An Objective Assessment of 3D Printed Models In Sinus Surgery

Ricardo Pulido, MD[1]; Seth Friedman, PhD[2]; Waleed Abuzeid, MD[1]; Ian Humphreys, DO[1]; Aria Jafari, MD[1]; Kris Moe, MD[1]; Randall Bly, MD[1]

[1]Department of Otolaryngology – Head and Neck Surgery, University of Washington

[2]Department of Radiology, Seattle Children's Hospital

Abstract

Introduction:

3D printed models are increasingly being utilized as an adjunctive to cadavers for endoscopic sinus surgery (ESS) in courses and demonstrations; however, there is sparse data to support the ability to objectively measure extent of ESS in 3D printed models. We aim to test the ability to reliably detect expected postoperative changes on computed tomography (CT) scans in 3D printed models.

Methods:

CT images were imported into the software system, Materialise Mimics (Leuven, Belgium), for segmentation of underlying sinus anatomy. The 3D model was printed based on anatomic presets to delineate the soft tissue and bony components as defined in current literature. The model underwent a preoperative CT scan and ESS was subsequently performed on 5 separate sinus inserts, each side of the insert acting as a separate sinus, for a total of 10 sinuses. The procedures performed were maxillary antrostomy, total ethmoidectomy, sphenoidotomy, frontal sinusotomy, and middle turbinate reduction. Each sinus underwent varying degrees of each listed sinus procedure and was performed by the resident physician. A postoperative CT scan was then completed for all sinus inserts and evaluated by 6 experienced sinus surgeons. Each surgeon rated all 10 sinuses based on the extent of each procedure.

Results:

The 6 experienced sinus surgeons individually evaluated each of the 10 postoperative sinuses to determine inter-rater reliability. A Fleiss Kappa of 0.51 (p <0.001; 95% CI: 0.33-0.7) was found for maxillary antrostomies. Fleiss Kappa of 0.53 (p <0.001; 95% CI: 0.36-0.71) for ethmoidectomies. Fleiss Kappa of 0.53 (p <0.001; 95% CI: 0.36-0.71) for middle turbinate reduction. Fleiss Kappa of 0.24 (p = 0.021; 95% CI: 0.04-0.44) for frontal sinusotomies. Fleiss Kappa of 0.36 (p = 0.002; 95% CI: 0.13-0.59) for sphenoidotomies.

Conclusion:

Our sample of experienced sinus surgeons evaluating our 3D printed model moderately agreed upon the extent of completion of maxillary antrostomies, ethmoidectomies, and middle turbinate reduction. Our raters mildly agreed upon the extent of completion of frontal sinusotomies and sphenoidotomies.

Introduction

- 3D printing is increasingly being used for simulation purposes and for patient specific preoperative planning.[1-5]
- The application of 3D printing is limited in sinus and skull base surgery, however the role for this is expanding.
- We aim to test the ability to reliably detect expected postoperative changes on computed tomography (CT) scans in 3D printed models.

