THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center
Making Cancer History®

Predicting tumor displacement from intraoperative magnetic resonance imaging using viscoelastic finite element biomechanical modelling.

Authors, A.C. LESAGE [1], A. SEN[1], M. CHEN[2], G. CAZOULAT[1], J.S. WEINBERG[3] and K.K. BROCK[1]

1 **Department of Imaging Physics, The University of Texas MD Anderson Cancer Center, Houston, TX**

2 **Department of Neuroradiology, The University of Texas MD Anderson Cancer Center, Houston, TX**

3 **Department of Neurosurgery, The University of Texas MD Anderson Cancer Center, Houston, TX**

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

During neurosurgical tumor resection, **brain-shift negatively impacts the localization accuracy** of both the residual tumor and vital structures to be avoided. Two solutions: **re-image the brain during surgery or predict/compensate the brain-shift**.

AIM

In this study, we analyzed **the performance of a viscoelastic finite element model (FEM) considering gravity-induced brain-shift to predict tumor displacement during partial resection**.

METHOD

A combination of preoperative and intraoperative Magnetic Resonance (pMR and iMR) images after partial tumor resection were retrospectively collected for five patients under an IRB approved study. For each patient, the steps to build the patient specific FEM were the following:

- **Contouring the different brain tissues** in a radiation therapy treatment planning system (Raystation v9, RaySearch Laboratories, Stockholm, Sweden). The preoperative tumor and residual tumor were manually contoured on pMR (T2 and Flair) and iMR Flair and reviewed for accuracy by a neuroradiologist (M.C.). The brainstem, cerebellum and dura were manually contoured on both pMR and iMR T1. After applying the dura contour as a mask for skull stripping, the gray matter and cerebrospinal fluid (CSF) were automatically contoured by the FSL software [1].
- **Build a second order tetrahedral FEM [2] under the hypothesis of gravity-induced brain-shift and complete cerebrospinal fluid (CSF) drainage (cf figure 1).** A commercial finite element solver (Radioss, Altair, Troy, Michigan) was used to run the simulations on a high-performance computing cluster local to The University of Texas MD Anderson Cancer Center.
- **Determine an optimal patient-specific brain** based on the Dice Similarity Coefficient (DSC) between the smoothed cortical surface from the iMR and the predicted displaced surface from the pMR.

Based on the final brain displacement results, **the false negative (FNF) and true positive (TPF) fractions were measured to compare the FEM and the rigid registration performance** on predicting the position of the residual tumor and the union of the residual tumor and surgical cavity.

The student's t-test was performed on the five patient results to measure improvement between the FEM prediction and the rigid registration.

RESULTS

Table 1 shows the evaluation of the accuracy of gravity-induced viscoelastic FE brain shift modeling to predict tumor residual position after partial tumor resection for the five patients. The optimal brain shear modulus for each patient ranged from 0.6 to 1.4 kPa, with a median value of 1.12 kPa. The average FNF was 0.5 (range 0.23-0.89) and 0.32 (range 0.21-0.57) for the rigid registration and FEM-based registration, respectively, (P=0.016). The average TPF was 0.43 (range 0.03-0.68) and 0.61, range 0.29-0.88, for rigid registration and FEM-based registration, respectively (p<0.01).

Table 2 shows the evaluation of the accuracy of gravity-induced viscoelastic FE brain shift modeling to predict the union of the residual tumor and cavity position. The average FNF was 0.39 (range 0.2-0.7) and 0.32 (range 0.07-0.54) for the rigid registration and FEM-based registration, respectively, (P=0.158). The average TPF was 0.59 (range 0.33-0.68) and 0.67 (range 0.44-0.92), for rigid registration and FEM-based registration, respectively (p<0.15).

For all patients, we observe a significant improvement of FNF and TPF with the FEM prediction versus the rigid registration when considering the residual tumor position prediction. However when considering the residual tumor plus surgical cavity, there is no improvement for patients 2 and 3. Those two patients present a resection of more than 70% of the tumor and a significant deformation of the surgical cavity.

