Model for Pre-Surgical Intracerebral Hemorrhage Planning

Department of Biomedical Engineering, University of Wisconsin
BME Design
Alex Truettner, Joseph Kerwin, Payton Parmett, Kurt Vanderheyden, Evan Ryser
Client: Dr. Walter Block Advisor: Dr. Paul Campagnola

Abstract

Intracerebral hemorrhaging (ICH) is an extremely dangerous condition that without intervention can ultimately lead to death. Recently, new methods have been developed for evacuating blood clots formed as a result of ICH. However, the mechanical properties of the clots can be very different from patient to patient, which complicates the decision of what method of evacuation to utilize. Professor Walter Block presented the team with the challenge of designing a brain phantom that will eventually be used to generate a database that allows neurosurgeons to compare magnetic resonance elastography (MRE) phantom images to MRE images of ICH patients. By comparing the patient's scan to the database of phantom images, the surgeon is able to determine the stiffness of the clot and the best method of evacuation prior to surgery. This project presents a polyacrylamide phantom with "clots" inside of base gels of relevant anatomical stiffness (verified by rheology) to prove materials of different mechanical properties can be differentiated in MRE images. Future development will involve refining the anatomical features of the model and fine-tuning gel properties.

Problem Definition

- ICH: blood vessels burst in brain → blood clots
- Treatment choice varies with material properties of clot
- Brain phantom database to compare to MRI scans of patient can assist determination
- Model incorporates polyacrylamide gels of varying known stiffness to create image database for reference to patient cerebral blood clots

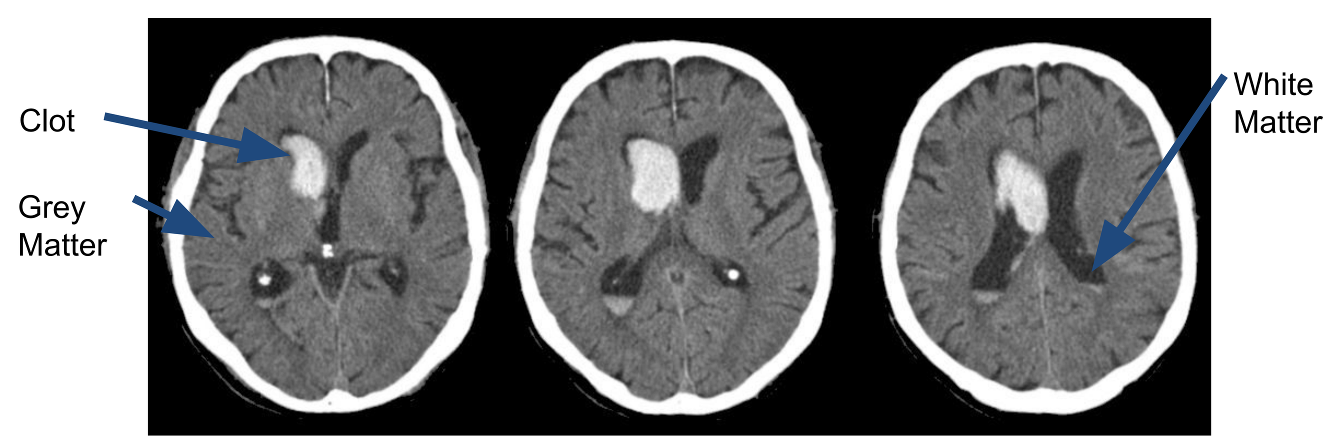

Figure 1.1 ICH MRI Scan [1]. The white mass in the image indicates a blood clot.

Previous Phantom Design

- Gels were alginate, far too stiff
- Box shape did not fit with curvature of MRI bed
  - Distorted images
- Needed new material and phantom shape

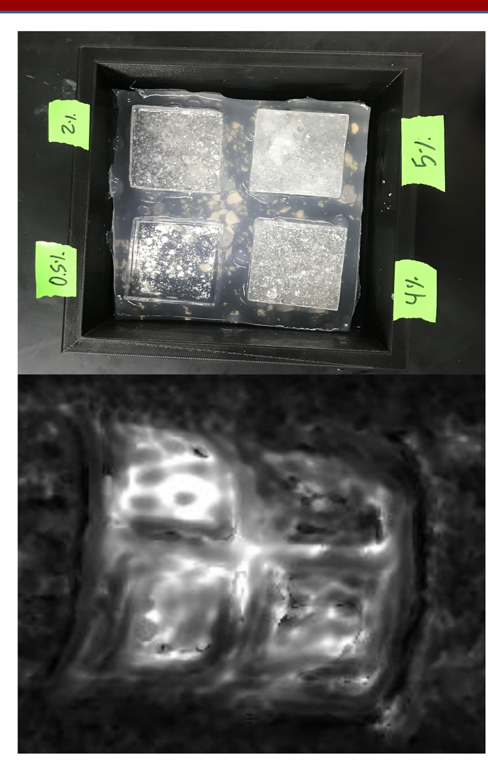

Figure 2.1 Previous iteration of phantom and resulting blurry image.

Shell Development

- Skull shape is best to fit in MRI curvature and improve relevance
- CT scans of skull provided by client, loaded into MeshMixer software (Autodesk, 2018)
- Skull halved, shelled, prepared for 3D printing
- Filled with alginate and sent to client for preliminary test with new shape while team worked on new material development

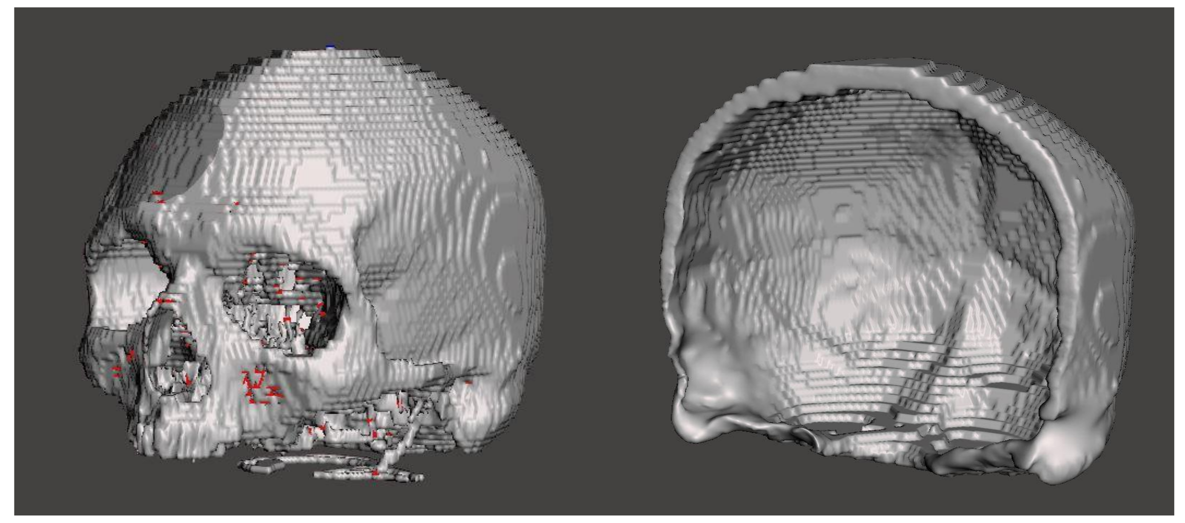

Figure 3.1 Left: skull loaded into MeshMixer. Right: skull shelled and halved post-processing.

