Patient-Specific 3D Models for Open Frontal Sinus Surgery: Enhancing Precision with Facial Mask-Guidance

Case Report

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Abstract

In osteoplastic frontal sinus surgery, the precision of initial bony incisions is critically important. Conventional techniques such as 6-ft Caldwell radiographs, burr holes method, transillumination and navigation systems are widely used. Recently, publications on the use of three-dimensional (3D) printed models in surgical navigation have increased. We aimed to enhance the accuracy of 3D model navigation—a cost-effective and accessible method that can be used alone or alongside conventional approaches—by developing a novel facial mask component not previously described. We developed a patient-specific planning system using open-source segmentation software and a desktop 3D printer. Computed tomography scans were segmented to isolate the anterior table, the sinus walls, and the osteoma when present. A novel feature was the custom-designed facial mask, which ensured accurate alignment of the incision guide. The mask, designed from tissue landmarks, incorporated a locking cylinder mechanism. All parts were printed in polylactic-acid at a cost of approximately 1$, with production times under 8 hours. The system was tested on two patients. In case-1, a patient with an anterior table defect, the 3D-printed model provided accurate incision guidance when navigation failed intraoperatively. In case-2, a frontal sinus osteoma was visualized with 1:1 scale printed models, which facilitated surgical planning. Surgeons reported better anatomical orientation, increased confidence in performing incisions, and more effective preoperative and intraoperative planning. The application of a facial mask to the 3D model has shown promising initial results. Further refinements and comparative studies are needed to standardize production, demonstrate accuracy, and validate its broader clinical utility.

Keywords: Frontal sinus, paranasal sinus diseases, anatomy, osteoma, three-dimensional printing, surgical procedures

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Introduction

In osteoplastic frontal sinus surgery, the accuracy of the initial bony cuts is of paramount importance. Inadequate incisions may result in both increased risk of intracranial complications and incomplete disease clearance due to poor exposure of anatomical boundaries.

Among conventional techniques, 6-ft Caldwell radiographs remain a readily accessible and cost-effective method. With the increasing availability of navigation systems, these have become the gold standard, providing high accuracy for determining incision boundaries. Burr hole and transillumination techniques are also among the methods described (1).

In rhinology, most publications related to three-dimensional (3D) printing have focused on preoperative surgical training models (2,3). However, in recent years, reports on the use of 3D models for surgical navigation have increased (4-6). Application of 3D model-based navigation has been described for various benign pathologies of the frontal sinus, including osteoma, mucocele, recurrent sinusitis, inverted papilloma, and Samter's polyps (4,6).

In this report, we present two cases in which we integrated a novel facial mask component into 3D model-based navigation. We hypothesized that this addition could improve the accuracy and usability of 3D models in frontal sinus navigation, particularly during the initial bone cuts.

Case Presentations

Device Description and Development

The device is composed of two components: a 3D-printed surgical incision guide and a patient-specific facial reference mask. Computed tomography (CT) data were segmented using 3D Slicer software to reconstruct anatomical structures. The incision guide was generated by reducing and anteriorly displacing the anterior table segment to fit above the periosteum. The mask was created by subtracting the facial soft tissue volume from a rectangular prism. Integration of a dual-cylinder alignment mechanism ensured consistent and precise reapplication of the guide to the same position (Figure 1).

All parts were printed using polylactic-acid (PLA) on a Bambu Lab P1S 3D printer (Figure 1). Total production time per case was less than 4 hours, with material costs under 2$.

Clinical Application Case-1

Case-1 involved an adult male with left forehead swelling and an anterior table defect. Models were printed in 3.2 hours. Intraoperatively, due to navigation system failure, the surgery was continued using the 3D-printed model for incision planning (Figure 2). The model provided reliable and accurate incision guidance.

Clinical Application Case-2

Case-2 involved an adult male with a right frontal sinus osteoma. Segmented models included the osteoma, sinus walls, and anterior table (Figure 3). Because of the similar radiodensity between the osteoma and sinus wall, manual segmentation was required. Print times were 10 minutes for the anterior table, 18 minutes for the osteoma, and 2.5 hours for the complete sinus model.

The 3D model allowed detailed visualization of the osteoma and the theoretical postoperative sinus cavity, assisting intraoperative orientation (Figure 3).

