Towards Validation of a Model-Based Deformation Correction Approach in Image-Guided Neurosurgery via Intraoperative Magnetic Resonance Imaging

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Abstract— **Soft tissue deformation is the primary source of error in conventional image-guided navigation systems for neurosurgical procedures. Biomechanical modeling techniques provide a cost effective method to compensate for brain deformation and may improve the fidelity of surgical navigation systems. Validation of model-based deformation compensation methods that have been proposed for use in neurosurgical image-guidance is a prerequisite for widespread clinical adoption. The focus of this work is to perform clinical validation of a model-based deformation correction pipeline using intraoperative magnetic resonance imaging data.**

I. Introduction

Intraoperative magnetic resonance (iMR) imaging studies of neurosurgical tumor resection procedures have quantitatively documented the extent of brain deformation during image-guided surgery (IGS). To summarize, moderate (3.0-6.9mm) to high shifts (> 7mm) of the cortical surface and deep tumor margins have been demonstrated in 75+% of neurosurgical cases. Studies have demonstrated that iMR imaging can facilitate improved clinical outcomes by providing insight into the anatomical changes that occur as a result of surgical interrogation [1]. While iMR will likely remain invaluable for critical and complex cases as well as research, impetus remains for an alternative, low-cost technology to provide deformation compensation functionality for conventional IGS systems that are used for the benefit of the larger population of neurosurgical patients. Clinical validation of the proposed model enhancements to current IGS systems is a prerequisite to widespread clinical adoption. As such, the goal of this work is to provide preliminary data from three clinical cases investigating the use of an iMR validation framework for a biomechanical model-based deformation correction pipeline.

II. Methods

The latest description of our model-based brain shift correction technique employed in this work was described in Chen *et al*. [2]. In short, the pipeline involves an inverse modeling technique built upon a biphasic model of brain biomechanics. A set of model solutions are pre-computed using a range of driving conditions representative of the surgical presentation (e.g. CSF-drainage induced brain sag, swelling conditions, and hyperosmotic drug reactions). The conventional IGS system is updated after an optimal combinatorial fit is determined to match intraoperatively measured cortical surface displacements.

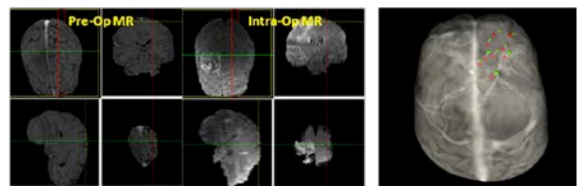

Figure 1. Visualization of Homologous Point Delineation

For this preliminary work, a series of anonymized preoperative and iMR image sets for three cases performed at the Brigham and Women's Hospital (Boston, MA) were retrospectively analyzed. The model validation procedure involved the selection of a series of homologous cortical surface points in the registered preop- and intraop- MR image sets (Figure 1). These homologous points served as displacement measurements and drove the inverse model.

III. Results

TABLE I. Comparison of Measured Displacement with Residual Displacement after Model Correction

Case	Homologous Cortical Surface Target Points		
	Measured Displacement	***Model Displacement***	***Shift Recapture***
Pt1	5.9±1.2mm	2.5±0.5mm	54.9±14.5%
Pt4	9.8±3.4mm	3.3±1.8mm	68.0±12.9%
Pt6	5.4±2.1mm	1.8±0.7mm	61.8±24.2%

IV. Conclusions

Clinical validation of deformation correction methods is paramount to physician adoption. The results presented here are initial steps towards an iMR-validation framework for evaluating a promising brain-shift compensation pipeline.

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