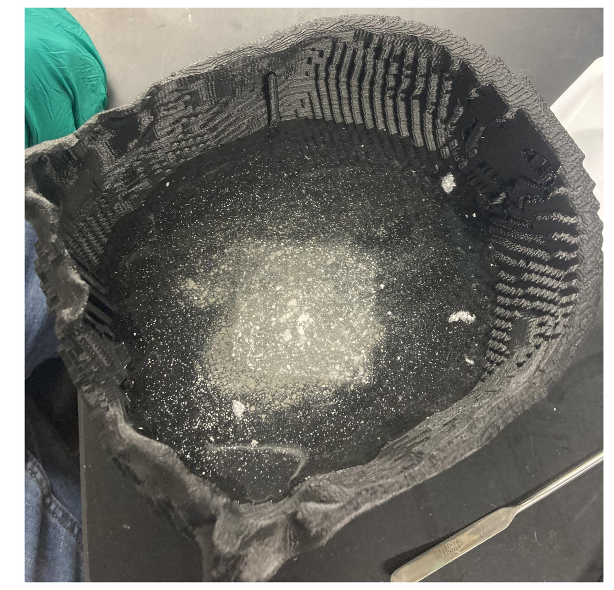

Figure 3.2 New shell 3D printed and filled with alginate brain/clot gels.

Material Development

New Material Selection:

- Materials chosen from literature
- PA chosen due to superior biomimicry and fabrication ability
- Fabricated as described in Sheth et al. [2]

Table 1.1 Design matrix considering three new materials for phantom.

Criteria	Polyacrylamide (PA)		Gelatin		Polydimethylsiloxane (PDMS)	
Ease of Fabrication (30)	4/5	24	3/5	18	4/5	24
Biomimicry (30)	5/5	30	2/5	12	4/5	24
Cost (15)	3/5	9	5/5	15	2/5	6
Safety (15)	4/5	12	5/5	15	3/5	9
Duration (10)	5/5	10	1/5	2	4/5	8
Total (100)	**85**		**62**		**71**	

Rheometric Analysis:

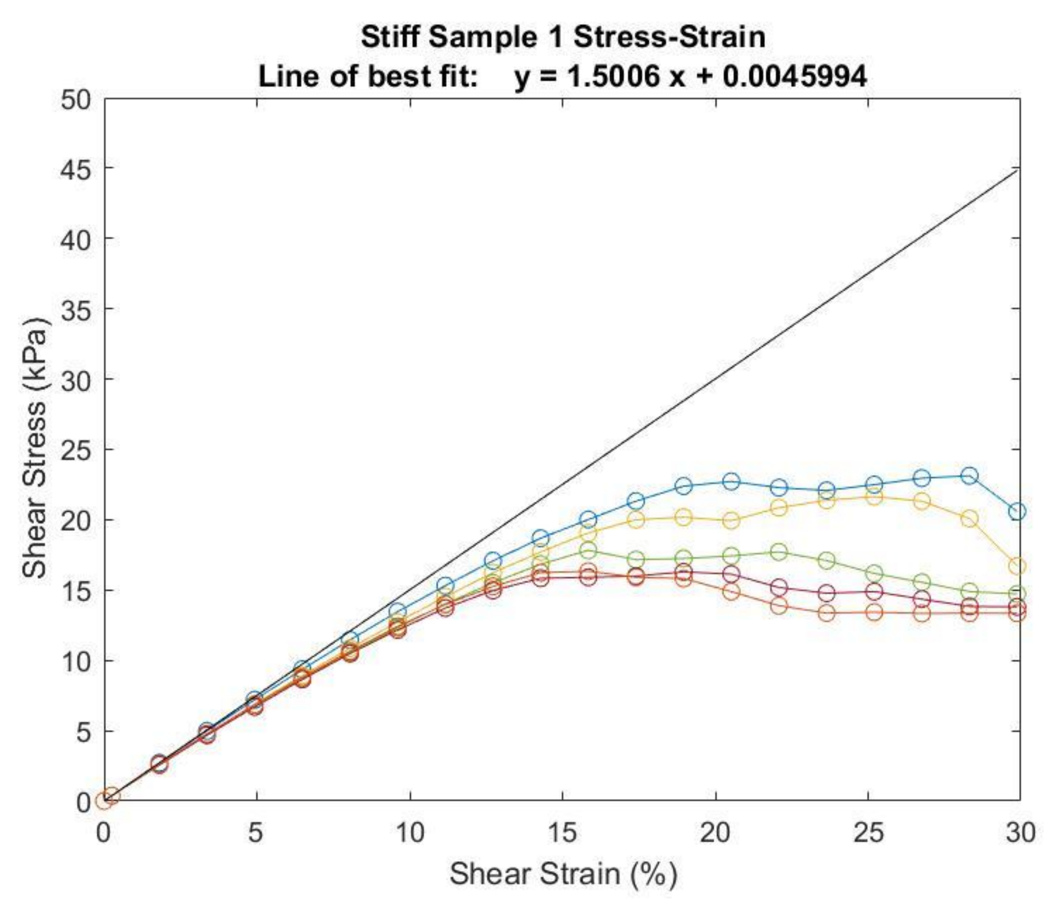

Figure 4.1 Sample stress-strain curve for stiff sample used to approximate shear modulus G.

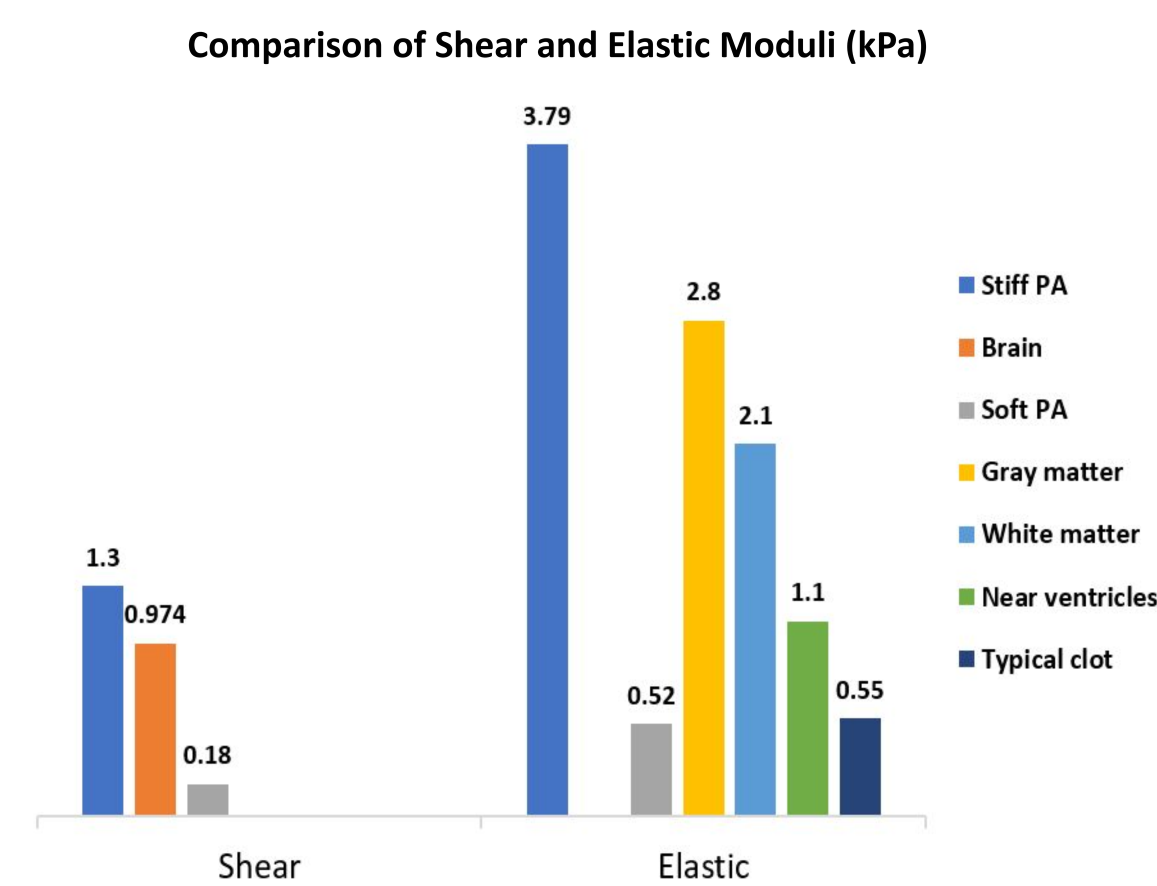

Figure 4.2 Comparison of shear and elastic moduli (kPa) for gels and literature data of brain [3].