Discussion

Previous studies utilizing 3D-printed templates lacked reference mechanisms for accurate placement, resulting in millimetric errors (4-7). By introducing a facial reference mask, we aimed to reduce uncertainty in the model's placement on the face and standardize reproducibility. Furthermore, the use of open-source software and in-house 3D printing substantially reduced costs.

The facial mask-assisted 3D model navigation system can theoretically be applied in all osteoplastic frontal sinus cases. However, its most valuable indication may be patients with anterior table defects, as demonstrated in case-1. After elevating the periosteum, the real defect can serve as an additional anatomical landmark that can be perfectly aligned with the defect in the 3D model, thereby defining the anterior table boundaries with high accuracy. In osteoma cases, as in case 2, creating a defect-free model of the frontal sinus from CT data may facilitate intraoperative orientation and save operative time in the absence of navigation.

Although the 6-ft Caldwell radiograph is cost-effective and easily applicable, it is fundamentally a 2D projection mapped onto a 3D structure. Studies comparing 6-ft

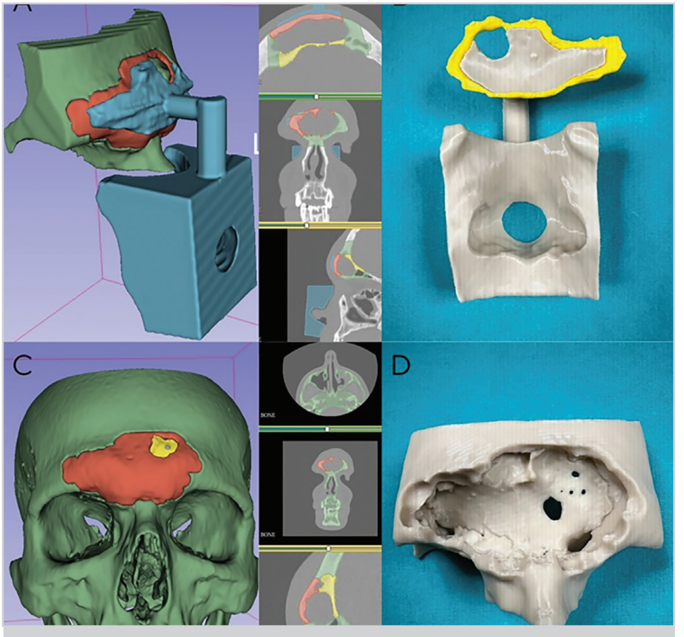

Figure 1. A) Frontal sinus (green), anterior table (red), and anterior table incision segment with facial mask (blue) segment, B) anterior table model with facial mask, C) cranium (green), anterior table (red) segments, D) 3D model of both frontal sinuses

Caldwell radiographs with CT-based 3D reconstructions and navigations have demonstrated the superiority of 3D methods in delineating anterior table boundaries (8). CT-based navigation systems are the best example of this. Our current study has introduced a low-cost, manual version of the high-cost CT-based navigation system. For centers without access to navigation systems, 3D navigation may serve as an alternative.

Navigation systems, which are CT-based, remain the gold standard when available, providing precise intraoperative orientation. However, their high cost and limited accessibility in non-tertiary centers restrict their use. In contrast, 3D-printed navigation is low-cost and accessible but depends on the operator's experience during segmentation and manual editing. In our study, we needed to repeat the segmentation process twice for the first case due to inexperience, but subsequent cases required less time and greater efficiency. This suggests a learning curve and highlights the need for further studies with larger cohorts.

PLA, although not autoclavable, was sterilized with povidone-iodine and ortho-phthalaldehyde solution. No adverse reactions were observed, but further research is needed regarding its contact with skin and subcutaneous tissues (9). A safer approach is to use sterile transparent covers to isolate the models during surgery, preventing contact with the skin and subcutaneous tissue and ensuring greater sterility.

Future work may focus on developing automated software capable of generating both surgical guides and the facial mask directly from CT images. Such software would shorten modeling time, reduce operator-dependent errors, lower costs, and improve standardization. We believe that this method may serve as a reliable incision-planning alternative in centers without navigation systems, and defect-free osteoma models may further facilitate intraoperative decision-making. However, as this was a pilot study, larger comparative studies with quantitative data are required to validate our findings.

