Introduction

- Craniotomies for glioma tumor resection are often challenging as brain shifting (due to fluid loss, gravity, pressure changes, edema, etc.) causes a mismatch when intra-operative anatomical positions are compared to pre-operative imaging.
- Low accuracy in pre-op planning due to uncertainty in brain shifts increases the difficulty of the procedure and the risk of harm to healthy tissue and further complications.
- Biomechanics and Finite Element Modeling (FEM) can be utilized to accurately simulate brain shifts (i.e., sagging or swelling) for improved surgical planning.

Materials & Methods

- Brain shift simulation is done through the cranio-spinal fluid (CSF) and low-level gravity.
- FEMs were created from a 3D mesh generated using several modeling software tools (RayStation, SimLab, HyperMesh, and various C scripts).
- Two material models were used in the FEM computation:
  - Viscoelastic – material with combination of viscous and elastic properties (i.e., gelatin). Models sagging behavior.
  - Poroelastic – material is porous and elastic (i.e., sponge). Takes into account more complex physics (brain drainage), and predicted to produce more accurate simulations. Models sagging, shrinking and swelling.
- In addition, varying levels of cranio-spinal fluid (CSF) and low-level gravity were investigated (Fig. 3).
- Finite element analysis (FEA) simulations were computed using open-source software GetFEM on the MD Anderson SeaDragon super-computer.
- FEA results were visualized on ParaView.
- Accuracy of the model is determined using target registration error (TRE) based on pre-op MR images with ~15 set landmarks and compared to a grand truth based on intra-op ultrasound (IUS) of the same patient (Fig 3).

Results

A. Sagging: Poroelastic vs. Viscoelastic

- RESECT Case 17
- Initial TRE: 4.2
- Uncure All: 2.1, Viscous Tum: 2.1, Opt: 2.1
- TREs with lowest TRE

- RESECT Case 25
- Initial TRE: 4.2
- Uncure All: 2.1, Viscous Tum: 2.1, Opt: 2.1
- TREs with lowest TRE

B. Swelling

- Fig. 6. Box and whisker plot of RESECT case 23 (swelling). Poroelastic optimized target registration error is compared to initial TRE (original pre-operative landmark without simulation).
- Optimized TRE with 7 POIs (about half of all) are also reported to demonstrate accuracy of model with fewer data. Poroelastic model was found to produce lower TREs than viscoelastic.

Conclusion

- Poroelastic model is more accurate than viscoelastic.
- Supports prediction that including more physical parameters increases simulation accuracy.
- Also took less time due to its formula – elastic modulus does not vary with time whereas visco does not.
- Currently working on improving run time and accuracy.
- FOM code runs into some bugs due to minor errors in mesh modeling.
- Future works: developing deep learning to automate simulation process and translate work to clinic.

References

1. Leaue et al. 2020, IPUM “Viscoelastic biomechanical models to predict inward brain shift using public benchmark data”
4. Probst et al., 2016, open-source software GetFEM

Acknowledgements

Brain imaging data used in this work was provided by the RESECT study. This work was supported by the Image Guided Cancer Therapy (IGCT) Research Program at MD Anderson Cancer Center. NIH was supported by CPRIT-CURE Summer Program. For further information, please contact Ali Nilloforoush at nillnfroush@gmail.com