MRE Analysis

- Alginate phantom, ultimately had to reconstruct from old gels
- Significantly improved coupling of vibrations, less distortion
- Better anatomical accuracy than previous attempts

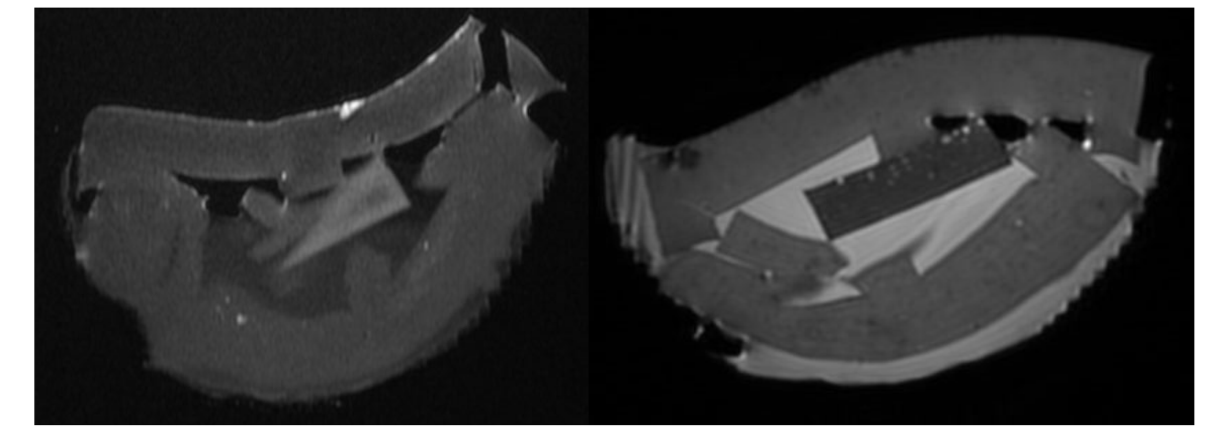

Figure 5.1 T1 (left) and T2 (right) images of skull phantom.

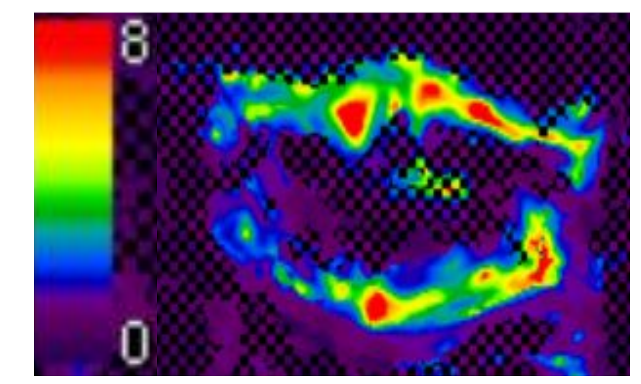

Figure 5.2 Shear stiffness (kPa) masked RGB map.

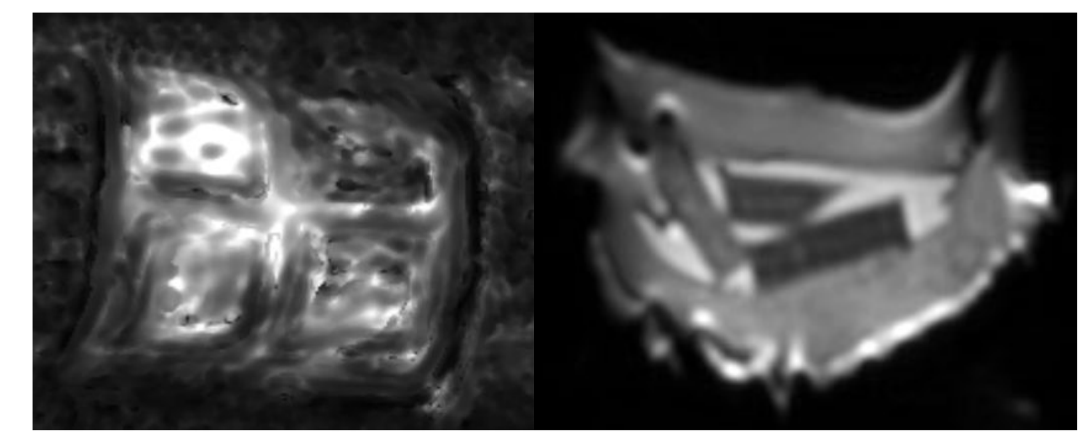

Figure 5.3 Comparison of previous (left) and current (right) phantom elastography images.

Future Project Development

- Air and fluid compartments
- Fine tune gel stiffness
- Enclose to replicate pressure within skull

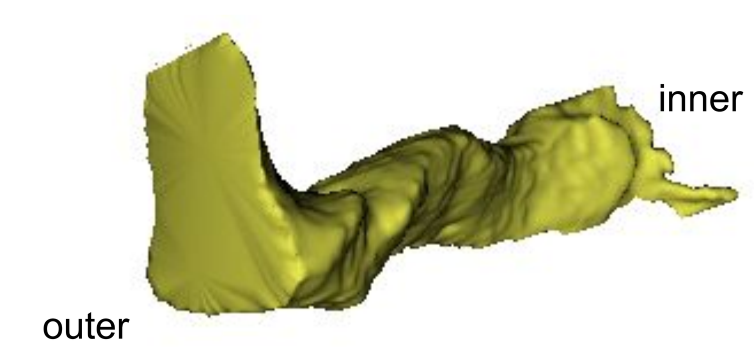

Figure 6.1 Model of inner ear canal to be placed into phantom.

Figure 6.2 3D printed result of ear canal. Printed with PLA.

Acknowledgements

- Dr. Aviad Hai
- Dr. Kristyn Masters
- Dr. Walter Block
- Dr. Paul Campagnola
- Elizabeth Bremer
- Anna Kiyanova
- Robert Moskwa
- UW-Madison Makerspace
- Dept. of Biomedical Engineering

References

[1] "Figure 2f from: Irimia R, Gottschling M (2016) Taxonomic revision of Rochefortia Sw. (Ehretiaceae, Boraginales). Biodiversity Data Journal 4: e7720. https://doi.org/10.3897/BDJ.4.e7720."
[2] S. Sheth, E. Jain, A. Karadaghy, S. Syed, H. Stevenson, and S. P. Zustiak, "UV Dose Governs UV-Polymerized Polyacrylamide Hydrogel Modulus," *International Journal of Polymer Science*, vol. 2017, pp. 1–9, 2017.
T. Takigawa, Y. Morino, K. Urayama and T. Masuda, "Poisson's ratio of polyacrylamide (PAAm) gels", Polymer Gels and Networks, vol. 4, no. 1, pp. 1-5, 1996. Available: 10.1016/0966-7822(95)00013-5 [Accessed 12 April 2021].
[3] G. Fallenstein, V. Hulce and J. Melvin, "Dynamic mechanical properties of human brain tissue", Journal of Biomechanics, vol. 2, no. 3, pp. 217-226, 1969. Available: 10.1016/0021-9290(69)90079-7 [Accessed 16 April 2021].
[4] M. Green, R. Sinkus and L. Bilston, "High Resolution 3D Brain MR-Elastography", ISMRM, vol. 14, 2006. [Accessed 14 April 2021].
[5] L. Landau and E. Lifshitz, Theory of Elasticity, 2nd ed. Oxford: Pergamon Press, 1970, p. 13.

