Image Updating After Brain Deformation in Image-Guided Neurosurgery: A Workflow for Image Registration

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INTRODUCTION

Image-guided neurosurgery typically relies on preoperative magnetic resonance (pMR) imaging that is rigidly aligned to the patient's anatomy in the operating room (OR) using fiducial-based registration. The accuracy of this alignment is critical for commercial image-guided systems to track surgical instruments in real-time throughout the surgery and is heavily dependent on several procedural factors, including edema, intracranial pressure, blood loss, and tissue retraction. Therefore, image updating using navigational information is needed to account for brain deformation that occurs during major surgical timepoints, including dural opening and resection. We aim to quantify deformation between pMR and intraoperative magnetic resonance (iMR) imaging in neurosurgical resection cases for which intraoperative stereovision (iSV) data was acquired. We will then apply the deformation to the pMR using iSV to generate a uMR that can then be compared to the iMR (Figure 1).

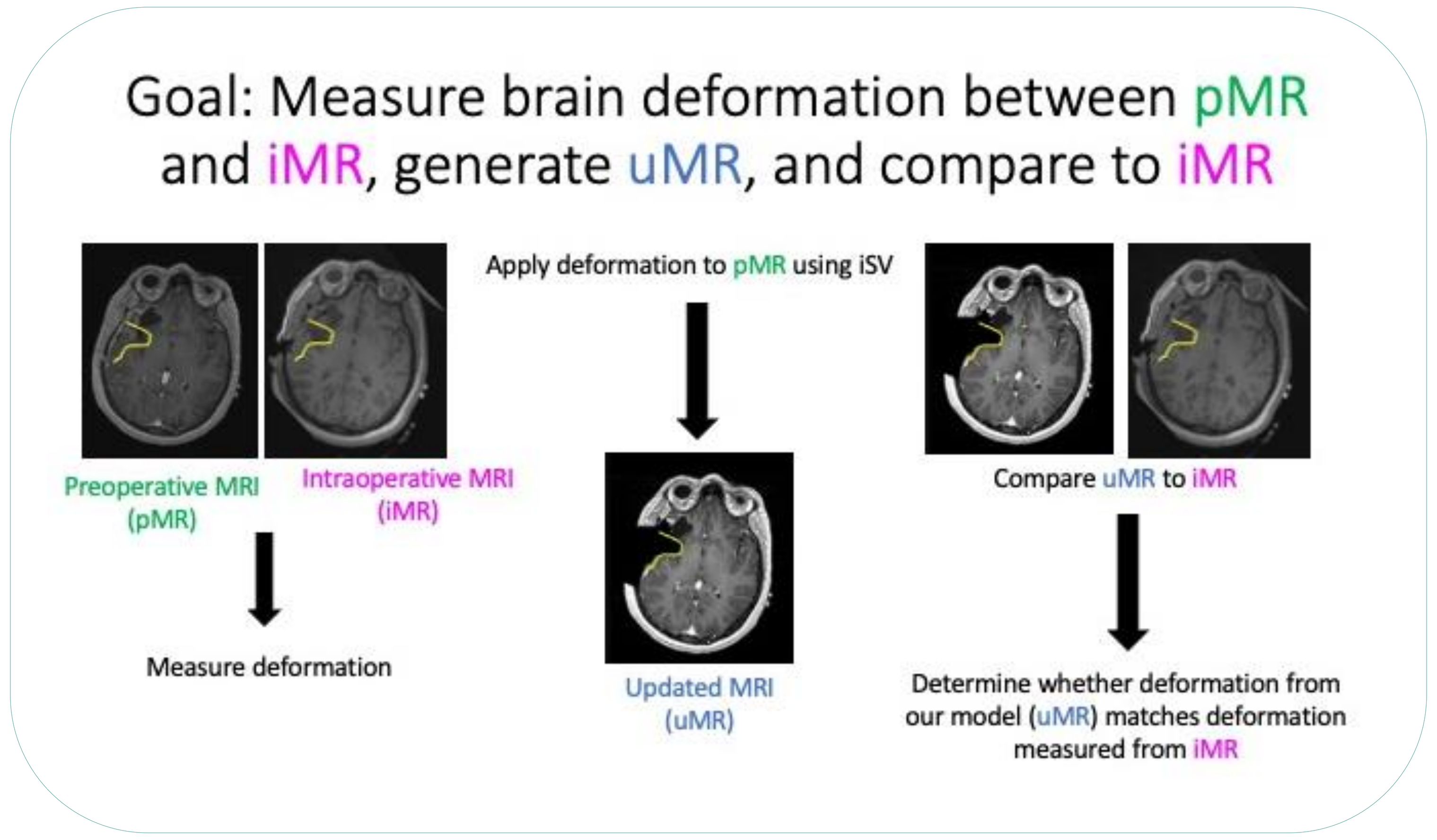

Figure 1. Imaging workflow for measuring brain deformation and generating updated magnetic resonance (uMR). Preoperative MRI (pMR) and intraoperative (iMR) scans are rigidly registered and deformation is measured and applied to pMR to generate uMR. Scans used from Fan X, Ji S, Olson JD, Roberts DW, Hartov A, Paulsen KD. Image updating for brain deformation compensation in tumor resection. *SPIE Proceedings*. 2016;9786. doi:10.1117/12.2217223

METHODS

Six retrospective neurosurgical cases were identified with pMR, iMR, and iSV (March 2014-July 2015). pMR and iMR scans were first manually aligned, followed by an automatic registration using the General Registration (BRAINs) tool and finally a fiducial-based registration in 3D Slicer (v4.11.20210226). Approximately ten fiducial points were placed on stable anatomic features such as blood vessels or white matter changes that were distant from the resection cavity. A fiducial registration error (FRE) and target registration error (TRE) was calculated for each alignment using Fiducial Registration Wizard in 3D Slicer or Matlab 9.12.0.2009381 (R2022a). Brain deformation was then measured in 3D Slicer by placing approximately ten fiducials around the resection cavity using the pMR and iMR images and calculating deformation.

