Clinical evaluation of SLAM-based Trackerless Surgical Navigation in the Lateral Skull Base

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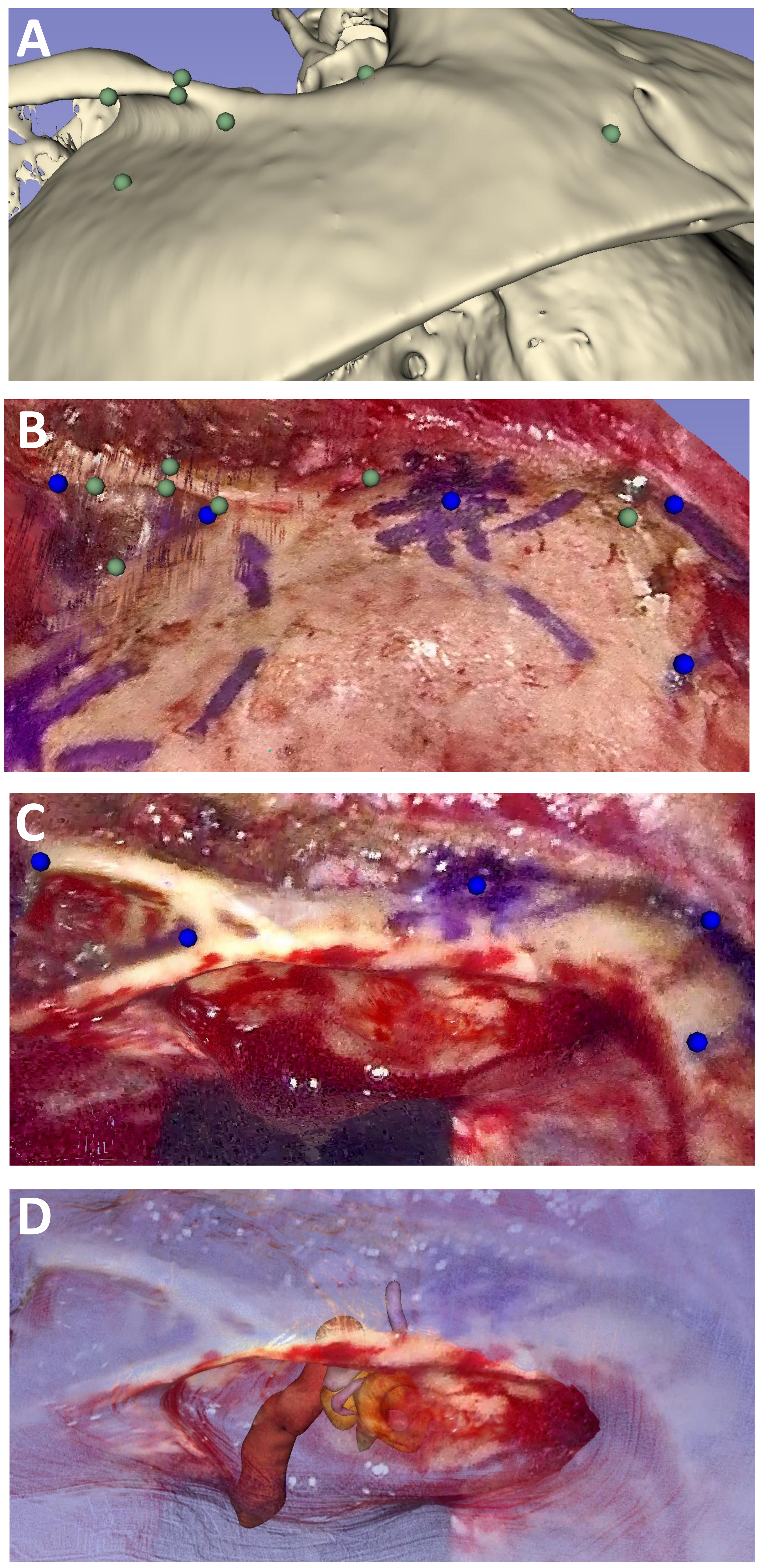
Introduction

- We recently developed a novel approach to surgical navigation employing simultaneous localization and mapping (SLAM) algorithms with 3D endoscopy.[1] 3D models of the operative field surface are reconstructed in real time and registered to volumetric models segmented from pre-operative imaging, all without requiring external tracking equipment. The surgeon is thereby provided with continuous information about anatomic structures underlying the exposed tissue surface.
- Validation in cadaveric models of both anterior[2] and lateral skull base surgery[3] have demonstrated approximately 1 mm mean surgical navigation errors.