Our strategy to **improve the accuracy of these results is to add complexity to our FEM by investigating the impact of additional brain shift forcing conditions**. To guide us in our investigation, we performed a detailed visual analysis of the brain shift scenario for the two first patients. Figure 2 and 3 show the preoperative tumor, residual tumor, FEM displaced tumor and surgery for patient 1 and 2. For patient 1, we observe a significant motion of the tumor to the brain midline that is underpredicted. This indicate that a poroelastic modeling of the brain could lead to a result improvement [3]. We will also consider a CSF drainage in the ventricles. For patient 2, the tumor displacement is over predicted, we will test improvement with a partial CSF drainage and modeling partial tumor resection.

Table 1. Evaluation of the accuracy of gravity-induced viscoelastic FE brain shift modeling to predict residual tumor position after partial tumor resection.

	Brain shear modulus used in the Zener model initial/final in kPA	Tumor volume in cm3	Residual tumor volume in cm3	Tumor shape on preoperative MR (rigid registration)		Predicted displaced tumor (FEM)	
				False Negative Fraction	True Positive Fraction	False Negative Fraction	True Positive Fraction
Patient 1	3/0.6	11.82	9.97	0.71	0.27	0.47	0.5
Patient 2	7/1.4	24.02	4.75	0.38	0.54	0.31	0.62
Patient 3	7/1.4	13.69	3.94	0.31	0.63	0.21	0.74
Patient 4	7/1.4	30.82	3.79	0.23	0.68	0.05	0.88
Patient 5	4/ 0.8	7.75	0.35	0.89	0.03	0.57	0.29

Table 2. Evaluation of the accuracy of gravity-induced viscoelastic FE brain shift modeling to predict the union of the residual tumor and cavity position after partial tumor resection.

	Brain shear modulus used in the Zener model initial/final in kPA	Tumor volume in cm3	Residual tumor+ cavity volume in cm3	Tumor shape on preoperative MR (rigid registration)		Predicted displaced tumor (FEM)	
				False Negative Fraction	True Positive Fraction	False Negative Fraction	True Positive Fraction
Patient 1	3/0.6	11.82	12.08	0.66	0.33	0.48	0.51
Patient 2	7/1.4	24.02	17.44	0.26	0.72	0.29	0.69
Patient 3	7/1.4	13.69	10.58	0.2	0.79	0.21	0.78
Patient 4	7/1.4	30.82	11.18	0.14	0.84	0.07	0.92
Patient 5	4/ 0.8	7.75	11.3	0.7	0.28	0.54	0.44

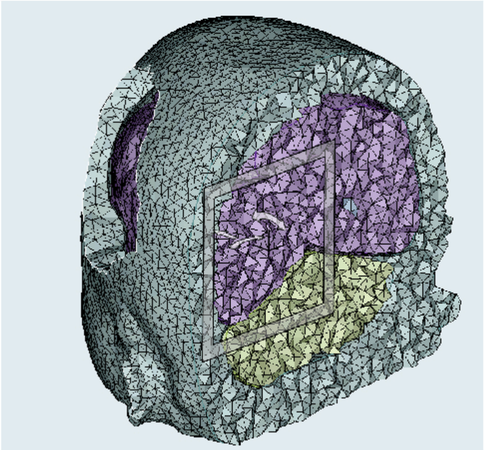

Figure 1. Finite-element model patient 1. Gray head with craniotomy. Purple cortex. Green: Cerebellum.

