Augmented Reality in Skull Base Oncology: A Pilot Study Focused on Tumor Resection and Skull Base Reconstruction

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Abstract

Advances in augmented reality (AR) tools entail major promises to significantly assist skull base surgeons in the perioperative management of complex skull base tumors, encompassing preoperative surgical planning, intraoperative visualization of intricate anatomical structures, and post-tumor removal skull base reconstruction.

We developed a pilot study within our multi-departmental specialized skull base team to develop intraoperative AR models for skull base tumors resection and reconstruction. In total, 3 cases were completed and retrospectively analyzed, focusing on registration accuracy and surgical applicability of AR models.

In our pilot study, we describe our early experience with the use of AR in skull base oncological surgery, confirming its accessibility, easiness to use, and, most importantly, accuracy. Future endeavors in the use of AR should focusing on optimizing current registration strategies and improving intraoperative 3D model visualization within the surgical field.

Introduction

Tumors with significant bony invasion alter the normal skull base anatomy, leading to intraoperative difficulties in defining tumor borders despite advanced navigation systems. Similarly, they can also challenge optimal skull base reconstruction.

By overlaying patient-specific data onto patients during surgery, augmented reality (AR) is a promising tool for preoperatively creating surgical modes and intraoperatively defining tumor borders with consequent patient-specific skull base reconstruction.

We present our pilot study using AR in skull base tumor surgery, aimed at accurately defining extent of tumor resection and plan for reconstruction with patient-specific titanium implants.

Methods and Materials

A retrospective chart review was performed to identify patients with skull base bone tumors requiring resection and bony reconstruction.

Brainlab navigation software was used for segmentation/mirroring of the preoperative CT and MRI data and generation of a 3D virtual surgical plan including definition of tumor borders and surrounding critical neurovascular structures, patient specific implants, and bony anatomic models to guide reconstruction.

Each plan was developed with Xironetic, loaded onto IntraOpVSP software, and transferred to the Microsoft HoloLens 2, an AR head-mounted display. Optical landmark registration via individualized AR tracking QR-codes was used to orient each plan to the patient intraoperatively.

The surgeon then utilized the goggles during critical portions of each procedure to localized tumor borders segments and reconstruction implants.

Qualitative analysis included assessment of 1) time for registration, 2) registration accuracy, 3) time of use, 4) ease of use, and 5) surgical applicability.

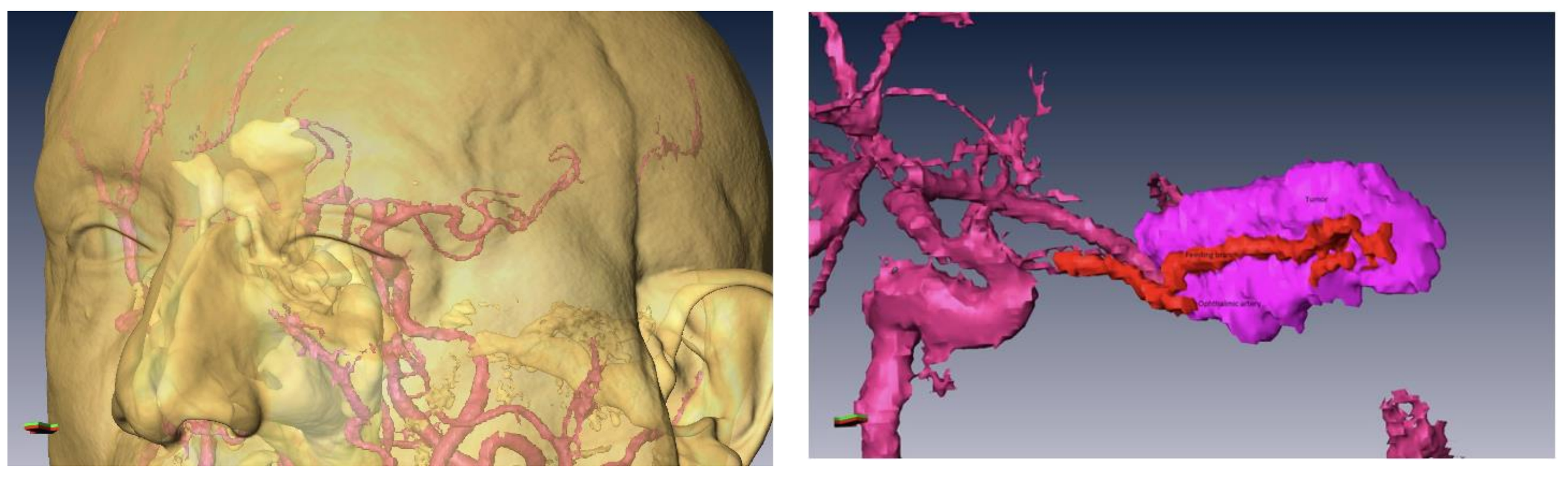

Figure 1. Preoperative 3D surgical planning of complex left sphenoid wing meningioma resection.