RESULTS

Three out of the six cases were aligned with deformation measured (Table 1). Alignment improved with each registration from manual to automatic to fiducial-based alignment (Figure 2). Deformation was calculated for the three cases (Table 1).

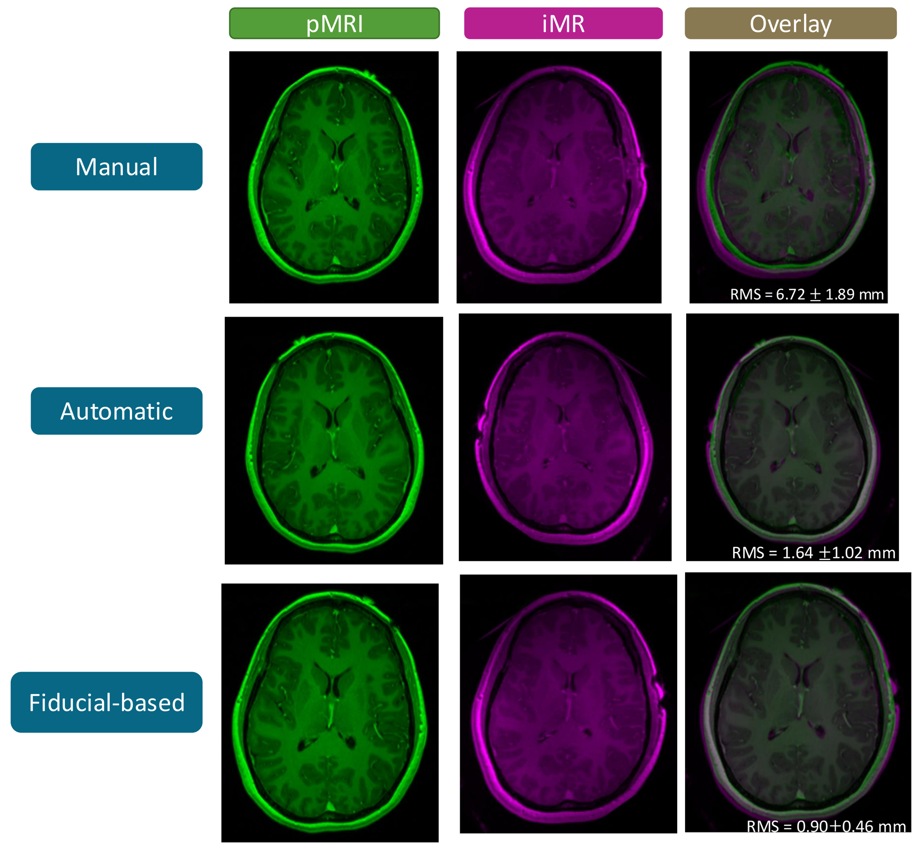

Figure 2. Example of alignment workflow for case 2 prior to deformation measurement. pMR (left column) and iMR (middle column) were first manually alignment and overlayed (left column with RMS displayed). The manual transform was applied and the process was repeated with an automatic registration and fiducial-based registration. This process was repeated for all cases.

Case	Sex	Tumor type	FRE $\pm$ SD (mm)	TRE $\pm$ SD (mm)	Deformation TRE $\pm$ SD (mm)
Case 1	F	Glioblastoma	0.47 $\pm$ 0.22	0.54 $\pm$ 0.29	3.89 $\pm$ 1.19
Case 2	F		0.90 $\pm$ 0.46	0.72 $\pm$ 0.30	1.58 $\pm$ 0.69
Case 3	F		0.69 $\pm$ 0.31	1.21 $\pm$ 0.47	3.57 $\pm$ 1.37

Table 1. Baseline patient demographics, clinical information, fiducial registration error (FRE), target registration error (TRE), and deformation target registration error.

DISCUSSION

While this project is still ongoing, the preliminary work shows that it is feasible to align the pMR and iMR scans well within the acceptable clinical margin of error of 2 mm (FRE 0.47-0.90 mm for the first three cases). Utilizing three separate registration techniques (manual, automatic, and fiducial-based) ensures the most accurate alignment possible prior to deformation measurement, which relies on the scans being in the same space. Further work involving uMR generation and comparison of uMR to iMR requires an accurate measurement of brain deformation intraoperatively so these efforts to accurately align pMR and iMR scans are imperative.

Project Limitations

This study has several limitations. The small sample size may make it difficult to detect real effects in uMR to iMR comparison. Additionally, the study is measuring brain deformation primarily in cortical features and future analyses will have to account for uMR accuracy deeper in the brain.

Future Directions

- Finish brain deformation calculations
- Apply deformation to pMR with iSV to generate uMR
- Compare uMR and iMR to determine if real-time measurement of brain deformation can create accurate updated images that reflect surgical anatomy during dural opening and resection
- Explore ultrasound as a modality for generating uMR in cases with deeper brain deformation

CONCLUSIONS

Our work describes a workflow for 1) registering pMR and iMR images and 2) measuring brain deformation after these registrations for the purpose of validating image updating during image-guided neurosurgery. Future work will explore the agreement between iMR (gold standard) and uMR.

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