Intraoperative navigation and augmented reality in sinonasal tumors: A comparative preclinical study.

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Abstract

Objective: To report the use of a novel Augmented Reality (AR) system in open sinonasal tumor resections in preclinical models, and to compare the AR approach with an advanced Intraoperative Navigation (IN) system.
Methods: Four tumor models were created. Five surgeons participated in the study performing virtual osteotomies. Unguided, AR, IN, and AR + IN simulations were performed. Statistical comparisons between approaches were obtained. Intratumoral cut rates was the main outcome. The groups were also compared in terms of percentage of intratumoral, close, adequate, and excessive distances from the tumor. Information of a wearable gaze-tracker headset was analyzed as well.
Results: A total of 335 cuts were simulated. Intratumoral cuts were observed in 20.7%, 9.4%, 1.2% and 0% of the unguided, AR, IN and AR + IN simulations respectively (p<0.0001). The AR was superior than the unguided approach in univariate and multivariate models. The percentage of time looking at the screen during the procedures was 55.5% for the unguided approaches and 0%, 78.5% and 61.8% in AR, IN and AR + IN, respectively (p<0.001). The combined approach significantly reduced the screen-time compared with the IN procedures alone.
Conclusion: The AR system improved margin delineation compared with unguided techniques. AR improved the gaze-toggling drawback of IN. Further refinements of the AR system are needed before translating our experience to clinical practice.

Introduction

The complex anatomy represent a major challenge for surgeons when treating advanced sinonasal tumors[1]. Intraoperative Navigation (IN) has been proposed as a potential strategy to improve surgical margins[2]. Still, one key drawback of all IN systems is that the information is displayed outside the surgical field, and therefore surgeons are forced to switch their gaze between the actual procedure and the navigation monitor, which can impact safety and efficiency[3].

Augmented reality (AR) uses visual inputs to enhance the user's natural vision, and therefore can integrate navigation information onto the surgical field[4,5]. This feature can potentially address the gaze toggling drawback of IN, and at the same time provide valuable information to the surgeon, for example facilitating tumor localization and delineation[6,7].
We endeavored to report the first use of a novel AR system in open sinonasal tumor resections in preclinical models, and to compare an AR approach with an advanced IN navigation system.

Methods and Materials

Four locally advanced sinonasal tumor models **(Fig 1-A**) were made using artificial skulls. Tumor surfaces were disguised with tape. Five different areas to be osteotomized were delineated: palatal osteotomy (Pa), fronto-maxillary junction (FMJ), latero-inferior orbital rim (LIOR), zygomatic arch (Zy) and pterygomaxillary junction (PMJ) **(Fig 1-B)**. Cone-beam computed tomography (CBCT) scans acquired 3D images of the skull models[6] **(Fig 1-C/D)**. An in-house IN (GTx-Eyes), was used to compare this approach with AR **(Fig 2-A/B/C/D)**.This advanced IN system allows visualization of the entire trajectory of the cutting instrument with respect to the tumor in 3D views[4].

The AR system was composed of a portable high-definition projector, a stereoscopic infrared camera, a USB 2.0M pixel generic camera, and a laptop computer **(Fig 4)**. The AR system was registered into a single coordinate system by pairing correspondent landmarks using fiducial markers identifiable in both the images and projection surface. This approach facilitated identification of the tumors and in consequence guided the virtual cuts of the participants **(Fig 4)**. A wearable gaze-tracker headset quantified gaze direction (e.g., surgical field vs. navigation monitor) during surgical tasks.

Five head and neck surgeons participated in the simulations. Surgeons were instructed to position the osteotome between the delineated areas of the different osteotomy sites in a sequential order (Pa-FMJ-LIOR-Zy-PMJ) and to provide a 1cm margin. Virtual cuts were performed, and this involved recording the osteotome position and orientation in the navigation software. The analysis was performed on the virtual cutting trajectory after all the simulations were completed. Four procedures were performed: 1) Unguided using axial, sagittal, coronal images, 2) Guided -AR- 3) Guided -IN-, and 4) Guided -AR and IN-. Statistical analysis was run through XLSTAT®. Rates of intratumoral virtual cuts was the main outcome and was assessed with the Fisher test. Multivariable analysis adjusting for surgeon and tumor was performed through logistic regression analysis.

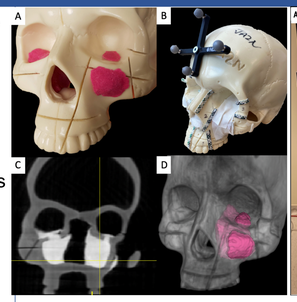

Fig 1: A) Artificial skulls with mouldable material simulating advanced sinonasal tumors. B) Final tumor model. A 4-sphere reference co-registered the intraoperative navigation. C) Higher attenuation of the artificial tumor models in the CBCT images. D) 3D contouring of the left tumor.

