Modeling Deformation Dynamics during Trans-oral Surgery
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Introduction: There is a critical need to improve the safety and efficacy of trans-oral surgery (TOS) in the management of head and neck cancer. Surgical navigation with intraoperative image guidance has shown improved safety and efficacy with other surgical procedures such as sinus, skull base, and neurosurgery; however, it is currently not feasible in TOS due to the complex soft tissue and airway deformation that occurs with placement of laryngoscopes and retractors, which limits the usefulness of preoperative scans in the intraoperative setting. To address this, we are developing hybrid multibody-deformable models that simulate both the bony anatomic displacements as well as dynamic soft tissue deformations that occur during TOS. This will ultimately allow us to adapt information more accurately from preoperative scans, providing better guidance to surgeons in avoiding critical anatomic structures (e.g., vasculature) and in ensuring that the tumor is fully resected.

Materials and Methods: Diagnostic laryngoscopy was performed using a previously reported CT-compatible laryngoscope. Seventeen fiducials were secured to the tongue of the patient and used to track deformation following instrumentation. A CT was acquired both prior to instrumentation (undeformed state) and after the laryngoscope was placed (deformed state). The preoperative CT was accurately segmented to extract 3D geometries of the skull, mandible and tongue, which were used to construct a hybrid dynamic simulation model of patient anatomy. ArtiSynth, an open-source biomechanical modelling package, was used to simulate the dynamic motion of the tongue and mandible during laryngoscope insertion. The final position of the laryngoscope was used to simulate a trajectory path of the scope to deform the model. Model tissue parameters were iteratively tuned to optimize the fit between the model and the actual deformation as defined by the CT acquired in the deformed state. We used fiducial registration error (FRE) to define the accuracy of our approach.

Results and Discussion: Example motion of the laryngoscope and model deformation is depicted in Fig. 1A. A comparison of the deformed tongue, as well as ground truth extracted from the intraoperative CT are depicted in Fig. 1B. A rigid registration was performed based on the extracted skull geometries to align the model to the target. Prior to deformation, the initial TRE was 27mm (std=10mm). After deformation and parameter tuning, we were able to reduce the FRE to 6.6mm (std=4.2mm). While larger than the clinically required accuracy of 1-2mm, this is a significant improvement over the initial 27mm FRE when no deformation modeling is included and demonstrates the improvements possible with deformation modeling. Despite the complex deformation and displacement that occurs during instrumentation of the upper aerodigestive tract, these preliminary results suggest that using a hybrid dynamic simulation model with additional intraoperative data such as laryngoscope tracking might lead to an acceptable FRE for image-guided trans-oral surgery.

Translational Impact: The ability to accurately estimate the deformation of soft tissues and displacement of bony anatomy during TOS procedures may help to reduce the incidence of iatrogenic injuries and rates of positive surgical margins and ultimately improve long-term outcomes for patients following TOS.

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