
- Decreased brain stiffness was associated with multiple shunt revisions.

Objective 1A: Patient and control brain stiffness

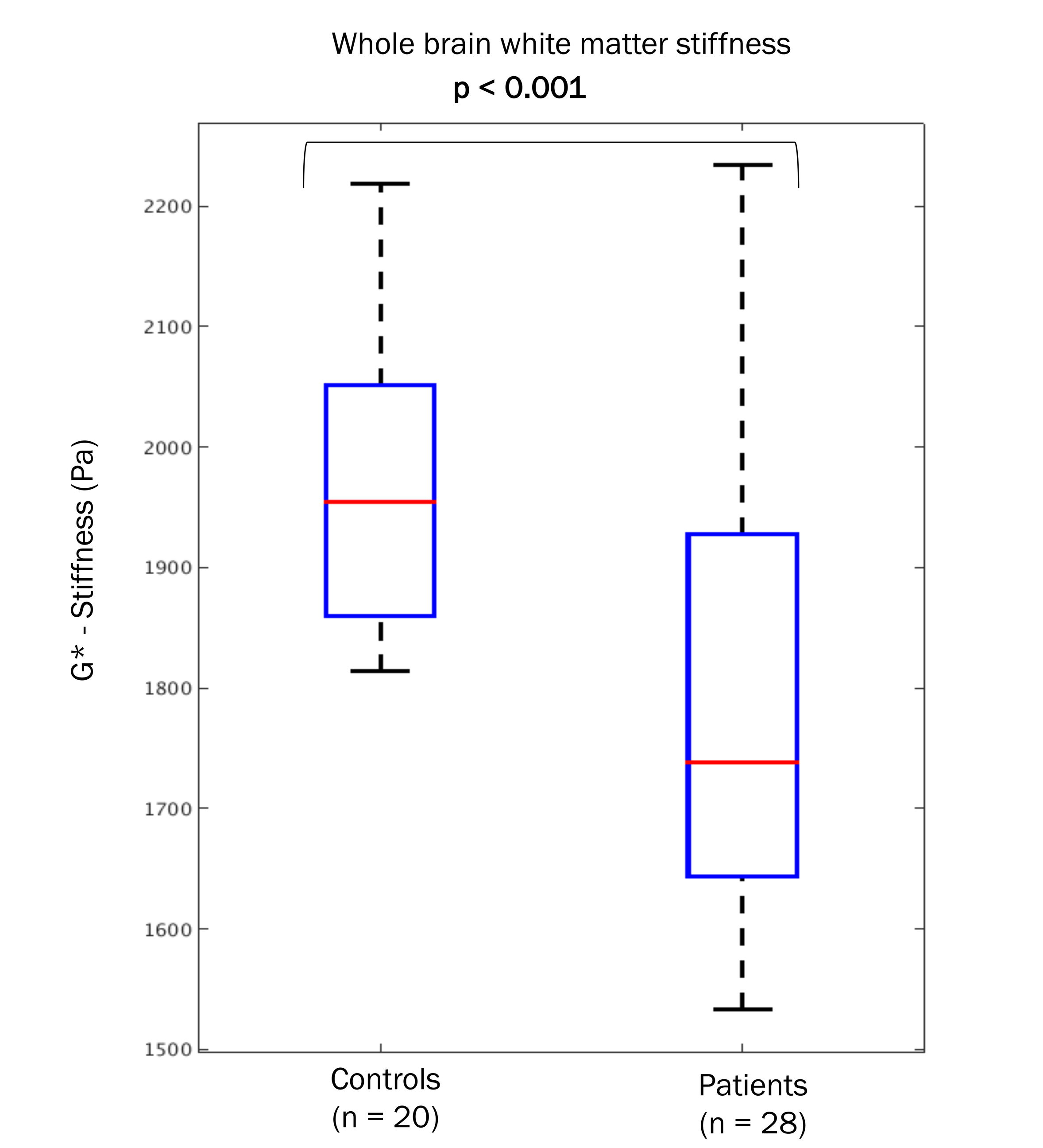


Figure 2: *Bar Graph of Brain Stiffness in Patients and Control Group.* Brain stiffness is decreased in white matter in chronically shunted patients compared to healthy controls WM: G* = 1.71 ± 0.20 kPa vs. 1.93 ± 0.13 kPa respectively.

