Fabrication and Characterization of Hydrogels as Tissue Mimics for Blast-Induced Traumatic Brain Injury

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Motivation

- ❖ Members of the U.S. military often suffer from post-traumatic stress disorder (PTSD), which has been linked to traumatic brain injury (Hoge, 2008)
- ❖ The mechanism behind blast-induced traumatic brain injury is not well understood
- ❖ Human and animal tissue are difficult to use due to decay, demand, and mechanical property variation
- ❖ It is preferable to prepare samples a day or two before blast testing rather than immediately prior to testing


Figure 1. Setup of a blast test at an EMRTC facility

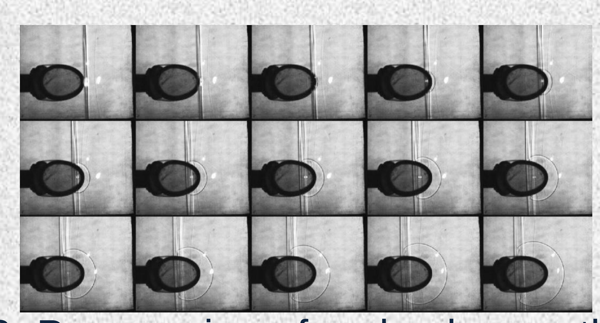
Figure 2. Progression of a shockwave through CSF simulating fluid (Hargather, 2017)

Design Criteria

Material Requirements:

- ❖ Transparent
- ❖ Reproducible
- ❖ Similar mechanical properties to white and gray brain matter
- ❖ Adhesion at the white-gray matter interface
- ❖ Correct geometric dimensions for anatomical features obtained from literature (Mata, 2010)

Chosen Material: Polyacrylamide Gel (PAA)

Materials and Methods

Fabrication of Test Objects

- ❖ Mold Design


Figure 3. 3D printed miniature brain mold

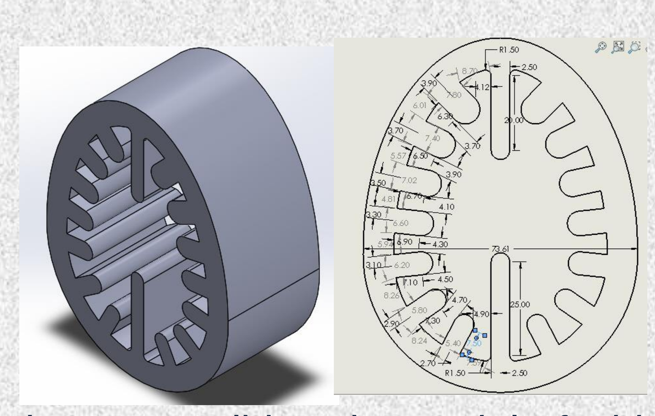
Figure 4. SolidWorks model of white matter insert


Figure 5. Pre-existing, three piece disk mold with 25 mm wells


Figure 6. Student synthesizing PAA (left) and filling disk molds with PAA solution (right)

Hydrogel Characterization

- ❖ Swell Testing


Figure 7. PAA disk samples swelled for 36 hours (left) and miniature brain mimics swelled for 3 days (right)

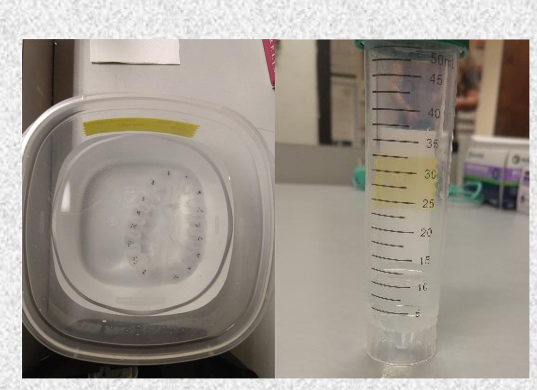
Figure 8. Samples were swelled in closed containers filled with Isoton II Diluent