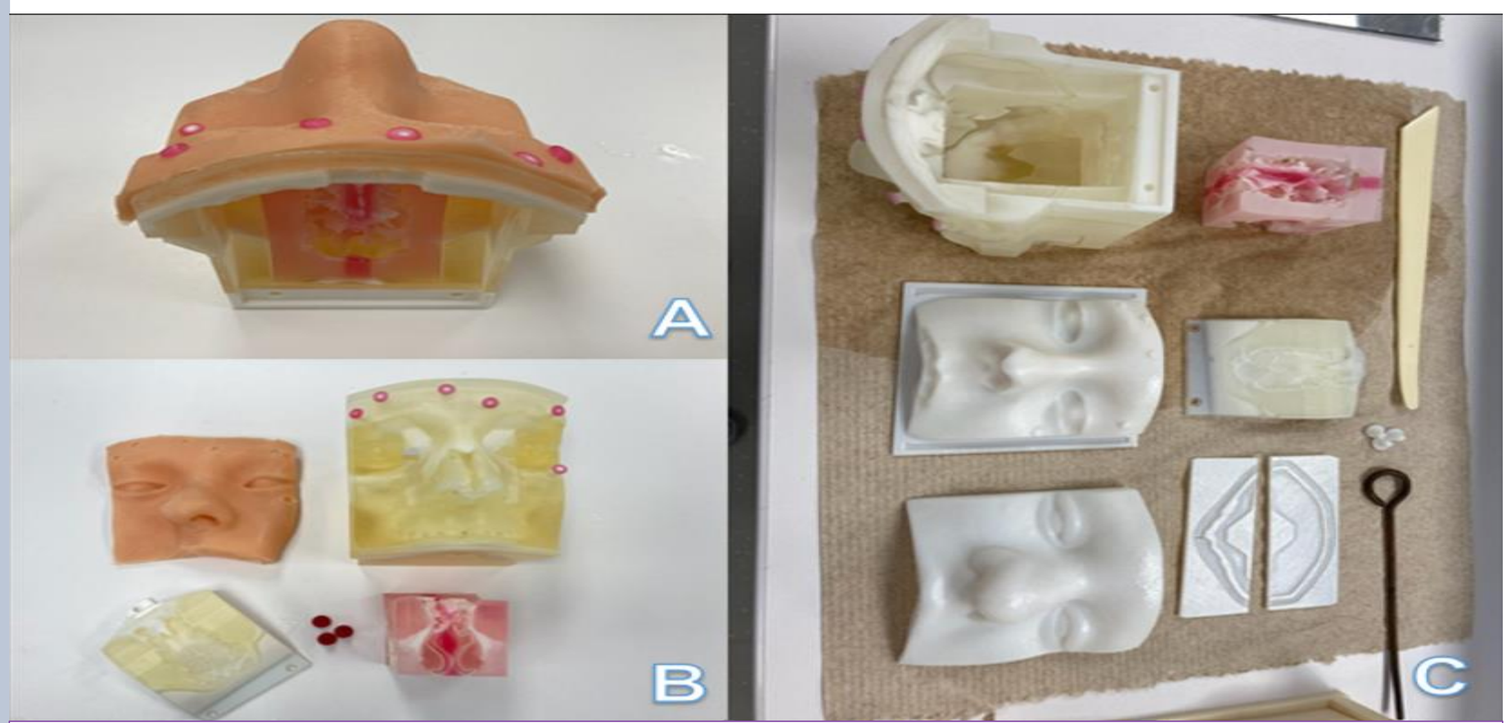

Figure 1: Novel Design of 3D Printed Model for Sinus Surgery.
A – Demonstrates the completed model (skull base removed) with the sinus component inserted into place.
B – Demonstrates the four components of the model. The skin, head (with pink bony fiducial points), and skull base are reusable for multiple sinus surgeries.
C – Representation of the model from a superior view during the cleaning phase.

Methods and Materials

- Institutional IRB was obtained and a deidentified patient's CT scan was used to construct a 3D printed model.
- The Digital Imaging and Communications in Medicine (DICOM) data was imported into Mimics (Materialise, Leuven, Belgium), a medical segmentation program, to create the Standard Tessellation Language (STL) code that was used by our 3D printer to create the 3D printed model.
- This STL code was then used on a J750 digital anatomy polyjet printer (Stratasys, Rehovot Israel), using anatomic presets as defined in the literature, to obtain a final 3D printed model.[6-7]

- **Notable Features of Our 3D Printed Model**
  1. **Constructed using four separate components.** This includes the head component (with bony fiducial points), sinus component, skull base, and skin (**Figure 1**).
  2. **On endoscopic view,** our model is capable of undergoing sinus surgery with **anatomy that mimics real tissue during dissection** as defined by the material characteristics used in prior literature **(Figure 2).**
- The model underwent a preoperative CT scan and ESS was subsequently performed on 5 separate sinus inserts, each side of the insert acting as a separate sinus, for a total of 10 sinuses.
- The procedures performed were maxillary antrostomy, total ethmoidectomy, sphenoidotomy, frontal sinusotomy, and middle turbinate reduction. Each sinus underwent varying degrees of each listed sinus procedure and was performed by the resident physician.
- A postoperative CT scan was then completed for all sinus inserts and evaluated by 6 experienced sinus surgeons. Each surgeon rated all 10 sinuses based on the extent of each procedure (**Table 1).**

	Fully Open/Removed	Partially Open/Partially Removed	Not Open/Middle turbinate intact
Maxillary Sinus	Uncinate completely removed	Partial uncinate remains	Not opened
Ethmoids	All septations removed	<50% of cells remain	>50% of cells remain
Sphenoid	Sphenoid is widely open	Sphenoid is partially open	Sphenoid is not opened
Frontal	Frontal is completely open	Frontal is partially open	Frontal is not opened
Middle Turbinate	The entire turbinate is removed	The head of turbinate is still present	Turbinate is intact

Table 1: Example of Questionnaire Provided to Each Rater.