Objective 1B: Regional differences in brain stiffness

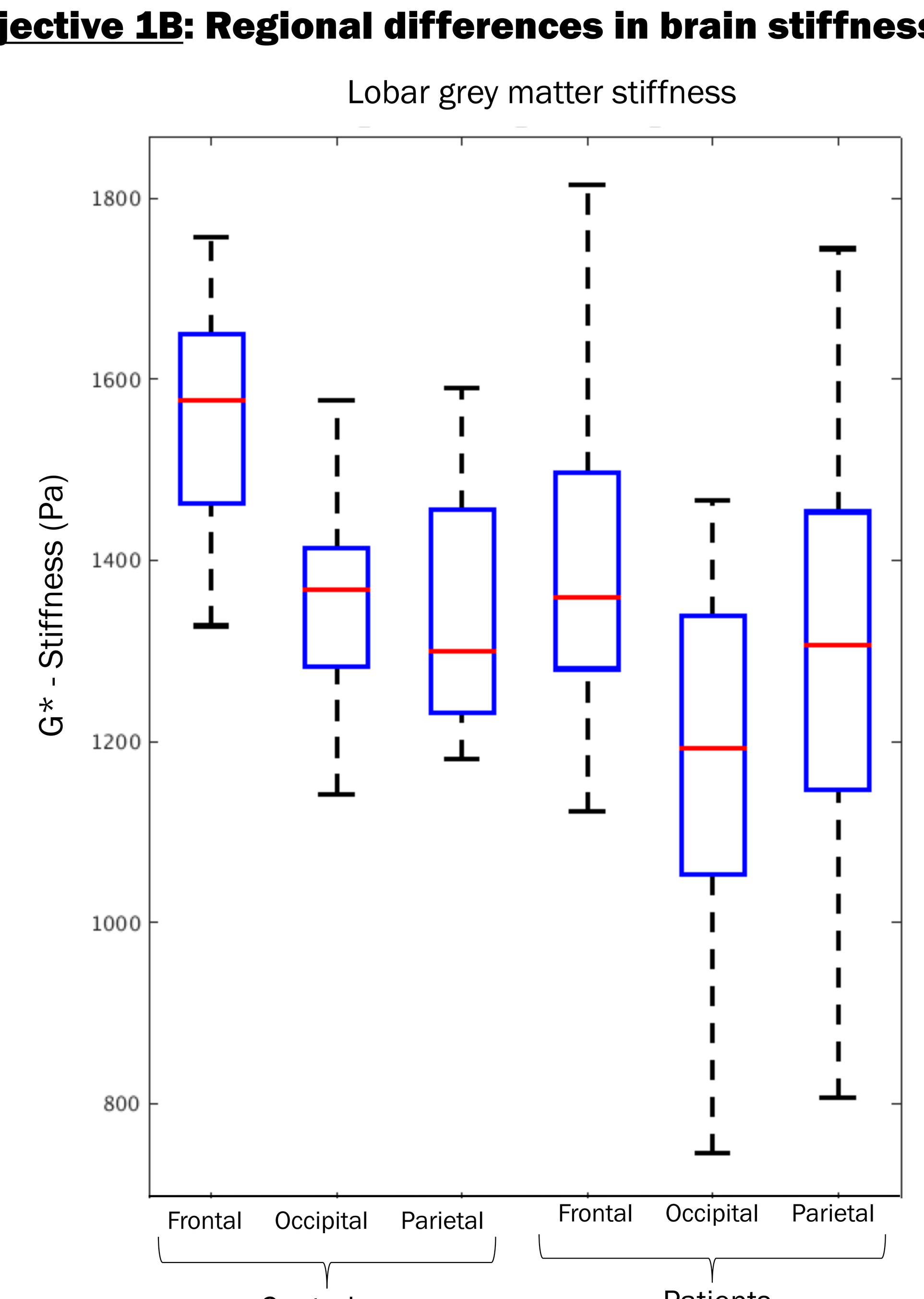


Figure 3: *Brain Regional Differences Between Patients and Control Group:* Stiffness is reduced in patients compared to controls