Problem Definition

- ICH occurs when blood vessels burst in the brain, resulting in blood clots
- Choosing treatment for clot evacuation can be difficult due to material properties of clot
- Brain phantom database for neurosurgeons to compare MRI scans of the phantom with a scan of patients' brains allows for determination of surgical method
- Purpose of phantom is to illustrate stiffness of clot
- This model incorporates polyacrylamide gels of varying known stiffness to create an image database for reference to cerebral blood clots

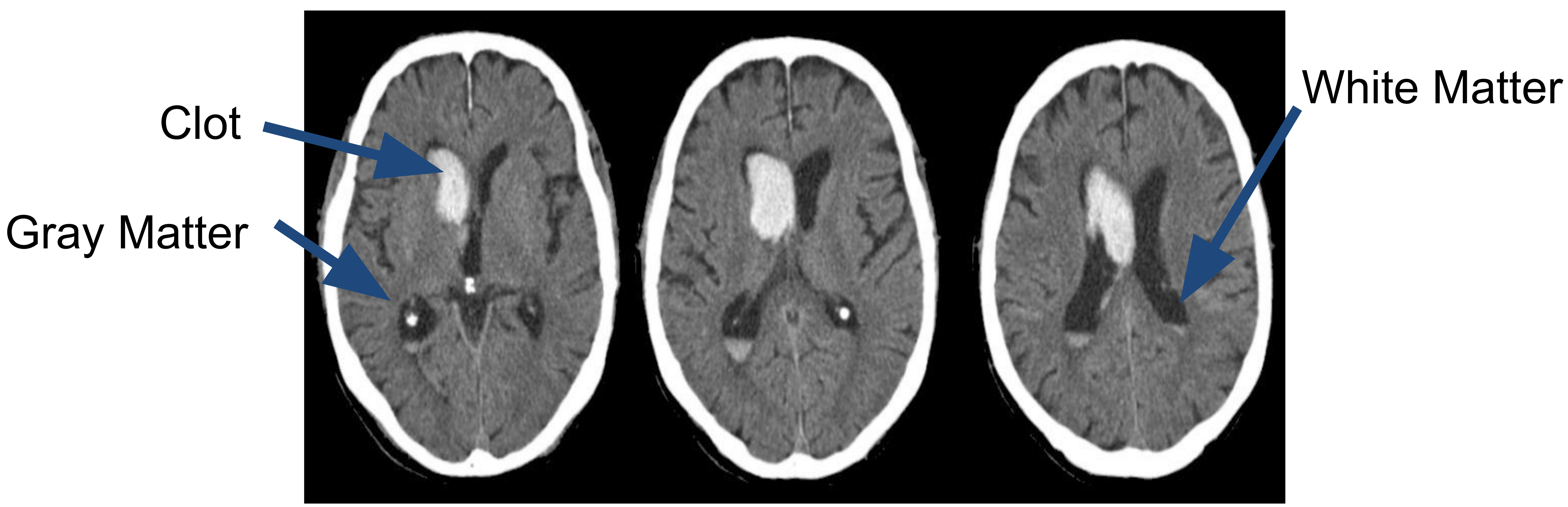

Figure 1.1 Intracerebral Hemorrhage MRI Scan [1]. The white mass in the image indicates a blood clot.

Previous Phantom Design

- Interface is entirely gel-gel to prevent air interference
- Gels were alginate, far too stiff
- Box shape did not fit with curvature of MRI bed
- Distorted images
- At end of semester: need for new material and new phantom shape

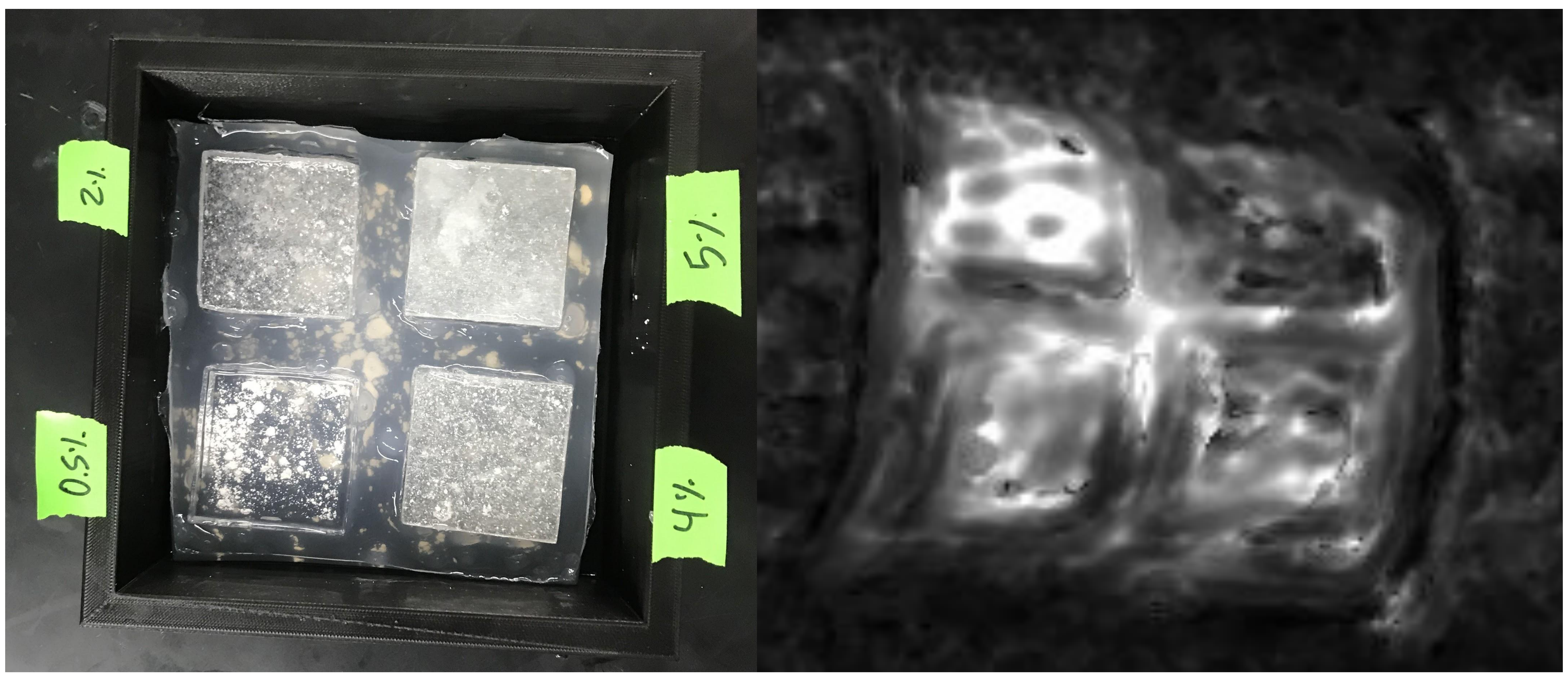

Figure 2.1 Previous iteration of phantom and resulting blurry image.

Shell Development

- Skull shape is best to fit in MRI curvature and improve relevance
- CT scans of skull provided by client, loaded into MeshMixer software (Autodesk, 2018)
- Skull halved, shelled, prepared for 3D printing
- 3D printed at MakerSpace using PLA
- Filled with alginate and sent to client for preliminary test with new shape while team worked on new material development