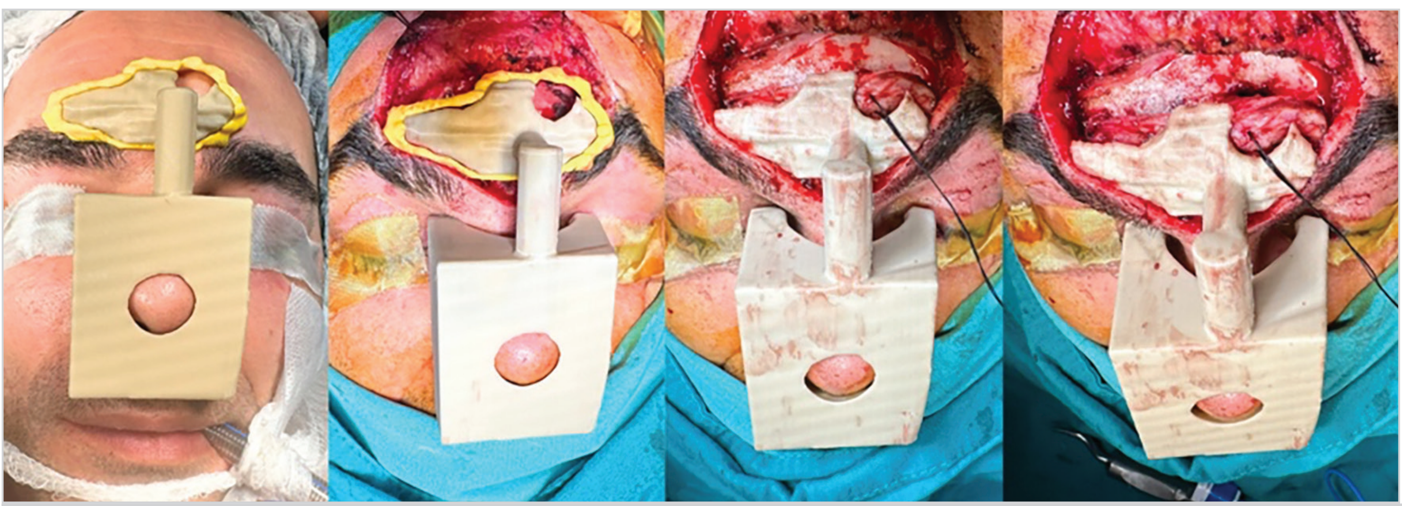

Figure 2. Preoperative and intraoperative applications of the 3D model. Identification of the anterior table boundaries (outer margin of the yellow model) and the bone incision line (inner margin of the yellow model)