Frontal GM : G* = 1.48± 0.14 kPa vs. 1.34 ± 0.16 kPa, p=0.00133

Occipital GM : G* = 1.28± 0.11 kPa vs. 1.11 ± 0.20 kPa, p<0.001

Parietal GM: G* = 1.30 ± 0.14 kPa vs. 1.23 ± 0.21 kPa, p=0.395

Results Cont'd

Objective 2A: Ventricular Size and Headache Disability Index Association with Brain Stiffness

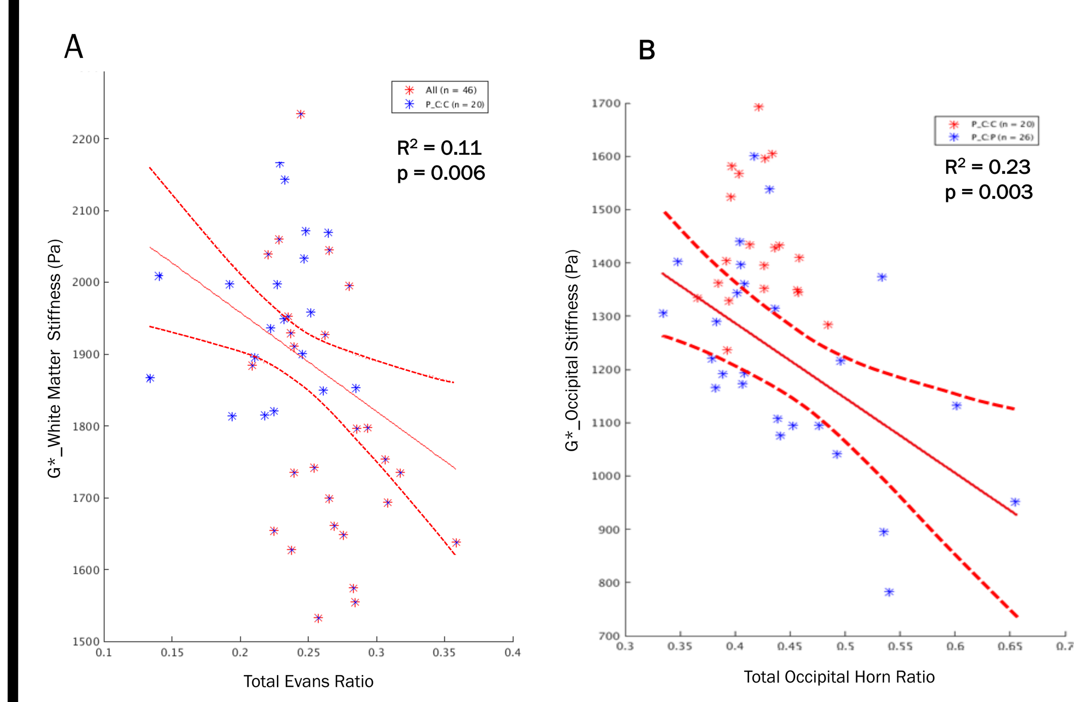
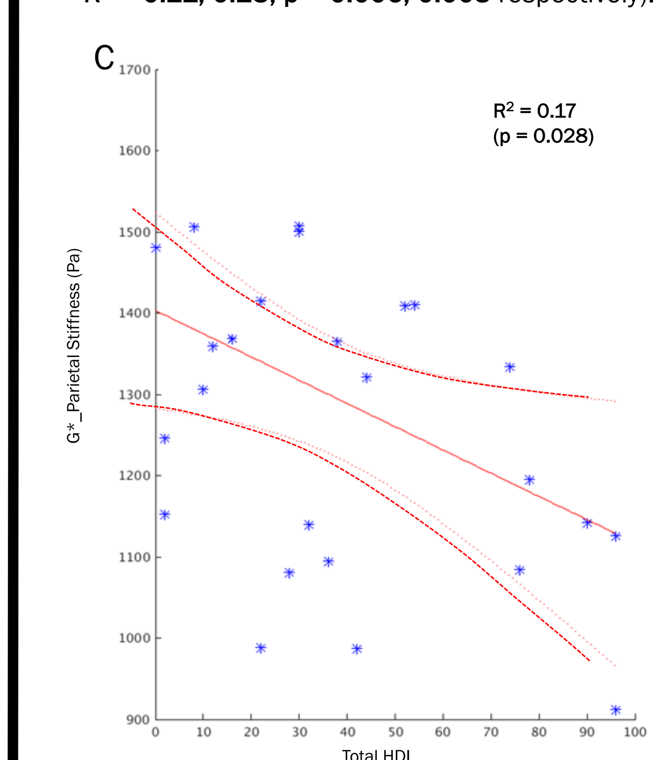


Figure 4: *Brain Regional Stiffness Correlations to ventricular size and Headache Disability Inventory Score HDI:*
A & B:. Correlational Between White matter and Occipital grey matter stiffness with ventricular size represented as Total Evans Ratio and Total Occipital Horn Ratio respectively. There was a negative correlation with ventricular size (WM, Occipital R^2 = 0.11; 0.23, p = 0.006; 0.003 respectively).