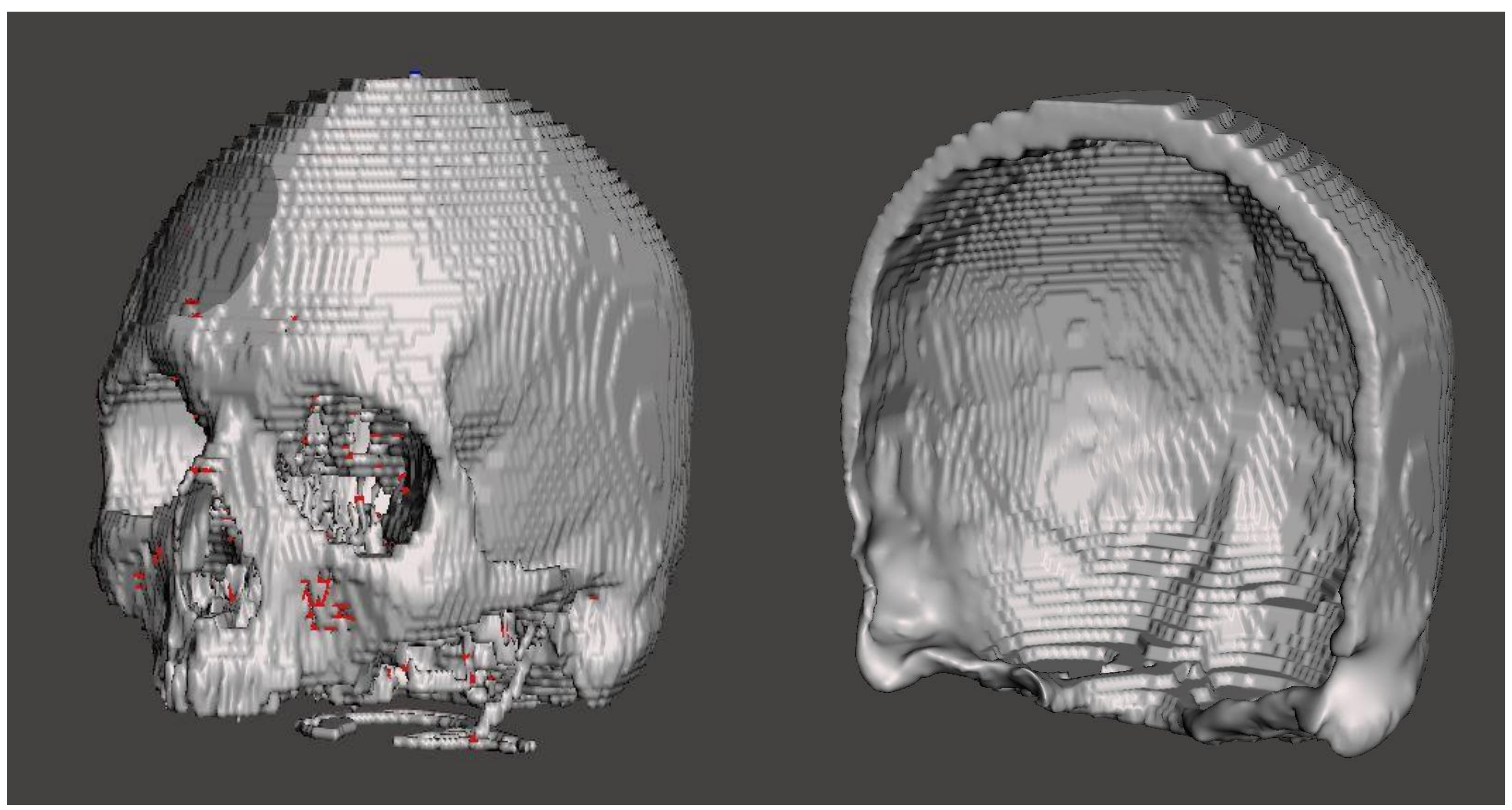

Figure 3.1 Left: skull loaded into MeshMixer. Right: skull shelled and halved post-processing, ready for 3D print.

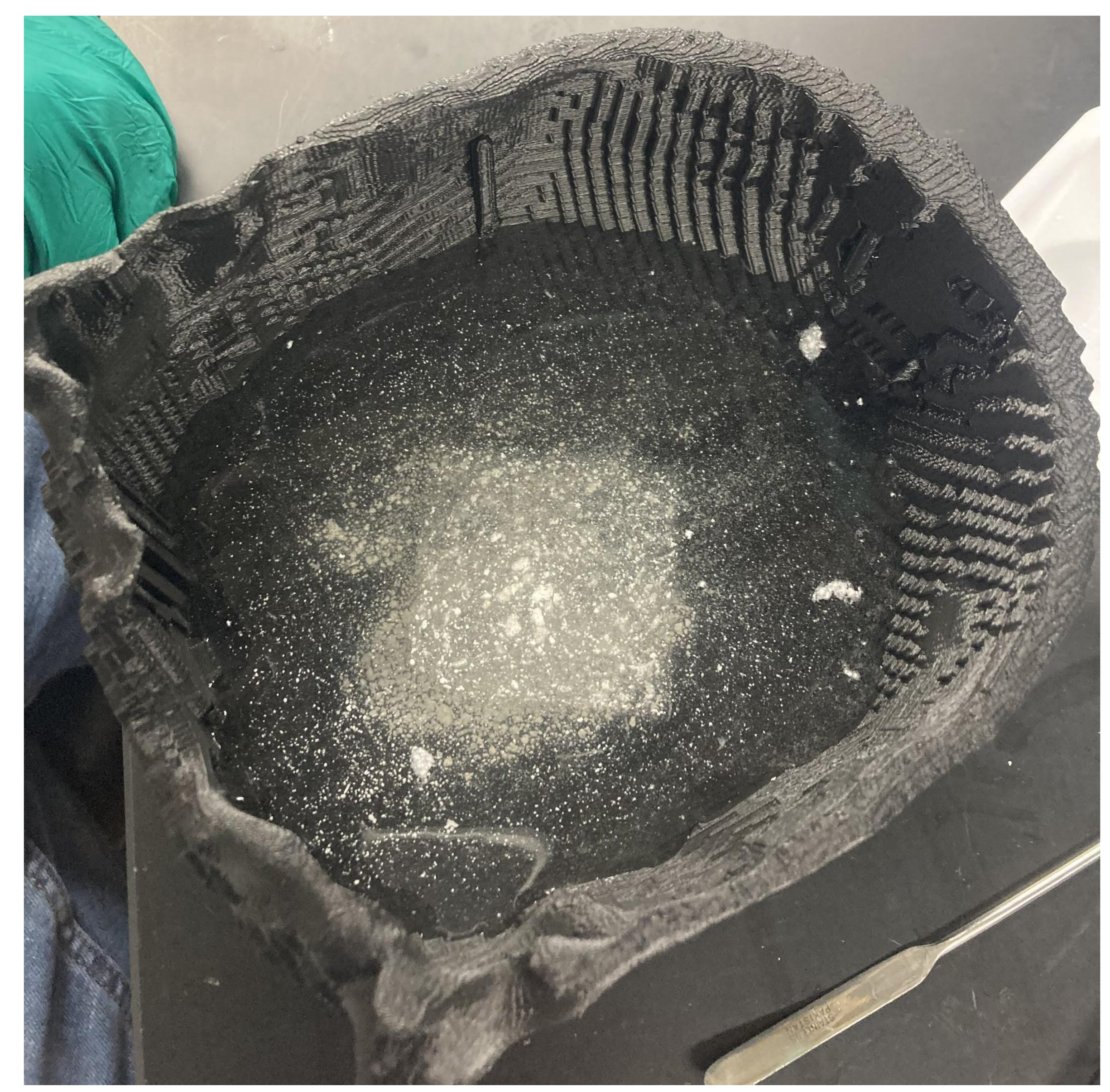

Figure 3.2 New shell 3D printed and filled with alginate brain/clot gels. Given to client for preliminary test.

Material Development

- Polyacrylamide (PA), gelatin, and polydimethylsiloxane (PDMS) considered from literature search
- PA ultimately chosen due to superior biomimicry and fabrication ability
  - » Fabrication as described by [1]

Table 1.1 Design matrix considering three new materials for phantom.