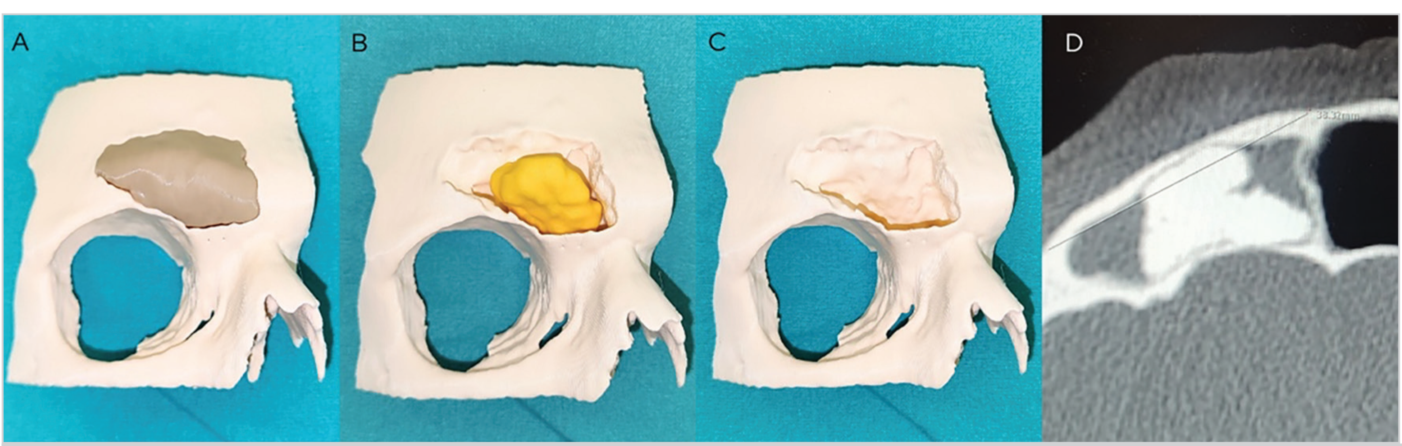

Figure 3. A) 3D model of the right frontal sinus and its anterior table, B) 3D model of the frontal sinus with the anterior table removed (the osteoma is shown in yellow), C) frontal sinus model with the osteoma removed, D) axial computed tomography image of the right frontal sinus

Conclusion

With the increasing use of 3D models in contemporary surgical planning, this study demonstrates that a patient-specific 3D model provides a practical and low-cost solution that enhances both bony incision accuracy and anatomical orientation in frontal sinus surgery. In both of our cases, the model improved anatomical guidance and increased surgical confidence. These preliminary results are promising, and further validation with standardized protocols and larger patient series will be essential to establish the method's accuracy and future clinical applicability.

Ethics

Informed Consent: Written informed consent was obtained from the patients for the use of clinical data, images, and the patient-specific 3D model for academic presentation and publication purposes.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.Ç., E.K., F.Ö., Concept: M.Ç., F.Ö., Design: M.Ç., E.K., F.Ö., Data Collection and/or Processing: M.Ç., Analysis and/or Interpretation: M.Ç., E.K., Literature Search: M.Ç., E.K., F.Ö., Writing: M.Ç.

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Main Points

- The use of patient-specific three-dimensional (3D) models with facial masks may provide intraoperative guidance and help to accurately locate the frontal sinus.
- This technique offers a low-cost and accessible solution for centers lacking advanced surgical navigation systems.
- Patient-specific 3D models support better planning and anatomical orientation in open frontal sinus surgery.
- When aligned using a facial mask, the model fits accurately on the patient, increasing surgical precision.
- This approach enables safer osteotomies, shortens operation time, and is especially useful in cases with complex anatomy or frontal sinus osteomas.
- The technique is easy to apply and can be integrated into routine surgical practice at low cost.

References

1. Hybels RL. Transillumination during osteoplastic frontal sinusotomy. Laryngoscope. 1981; 91: 1560. [Crossref]
2. Ergen A, Çakır M, Çaklılı M, Anık İ. Practical study on three-dimensional skull base models in endoscopic endonasal surgery training. J Nervous Sys Surgery. 2025; 10: 51-8. [Crossref]
3. Leong, SC, Strzembosz A, Tan NC. Validation of a three-dimensionally printed simulator for training in endoscopic sinonasal surgery. Rhinology. 2023; 61: 376-82. [Crossref]
4. Daniel M, Watson J, Hoskison E, Sama A. Frontal sinus models and onlay templates in osteoplastic flap surgery. J Laryngol Otol. 2011; 125: 82-5. [Crossref]
5. Roy R, Goyal S, Roy KN, Ravunnikutty M. Use of three-dimensional printing for the osteoplastic flap approach: a viable technique. Med J Armed Forces India. 2021; 77: 363-6. [Crossref]
6. Romano A, Troise S, Spinelli R, Abbate V, Dell'Aversana Orabona G. Guided frontal sinus osteotomy: a pilot study of a digital protocol for "in-house" manufacturing surgical cutting guides. J Clin Med. 2025; 14: 3141. [Crossref]
7. Fewins JL, Otto PM, Otto RA. Computed tomography generated templates: a new approach to frontal sinus osteoplastic flap surgery. Am J Rhinol. 2004; 18: 285-9. [Crossref]
8. Melroy CT, Dubin MG, Hardy SM, Senior BA. Analysis of methods to assess frontal sinus extent in osteoplastic flap surgery: transillumination versus 6-ft Caldwell versus image guidance. Am J Rhinol. 2006; 20: 77-83. [Crossref]
9. Khouri NG, Bahú JO, Blanco-Llamero C, Severino P, Concha VOC, Souto EB. Polylactic acid (PLA): properties, synthesis, and biomedical applications-a review of the literature. J Mol Struct. 2024; 1309: 138243. [Crossref]