C: Parietal stiffness vs Headache Disability Index HDI. There was a negative correlation between parietal lobe grey matter stiffness and HDI (decreased stiffness with more HDI score).

Objective 2B: Shunt revision number association to brain stiffness

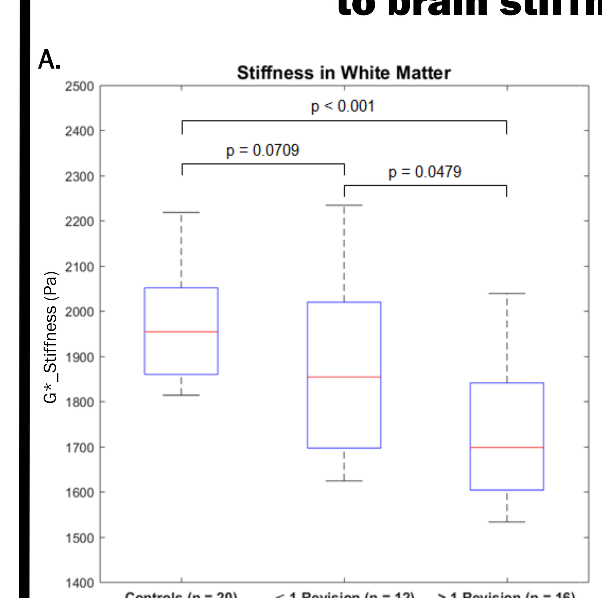
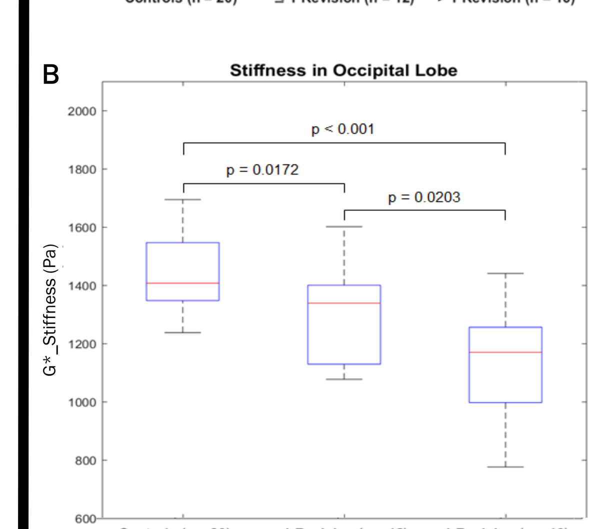


Figure 5: *White Matter and Occipital Grey Matter Stiffness of Control and Patient's Group with Different Numbers of Shunt Revisions*
A. White matter stiffness in the patients group with more than one revision had decreased stiffness compared to the controls and patients with less than one shunt revision.



B. Occipital Grey Matter stiffness in the patients group with more than one revision had decreased stiffness compared to the controls and patients with less than one shunt revision.

Conclusion & References

- Brain elastance is lower (softer) in chronically shunted hydrocephalus
- Enlarged ventricles, as indexed by linear measures of ventricle size, are associated with softer grey and white matter
- Softer brain tissue is associated with history of multiple shunt revisions

References:

1. Rekate, H.L., Shunt-related headaches: the slit ventricle syndromes. Childs Nerv Syst, 2008. 24(4): p. 423-30.
2. Foltz, E.L., Hydrocephalus: slit ventricles, shunt obstructions, and third ventricle shunts: a clinical study. Surgical neurology, 1993. 40(2): p. 119-124.
3. Benzel, E., et al., Slit ventricle syndrome in children: clinical presentation and treatment. Acta neurochirurgica, 1992. 117(1-2): p. 7-14.