Criteria	Polyacrylamide (PA)		Gelatin		Polydimethylsiloxane (PDMS)	
Ease of Fabrication (30)	4/5	24	3/5	18	4/5	24
Biomimicry (30)	5/5	30	2/5	12	4/5	24
Cost (15)	3/5	9	5/5	15	2/5	6
Safety (15)	4/5	12	5/5	15	3/5	9
Duration (10)	5/5	10	1/5	2	4/5	8
Total (100)	85		62		71	

Material Development

- Rheometry provides equilibrium shear modulus G, which will be compared with MRE
- Taken from early linear regime of shear sweep stress-strain curve

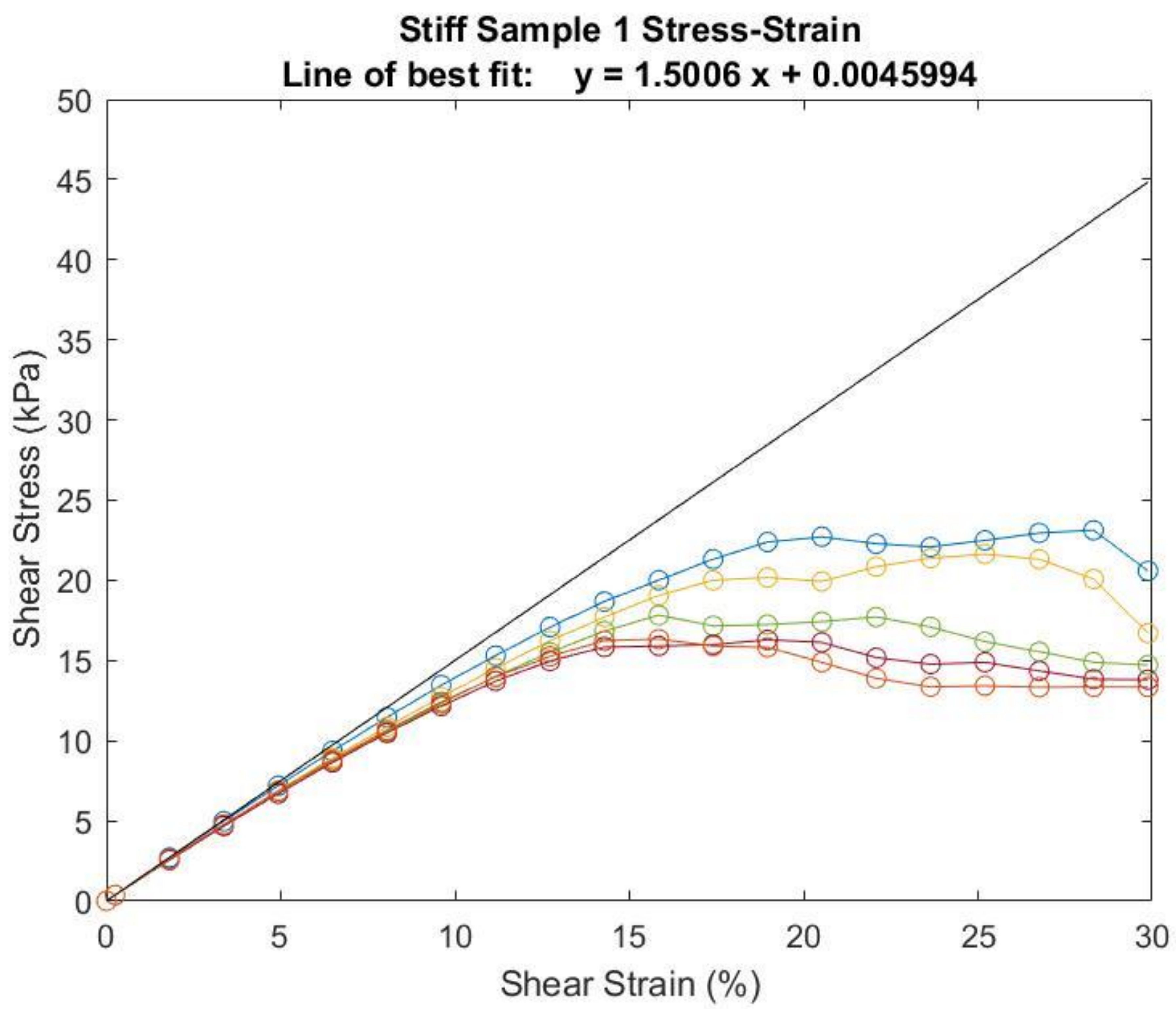

Figure 4.1 Sample stress-strain curve for stiff sample used to approximate shear modulus G.

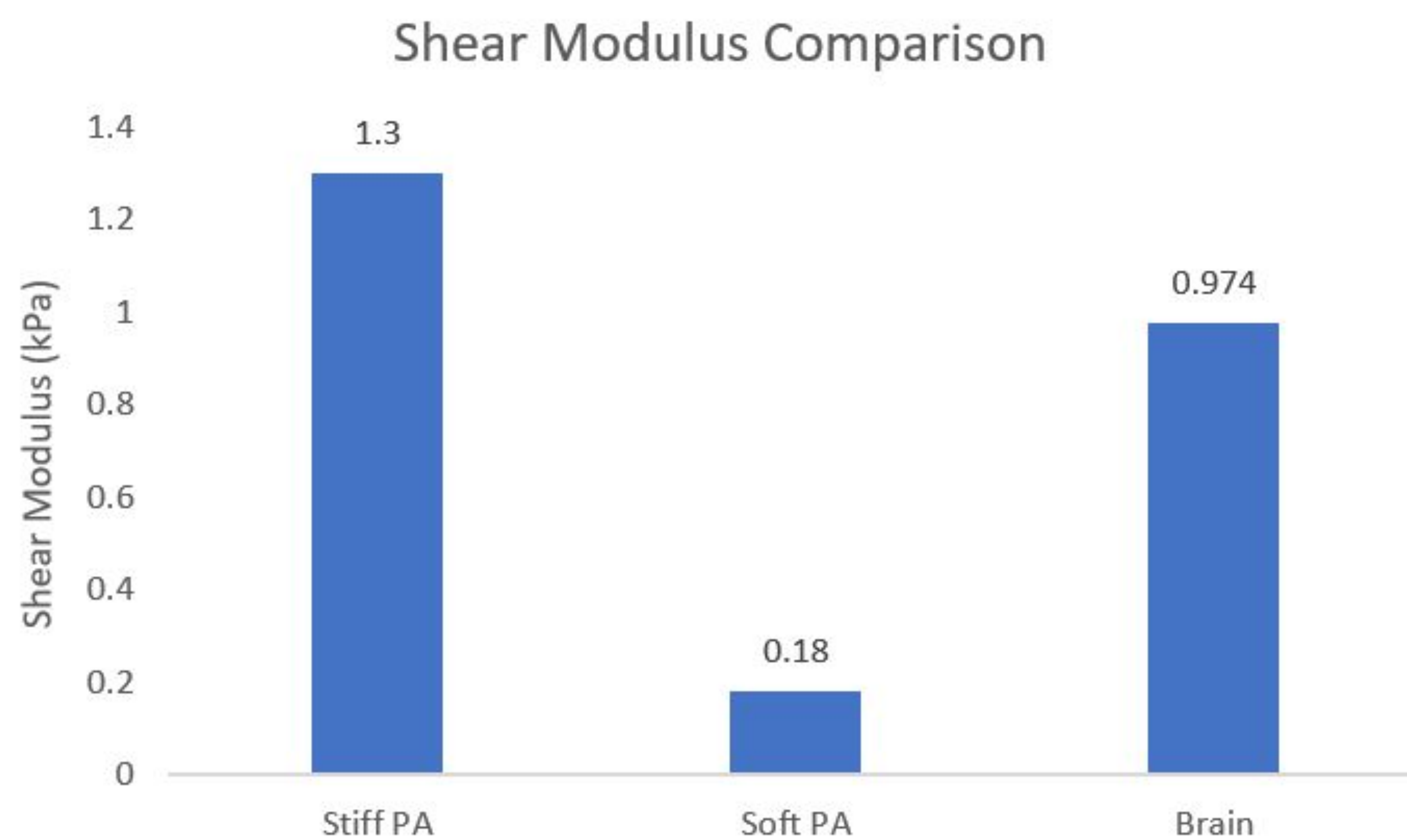

Figure 4.2 Comparison of shear moduli for gels and literature data of brain [3].