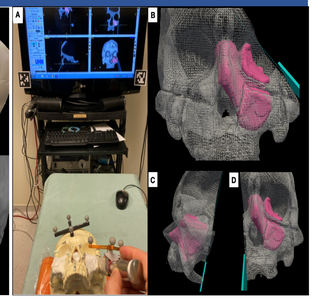

Fig 2: A) Setup of the IN system, depicting the triplanar cutting views and the 3D rendering of the tumor on the screen. The skull and the cutting instrument (osteotome) are referenced to be tracked and co-registered. B, C and D) The system allows users to visualize cutting trajectories of the instrument with respect to the tumor. B) Cutting of the latero-inferior orbital rim, C) Palate and D) Pterygomaxillary junction.

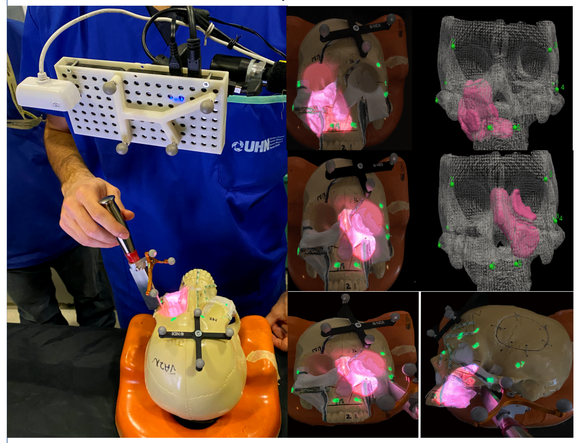

Fig 4: Augmented reality system mounted and projecting. Projection of the four sinonasal tumors using augmented reality, which enables tumor localization. The alignment points are depicted as well as the 3D reconstruction of the tumors. Pictures were taken without light for demonstration purposes, but good visualization is obtained with light as well. Virtual osteotomies guided by the AR.

Results

A total of 335 cuts were simulated. Intratumoral cuts were observed in 20.7%, 9.4%, 1.2% and 0% of the unguided, AR, IN and AR + IN simulations respectively (p<0.0001). Univariate analysis comparing different procedures with AR showed that this technology improved margins with respect to unguided simulations **(Table 1).**
Mean total duration of the simulation was 215 seconds for unguided procedures and 117, 134 and 120 seconds in the AR, IN and AR + IN respectively. Participants required significantly more time to perform the unguided simulations compared to the AR and IN guided ones (p=0.004). There were no differences between the AR, IN and AR + IN guided procedures. The percentage of time looking at the screen during the procedures was 55.5% for the unguided approaches and 0%, 78.5% and 61.8% in AR, IN and AR + IN, respectively (p<0.001). Adding the AR technology to the combined approach significantly reduced the screen-time compared with the advanced IN procedures alone **(Table 2)**.

Table 1: Intratumoral cuts analysis.

INTRATUMORAL CUTS AND TYPE OF PROCEDURE				
Intratumoral cut/Guidance	Unguided	AR	IN	AR+IN
No	65	77	83	84
Yes	17	8	1	0
Total	82	85	84	84
Percentage	20.7%	9.4%	1.2%	0.0%
UNIVARIATE ANALYSIS OF INTRATUMORAL CUTS				
Guidance	OR	95%-CI	p-value	
AR	REF	REF	REF	
Unguided	2.44	1.00-5.02	0.049	
SN	0.16	0.03-0.97	0.046	
AR+SN	0.05	0.00-0.97	0.047	
MULTIVARIATE ANALYSIS OF INTRATUMORAL CUTS				
Guidance	Adjusted* OR	95%-CI	p-value	
AR	REF	REF	REF	
Unguided	2.54	1.05-6.17	0.039	
SN	0.16	0.03-0.88	0.035	
AR+SN	0.06	0.00-0.81	0.035	

AR Augmented reality, IN intraoperative navigation, OR odds ratio, *Adjusted by tumor model and surgeon

Table 2: Total duration and screen time during the simulations.

Outcome	Unguided	AR	IN	AR+IN	p-value (Kruskal Wallis test)
Total duration (mean [IQR])	215.8" [154.7-263.8"][A]	117.4" [83.4-145.0"][B]	134.7" [83.7"-170"][B]	120.9" [81.8-145.0"][B]	0.0004
Screen time (mean [IQR])	55.5% [51.3-59.0%][A]	0.0% [0.0-0.0%][B]	78.5% [72.6-83.9%][C]	61.8% [53.4-70.0%][A]	<0.0001

[A,B,C]Groups significantly differed based on Steel-Dwass-Critchlow-Filgner post-hoc test. IQR- Interquartile range.
AR Augmented reality, IN intraoperative navigation.

Discussion and Conclusions

We were reported the use of AR for open sinonasal approaches, and improved margin delineation compared with unguided techniques. The advanced IN performed better in terms of margin delineation, but the AR improved the gaze-toggling drawback of IN. Further research within our group is currently underway before translating our experience to the clinical practice.

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