Type	Disk						Brain		
Matter Type							Gray	Gray and White	White
Acrylamide Weight %	5		7		10		5	7	10
Crosslink Ratio	15:1	60:1	15:1	60:1	15:1	60:1	60:1		

Table 1. Parameters for PAA Samples

- ❖ Density Testing
  - ❖ Disks were weighed and then submerged in water to determine change in volume.
- ❖ Rheology
  - ❖ A Rheometric Scientific SR5 Test Unit was used in conjunction with TA Orchestrator software to obtain the storage (G'), loss (G''), and shear (G*) moduli.


Figure 9. Rheometer test setup

Results

- ❖ The gyri in the brain mimics became large enough upon swelling that the sulci became practically nonexistent (average gyrus width change ~ 2.33 mm)

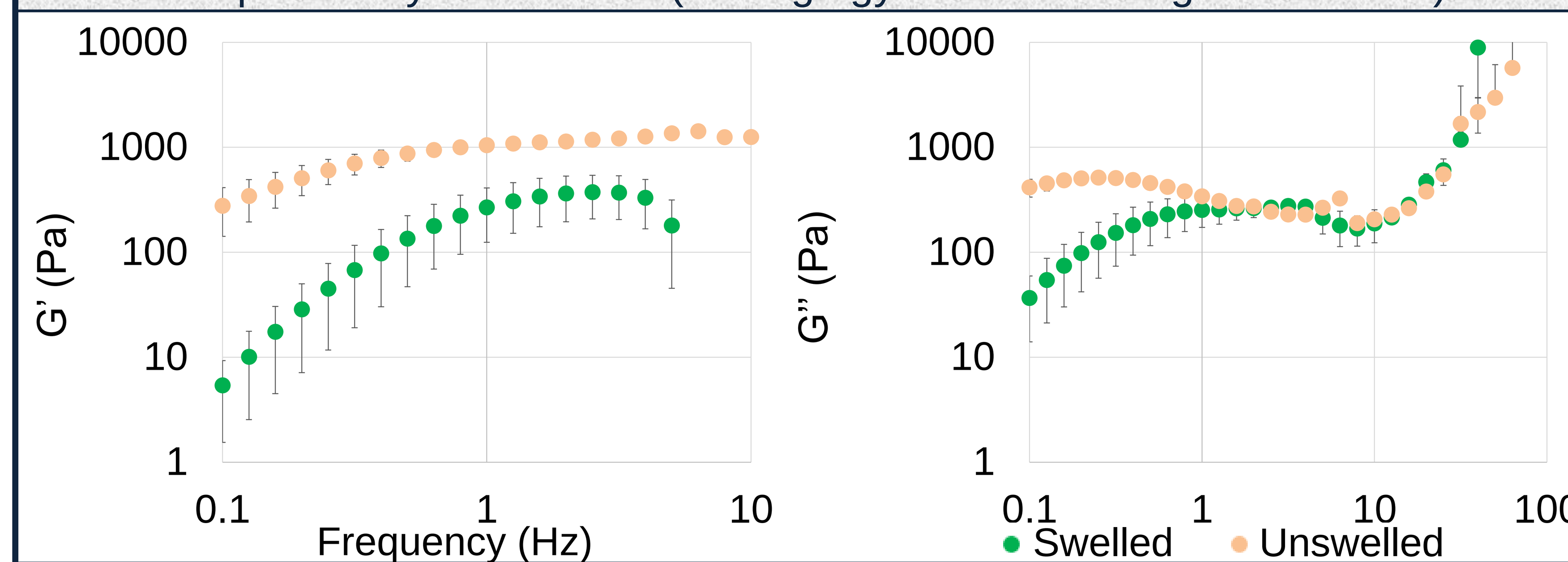

Figure 10. Comparison of G' and G'' between swelled and unswelled 5% PAA disks with a 60:1 crosslink ratio. The percent change in the storage modulus was 74.454% at 1 Hz and 173.045% at 10Hz.