Material Development

- Can estimate elastic modulus E from G [4]:
- Poisson's ratio of PA ν = 0.457 [5]

$$E = G * 2 * (1 + \nu)$$

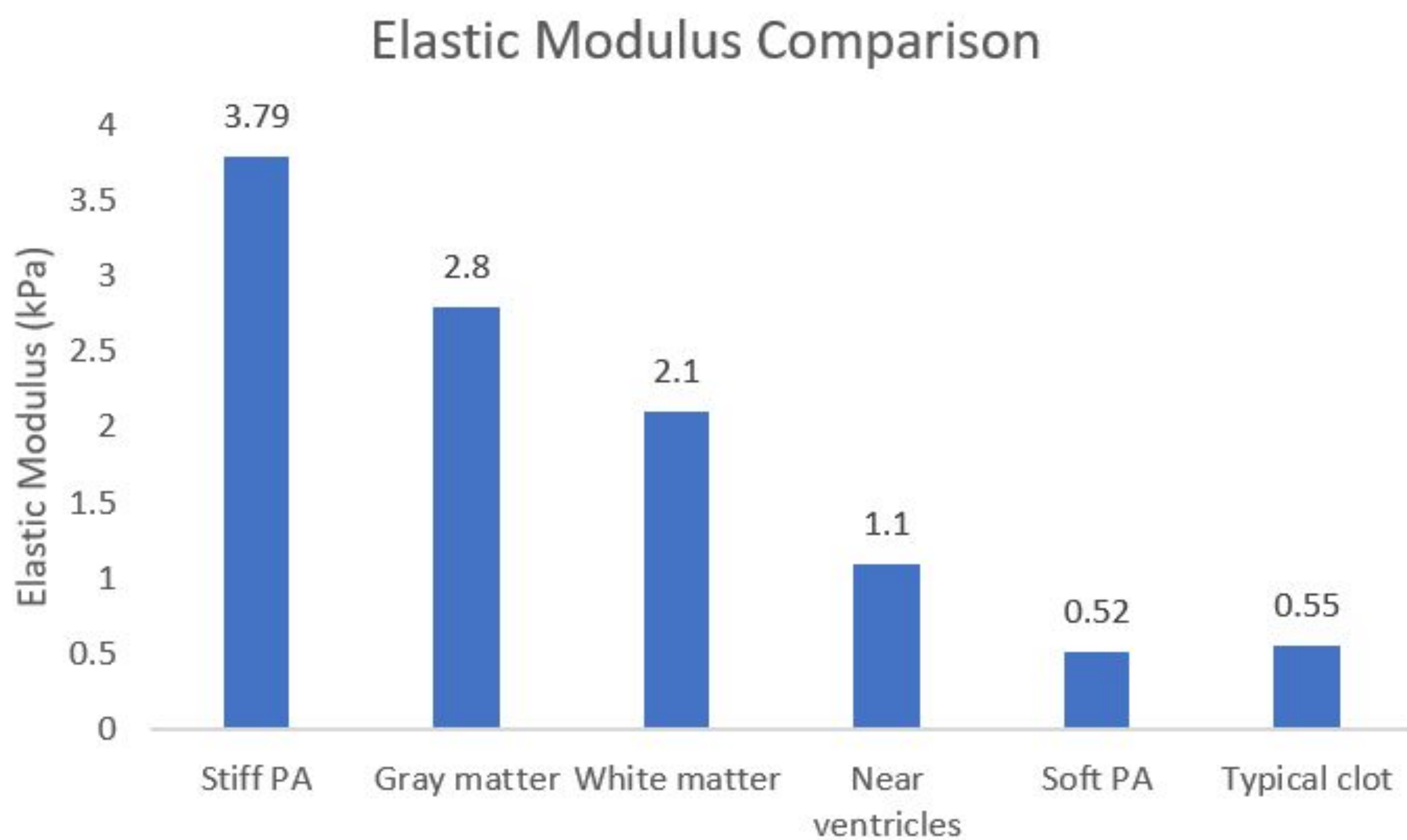

Figure 4.3 Elastic modulus comparison for different components of brain with PA gels [4]

MRE Analysis

- Alginate phantom created for scanning, ultimately had to reconstruct phantom from old iteration of alginate gels
- Significantly improved coupling of vibrations for less distorted MRE
- Better anatomical accuracy than previous attempts

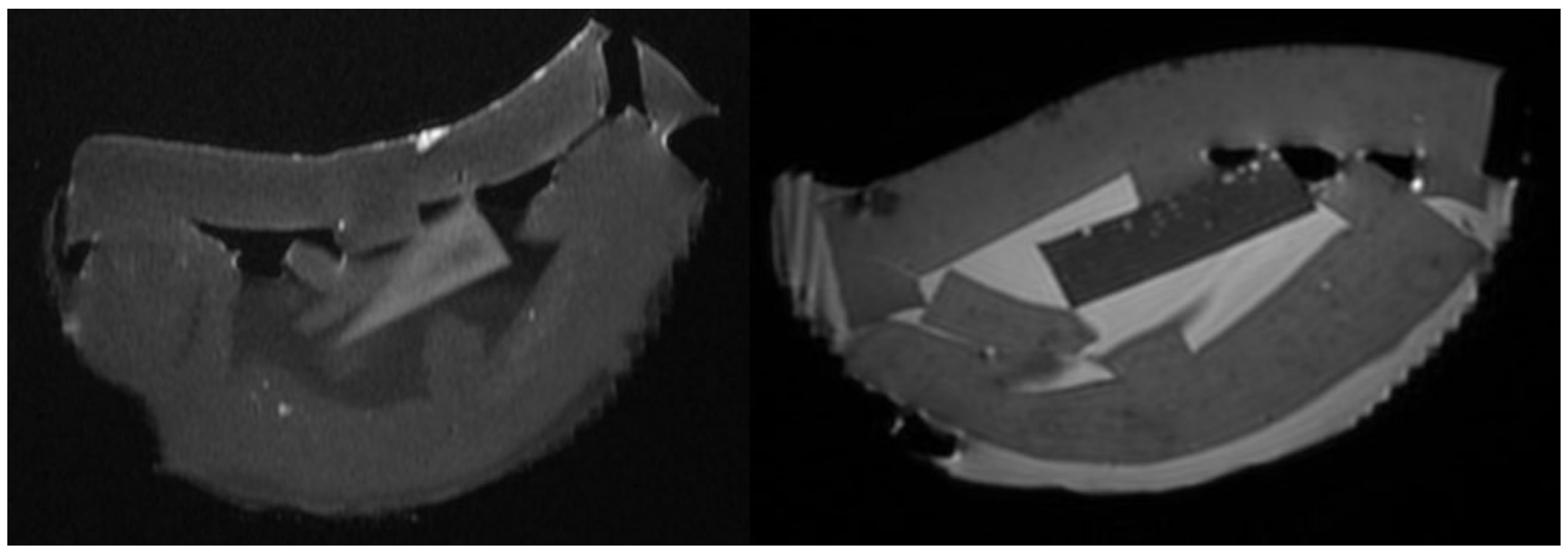

Figure 5.1 T1 (left) and T2 (right) images of skull phantom.