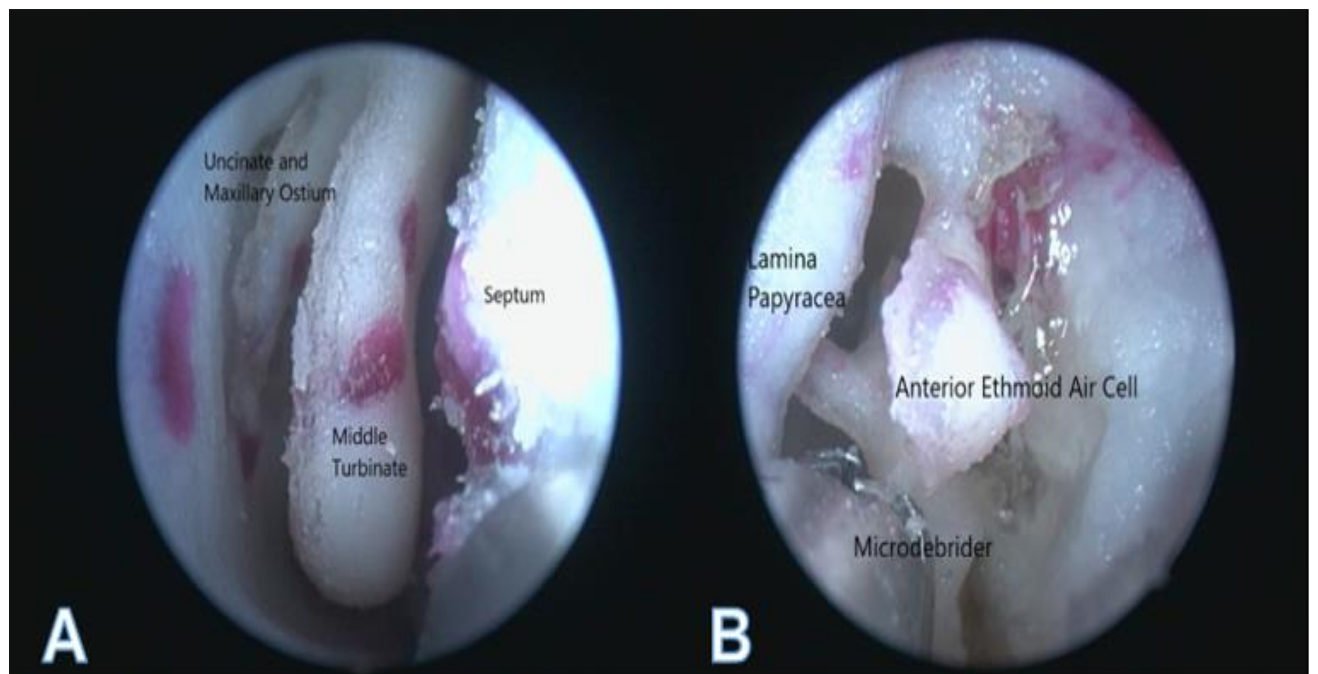

Figure 2: Endoscopic View of 3D Printed Model.
A – Endoscopic view of the right nasal cavity. The pink substrate located on the septum, uncinate, and middle turbinate reflects 3D printed blood vessels.
B – Endoscopic view of the right anterior ethmoid sinus that has been partially debrided with a microdebrider (labeled).

Results

- Performing surgery on the printed model demonstrated similar haptic feedback as sinus surgery in live patients.
- The 6 experienced sinus surgeons individually evaluated each of the 10 postoperative sinuses to determine inter-rater reliability.
- A Fleiss Kappa of 0.51 (p <0.001; 95% CI: 0.33-0.7) was found for maxillary antrostomies. Fleiss Kappa of 0.53 (p <0.001; 95% CI: 0.36-0.71) for ethmoidectomies. Fleiss Kappa of 0.53 (p <0.001; 95% CI: 0.36-0.71) for middle turbinate reduction. Fleiss Kappa of 0.24 (p = 0.021; 95% CI: 0.04-0.44) for frontal sinusotomies. Fleiss Kappa of 0.36 (p = 0.002; 95% CI: 0.13-0.59) for sphenoidotomies. This is demonstrated in **Table 2.**
- An example of images provided to each rater is shown in **Figure 4** for comparison.

Procedure	Fleiss Kappa	Standard Error	Lower 95% CI	Upper 95% CI	P-value
Maxillary Antrostomy	0.51	0.09	0.33	0.7	<0.001
Ethmoidectomy	0.53	0.09	0.36	0.71	<0.001
Sphenoidotomy	0.36	0.12	0.13	0.59	0.002
Frontal Sinusotomy	0.24	0.10	0.04	0.44	0.021
Turbinate Reduction	0.53	0.09	0.35	0.71	<0.001

Table 2: Summary of Results Demonstrating Inter-Rater Reliability Among 6 Experienced Sinus Surgeons