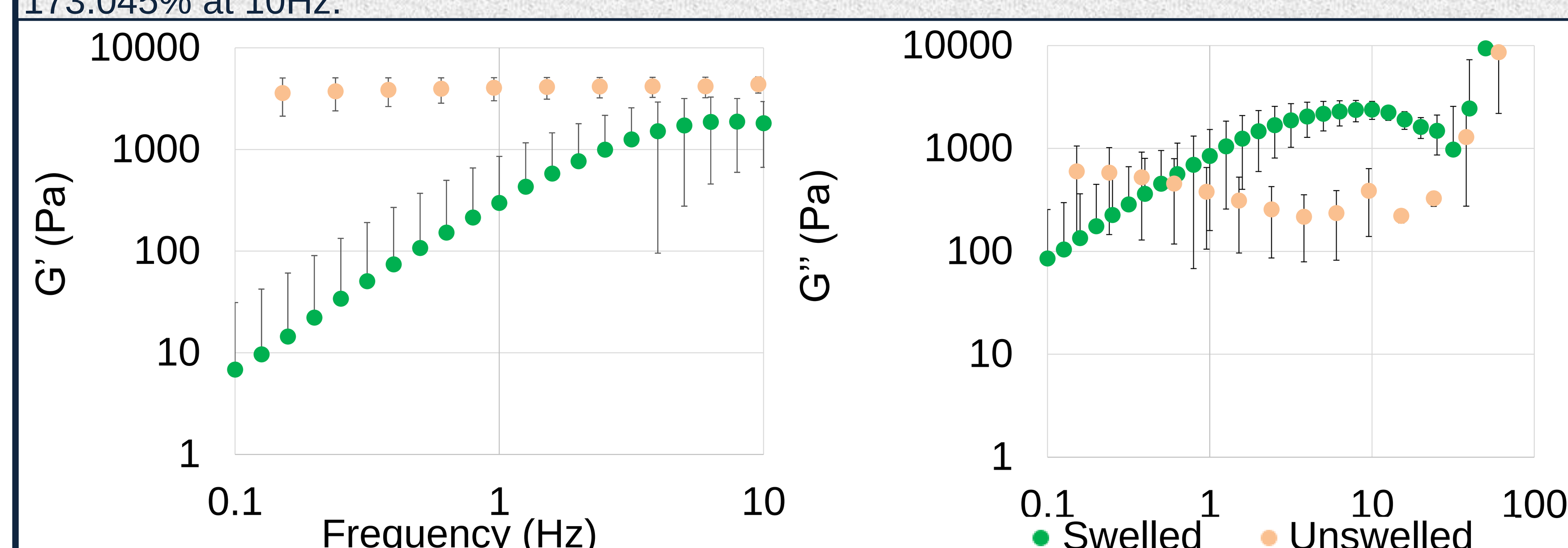

Figure 11. Comparison of G' and G'' between swelled and unswelled 10% PAA disks with a 60:1 crosslink ratio. The percent change in the storage modulus was 92.6506% at 1 Hz and 58.6045% at 10Hz.