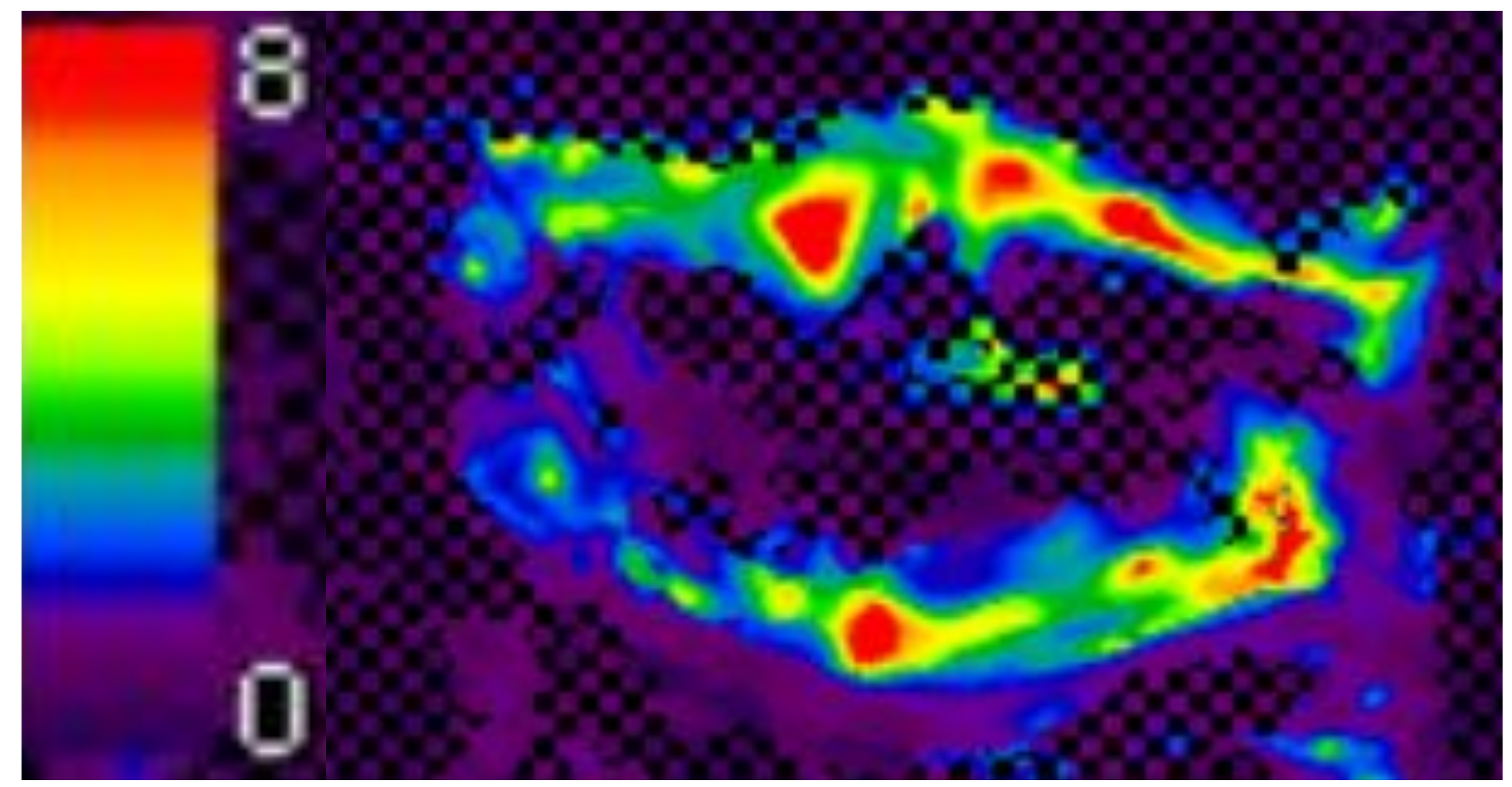

Figure 5.2 Shear stiffness (kPa) masked RGB map.

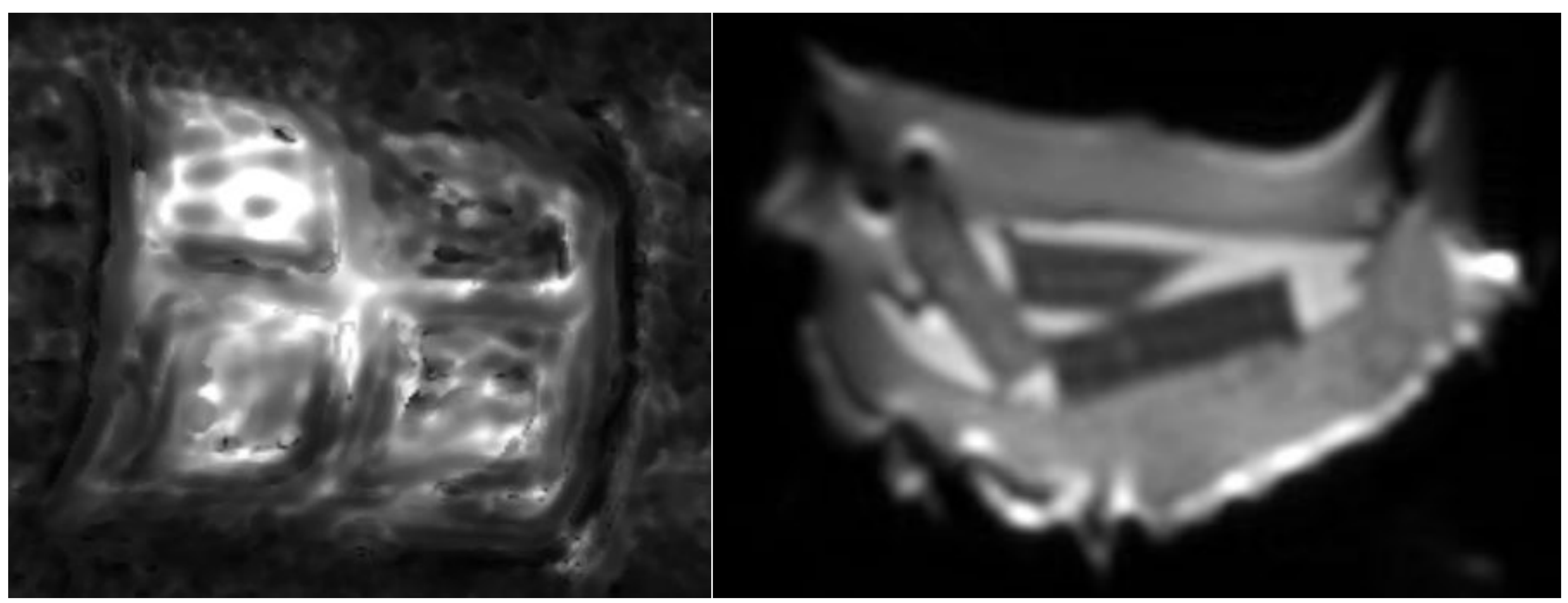

Figure 5.3 Comparison of previous (left) and current (right) phantom elastography images.

Future Project Development

- Incorporate air and liquid compartments into model
- Fine tune clot stiffness to white and gray matter, etc.
- Incorporate mechanical testing values with scans
- Enclose phantom to replicate pressure within skull

Figure 6.1 Model of the inner ear canal to be placed into the 3D brain phantom

Figure 6.2 3D printed result of ear canal. Printed with PLA.

Acknowledgements

- Dr. Walter Block
- Dr. Paul Campagnola
- Elizabeth Bremer
- Luke Summey
- Julie Morasch
- Anna Kiyanova
- Robert Moskwa
- Dr. Christian Franck
- Dr. Christa Wille
- Dr. Aviad Hai
- Dr. Kristyn Masters

Fall 2019 Team Members

- Cate Fitzgerald
- Zayn Kayali
- Kristen Schill

- UW-Madison Makerspace
- Dept. of Biomedical Engineering

References

[1] “Figure 2f from: Irimia R, Gottschling M (2016) Taxonomic revision of Rochefortia Sw. (Ehretiaceae, Boraginales). Biodiversity Data Journal 4: e7720. https://doi.org/10.3897/BDJ.4.e7720.”

[2] S. Sheth, E. Jain, A. Karadaghy, S. Syed, H. Stevenson, and S. P. Zustiak, “UV Dose Governs UV-Polymerized Polyacrylamide Hydrogel Modulus,” *International Journal of Polymer Science*, vol. 2017, pp. 1–9, 2017.

T. Takigawa, Y. Morino, K. Urayama and T. Masuda, "Poisson's ratio of polyacrylamide (PAAm) gels", Polymer Gels and Networks, vol. 4, no. 1, pp. 1-5, 1996. Available: 10.1016/0966-7822(95)00013-5 [Accessed 12 April 2021].

[3] G. Fallenstein, V. Hulce and J. Melvin, "Dynamic mechanical properties of human brain tissue", Journal of Biomechanics, vol. 2, no. 3, pp. 217-226, 1969. Available: 10.1016/0021-9290(69)90079-7 [Accessed 16 April 2021].

[4] M. Green, R. Sinkus and L. Bilston, "High Resolution 3D Brain MR-Elastography", ISMRM, vol. 14, 2006. [Accessed 14 April 2021].

[5] L. Landau and E. Lifshitz, Theory of Elasticity, 2nd ed. Oxford: Pergamon Press, 1970, p. 13.