Objective

- As an early test of clinical feasibility, we are retrospectively evaluating the fidelity of SLAM-based surface reconstruction using 3D-endoscopic lateral skull base surgical video from clinical encounters.

Methods

- Two models are generated:
  - Surface reconstruction models of the operative field at multiple timepoint. The models are generated by stitching video frames captured with 3D endoscopy (*4mm TIPCAM 3D Karl Storz*) into a 3D mosaic using stereo matching and then aligning the resultant data using SLAM.[1]
  - A volumetric CT model with anatomy segmented from high resolution CT imaging (0.6 mm slice thickness)
- The models are created in 3D Slicer[4] and then co-registered using corresponding fiducials placed on features present in both models. Registration accuracy is then assessed by calculating the resultant error between corresponding fiducials.

Figure 1: Visualization of SLAM-based surgical navigation using pilot clinical data from a middle fossa craniotomy case (surgical view). A 69-year-old woman underwent a 3D endoscopic assisted right middle fossa craniotomy for meningoencephalocele. A pre-operative segmented volumetric CT model (**A**) and surface models from two separate time points during surgery (**B**, exposure of cranium, and **C**, exposure of middle fossa floor) were generated. The first surface model (**B**) was registered to the CT model (**A**) using corresponding landmarks (green spheres). The second surface model (**C**) was then co-registered to the first surface model (**B**) using corresponding landmarks (blue spheres). Following co-registration, segmented CT structures are in anatomically appropriate locations when viewed through the semi-transparent surface model (**D**). Segmented structures shown include the otic capsule (yellow), facial nerve (purple), ossicles (grey), internal auditory canal (green), and internal carotid artery (red).

Results

- Data from 3 patients who underwent middle fossa craniotomy (MFC) were analyzed and yielded an average RMS surface-CT model registration error of 1.13 mm and surface-surface model registration error of 2.05 mm.
  - **Case 1**: 43 yr old woman who underwent right MFC for meningoencephalocele. Surface-CT registration error = 1.31 mm, surface-surface registration error = 2.28 mm
  - **Case 2** (See **figure 1**): 69 yr old woman who underwent right MFC for superior canal dehiscence repair. Surface-CT registration error = 1.71 mm, surface-surface registration error = 3.09 mm
  - **Case 3**: 64 yr old woman who underwent right MFC for meningoencephalocele. Surface-CT registration error = 0.36 mm, surface-surface registration error = 0.78 mm

Conclusions

- With further development, A SLAM-based approach to surgical navigation may one day enable lateral skull base surgeons to visualize the anatomy underlying opaque bone, providing a visual buffer zone while drilling within millimeters of critical structures.

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References

1. Zhou H, Jagadeesan J. Real-Time Dense Reconstruction of Tissue Surface From Stereo Optical Video. IEEE Trans Med Imaging. 2020;39(2):400-412.
2. Bartholomew RA, Zhou H, Boreel M, Suresh K, Gupta S, Mitchell MB, Hong C, Lee SE, Smith TR, Guenette JP, Corrales CE, Jagadeesan J. Surgical Navigation in the Anterior Skull Base Using 3-Dimensional Endoscopy and Surface Reconstruction. JAMA Otolaryngol Head Neck Surg. 2024 Apr 1;150(4):318-326.
3. Unpublished data, manuscript in preparation
4. Fedorov A, Beichel R, Kalpathy-Cramer J, et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magnetic Resonance Imaging. 2012