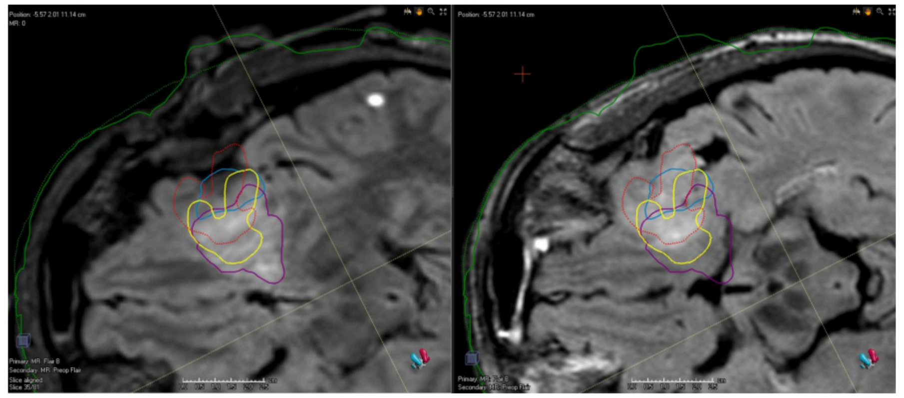

Figure 2. Left: iMR Flair. Right: pMR Flair for patient 1. Red: preoperative tumor. Purple: residual tumor. Blue: surgery cavity. Yellow: tumor displacement predicted by the FEM.

RESULTS

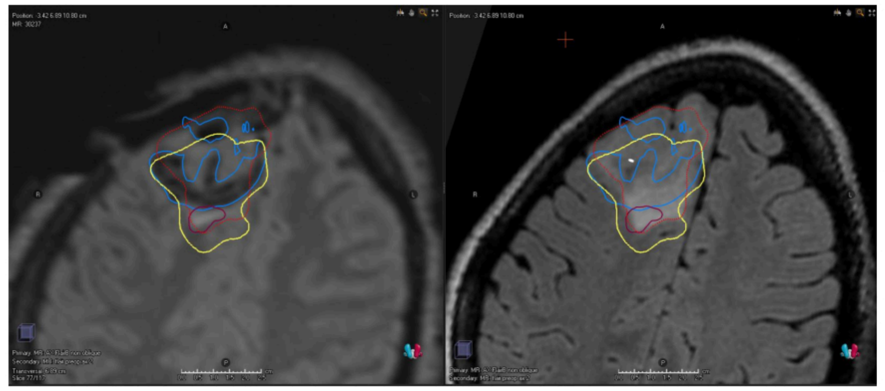

Figure 3. Left: iMR Flair. Right: pMR Flair for patient 2. Red: preoperative tumor. Purple: residual tumor. Blue: surgery cavity. : tumor displacement predicted by the FEM.

CONCLUSIONS

This exploratory research assesses the accuracy of gravity-induced viscoelastic brain-shift FEM in predicting tumor displacement during partial tumor resection. Our results indicate that FEM proves to be more accurate than current rigid registration methods. **Future work will investigate the impact of different neurosurgical scenario (poroelastic brain drainage, partial CSF drainage, partial tumor resection) on the accuracy metrics to further improve the TPF and FNF.** Moreover, we will extend the number of patients in this study to 10+.

ACKNOWLEDGEMENTS

This research work was supported by Apache Corporation, CPRIT Research Training Program (RP170067), the Helen Black Image-Guided Fund, and by the Image Guided Cancer Therapy Research Program at the University of Texas MD Anderson Cancer Center.

REFERENCES

[1] Smith, Stephen M, Mark Jenkinson, Mark W Woolrich, Christian F Beckmann, Timothy E.J. Behrens, Heidi Johansen-Berg, Peter R Bannister, et al. 2004. "Advances in functional and structural MR image analysis and implementation as FSL." *NeuroImage* 23: 208-219

[2] Hu, Jingwen, Xin Jin, Jong B Lee, Liying Zhang, Vipin Chaudhary, Murali Guthikonda, King Yang, and Albert King. 2007. "Intraoperative brain-shift prediction usg a 3D inhomogeneous patient-specific finite element model." *Journal of neurosurgery* 106: 164-169

[3] Miga, Michael I, Kay Sun , Ishita Chen, Logan W Clements , Thomas S Pheiffer, and Amber L Simpson. 2016. "Clinical evaluation of a model-updated image-guidance approach to brain-shift compensation: experience in 16 cases." *Int J CARS* 11: 1467-1474.

CONTACT INFORMATION

Email: ajlesage@mdanderson.org.