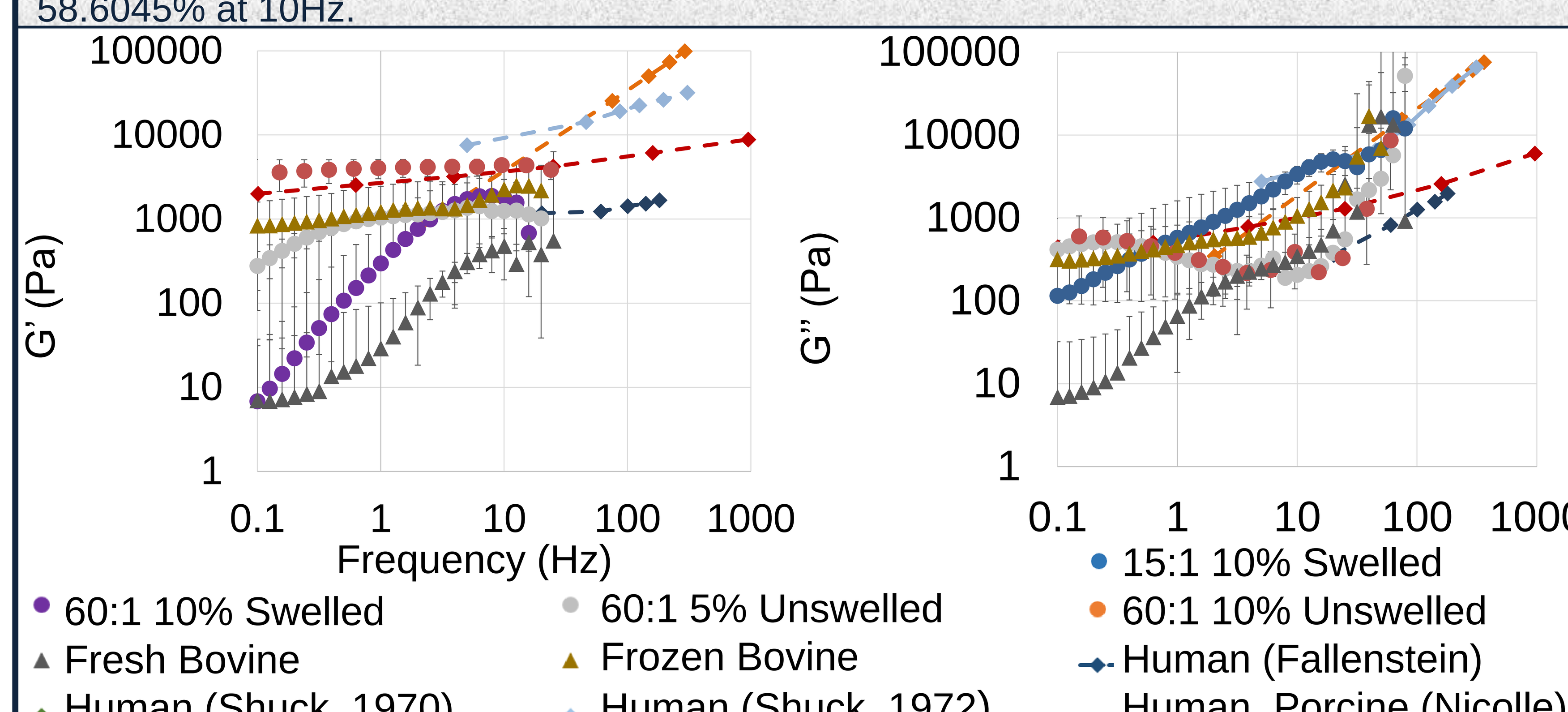

Figure 12. Comparison of G' and G'' for fresh bovine brain, frozen bovine brain, human brain (Chatelin, 2010), and selected PAA disks.

Discussion and Conclusion

- ❖ Swelled PAA disks are not a reliable representation of brain tissue
- ❖ Unswelled PAA maintains the desired mechanical properties
- ❖ Unconfined swell tests lead to asymmetrical swelling and material degradation
- ❖ Swell testing under confined conditions may produce better results

Limitations

- ❖ Cellular activity is not simulated
- ❖ PAA batches cannot be perfectly replicated

Future Work

- ❖ A material will be optimized to better simulate G' and G'' of brain tissue
- ❖ Once the swelled brains are optimized, they will be subjected to blast testing

Acknowledgements and References

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1. Chatelin S, Biorheology. 2010, 47, 255-76.
2. Hargather M, 2017, Progression of a shockwave through CSF simulating fluid (image).
3. Hoge CW, The New England Journal of Medicine, 2008, 358, 453-63.
4. Mata I, Brain Research, 2010, 1317, 297-304.