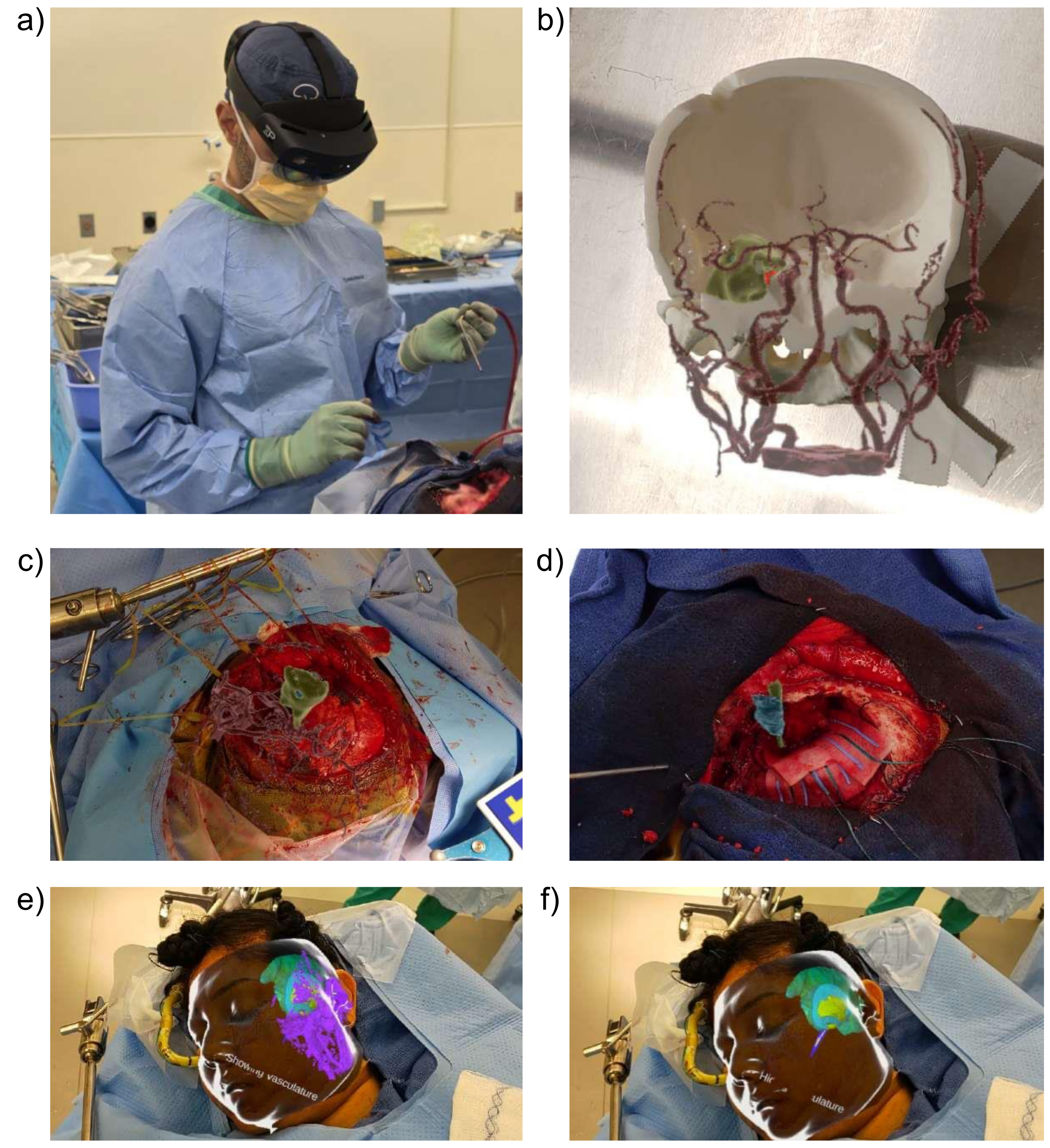

Figure 2. Intraoperative images of Augmented Reality (AR) overlays used in skull base oncologic surgery. a) Image of surgeon wearing headset. b) Photo of AR overlay on a 3D-printed model for a spheno-orbital meningioma resection. c) Identical AR overlay as Figure 1B, but projected on the patient. AR was used to visualize tumor margins and key nerves/vasculature. d) AR visualization of meningioma and optic nerve. e) AR visualization of temporal bone fibrous dysplasia with dural involvement. Purple = vasculature. Green = dura. Yellow = fibrous dysplasia. f) Alternate image without vasculature.

Results

A total of 3 institutional cases of skull base tumor surgery implementing AR tools were identified.
In the first case, AR was used in a patient with left squamous temporal bone fibrous dysplasia with dural involvement, assisting in intraoperatively visually assessing the accuracy of overlayed anatomic layers and planned resection margins.

In the second case, AR was used in a patient with a left zygoma chondroid myxoma for intraoperatively differentiate the destructive lesion from the surrounding normal bone, and for visualizing the relevant anatomic structures in the process of reconstruction following resection.

In the third case, AR was used in a patient with recurrent left sphenoid wing meningioma for intraoperative tumor margins definition and post-resection reconstruction of the left orbital roof. Gross total resection and optimal cosmesis were achieved in all cases.

Registration took on average 15 minutes (range, 10-25 minutes) per case. Accuracy was qualitatively comparable to traditional navigation, with intermittent virtual object drift requiring re-registration. The AR goggles were utilized for an average of 30 minutes (range, 15-45 minutes) per case. Surgeons found them lightweight, comfortable, and easy to intermittently wear during surgery.

Conclusions

Skull base bony tumors are often difficult to treat given their invasive nature and destruction of normal structures. In our early experience, AR greatly assisted in intraoperative settings by enhancing surgeons' ability in defining tumor borders, navigating the surrounding normal anatomy and preserving hidden underlying structures, displaying virtual cutting and drill guides, and precisely placing patient-specific implants. AR has the potential to enhance, or even replace, some forms of intraoperative surgical navigation.

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