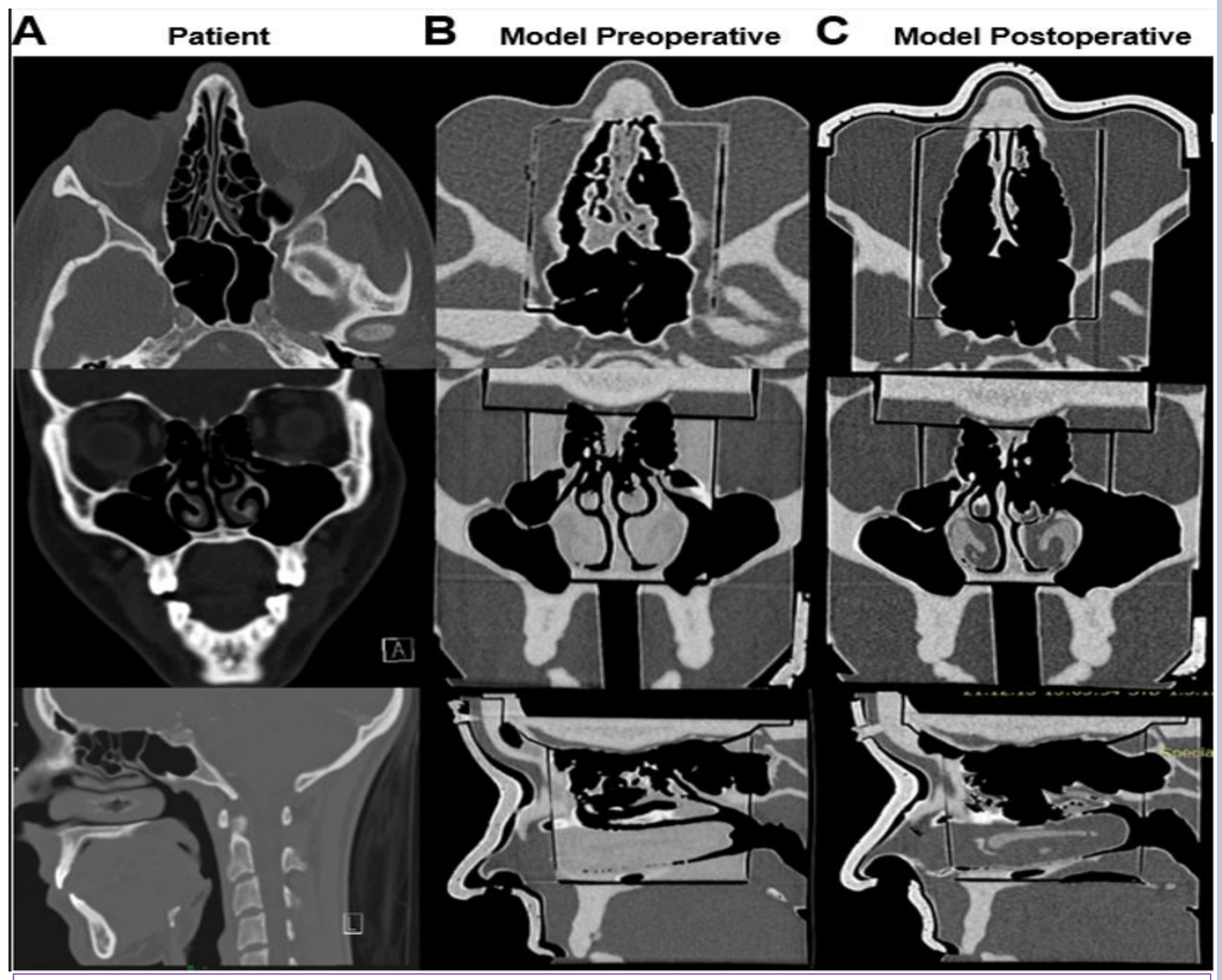

Figure 4: Comparison of Computed Tomography (CT) Scans of Patient and Model
Column A: Demonstration of the patient's CT scan used to create the 3D printed model.
Column B: Demonstration of the 3D printed model's preoperative CT scan.
Column C: Model underwent limited sinus surgery (left > right). The multiple views on CT demonstrates that the CT scan can identify the surgery performed on the model.

Conclusions

- The 3D printed model is capable of providing realistic haptic feedback during sinus surgery.
- Our raters moderately agreed upon the extent of completion of maxillary antrostomies, ethmoidectomies, and middle turbinate reduction.
- Our raters mildly agreed upon the extent of completion of frontal sinusotomies and sphenoidotomies.
- This study provides some objective evidence that 3D printed models can be used to objectively measure sinus surgery extent. This can be used to support the role for 3D printed models

Contact

Ricardo Pulido, MD
University of Washington
1959 NE Pacific Street, Seattle, WA 98195
Rwp251@uw.edu
(267)-391-6042

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