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Original Research

3D Patient-Specific Biomechanical Model of the Tongue for the Management of Tongue Tumors: Conceptualization to Reality

Piyush Sinha,[1] Bhanu Prakash Bylapudi,[1] Prashant Puranik,[2] Anand Subash,[1] Vishal Rao[1]

[1]Department of Head and Neck Surgical Oncology and Robotic Surgery, HealthCare Global (HCG) Cancer Centre, Bangalore, Karnataka, India
[2]Department of Plastic and Reconstructive Surgery, HealthCare Global (HCG) Cancer Centre, Bangalore, Karnataka, India

Abstract

Objectives: Increasing use of tobacco by the younger generation has resulted in an increase in oral cavity tumors. Surgical treatment is radical and results in severe functional morbidity. Using computer-aided designing technology, surgical and rehabilitative planning can be better. We present here our concept of a patient-specific biomechanical 3D model of the tongue and its clinical utility in the management of tongue tumors.

Methods: Using fused deposition modeling, the 3D model of the tongue was printed which easily differentiates the tumor and the uninvolved tongue by printing in two different colors. The 3D tongue model was used by the surgical and rehabilitation teams to frame the treatment and plan the rehabilitation taking into account the patient preferences and needs. The model was used in two patients with operable squamous cell carcinoma (SCC) of the tongue, and the utility of the model in margin planning, surgical defect assessment, and its aid in the reconstruction and rehabilitation was assessed.

Results: Two patients with Stage III SCC of the tongue underwent the surgery based on the plan evolved from the 3D model. All the surgical margins assessed by the frozen section analysis were clear. The model helped in addressing the discordance between patient expectations and surgical outcomes. We found that the model aided the reconstructive surgeon in planning the flap harvest based on the pre-operative defect assessment, which, in turn, translated into better rehabilitative outcomes.

Conclusion: 3D biomechanical tongue model is a novel concept and aids in improving the overall treatment outcomes. The realistic 3D reconstructed image model helps the oncologist in planning the resection, enables the reconstructive surgery to more precisely predict the defect volume, and lastly the rehabilitative team in developing better rehabilitation strategies.

Keywords: 3D model, Computer-aided designing, Free flap, Margin, Tongue cancer

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Tongue is one of the most commonly involved sites in oral cavity cancer and remains a serious health problem in many countries. The lateral border of the tongue and the adjacent floor of the mouth area are most prone to developing a malignancy.[1] To achieve an optimal oncological outcome, the resection margins should at least be 5 mm in all dimensions. Surgeons can be deceived by the two-dimensional imaging modalities to map the tumor. With

Address for correspondence: Anand Subash, MD. Department of Head and Neck Surgical Oncology and Robotic Surgery, HealthCare Global (HCG) Cancer Centre, Bangalore, Karnataka, India
Phone: +919914737111 **E-mail:** dranand.s@hcgel.com

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the third dimension often being assessed clinically and intraoperatively, surgeons may often over resect or end up compromising the surgical margins.[2] Although over resection is surgically safe, it results in the loss of tongue volume and consequently its dynamic functions.

Modern technology has made 3D printing a reality. 3D printing is an additive manufacturing technology, which involves the generation of a computer-aided design to create a 3D print by layering the material one above the other. This technology is being widely used for planning bony reconstruction but has still not found much utility in soft-tissue reconstruction. Having a 3D model to gauge the tumor extent can help not only the surgeon performing the ablative procedure but also the patient and family to understand the dynamics behind the extent of resection. Discordance is often noticed between the anticipation of the patients and the final surgical outcome. A 3D assembly would also help the reconstructive surgeon in planning better reconstructive strategies.[3]

Rehabilitating the patients following glossectomy is an uphill task. A disconnect between pre-operative planning of rehabilitation and its implementation often cripples the expertise of even a trained speech-language pathologist.[4] A better understanding of the surgical defect by the rehabilitative team preoperatively can help achieve realistic timeline-based goals.[5]

In the present work, we focus on the design of a 3D patient-specific biomechanical model of tongue used by us for comprehensive treatment planning and execution. The study evaluates the feasibility and role of a 3D patient-specific biomechanical model in the management of tongue tumors.

Methods

Patient Population

This study followed the guidelines of the declaration of Helsinki. The study was conducted at a tertiary cancer center in South India. Each participant provided written informed consent for the surgery. The Institutional Ethical Committee approved the present study (1365/12.05.19). The technical support for developing a 3D patient-specific biomechanical model was provided by Anatomiz3D LLP, Mumbai, India. In the present study, two patients with operable squamous cell carcinoma (SCC) of the lateral border of the tongue were included in the study. Staging was done according to AJCC eighth edition. These patients were informed about the use of the 3D biomechanical model for treatment planning and execution and consented to the same.

Pre-operative Imaging

All patients underwent a pre-operative magnetic resonance imaging (MRI) of the head-and-neck region at our center. The images were acquired on a 3 Tesla SIEMENS Skyra ® MRI machine without contrast, with 48 channels in multi-planar, multi-sequence of head-and-neck region with a pixel resolution of $0.9 \times 0.9 \times 0.9$ mm^3. The data acquired by the MRI were obtained in digital DICOM format.

3D Model and Materials

Using Materialise Mimics Innovation Suite 19 ®, Belgium, an FDA, and CE-approved software DICOM data were imported, visualized, edited, and segmented. Open-source software, MakerBot MakerWare 2.4.1, Brooklyn NY USA, was used to slice the 3D model, which serves as input data for the 3D Printer (Fig. 1).

Flashforge 'Creator-pro'3D Printer ®, Zhejiang, China was used. Fused deposition modeling technology was used to print the tumor and the uninvolved tongue in two different colors for easy identification. Recreus Filaflex ® Elda, Spain flexible filament 1.75 mm spool was used as the print material. The filament melts because of high temperature at the nozzle and liquefied plastic is deposited on the print bed, layer by layer as the previous layer cools (Fig. 2).

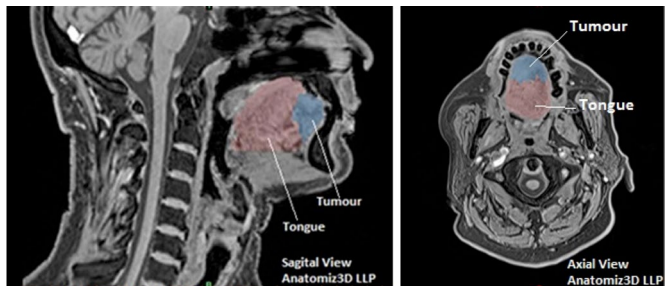


Figure 1. MRI Images post-processing.

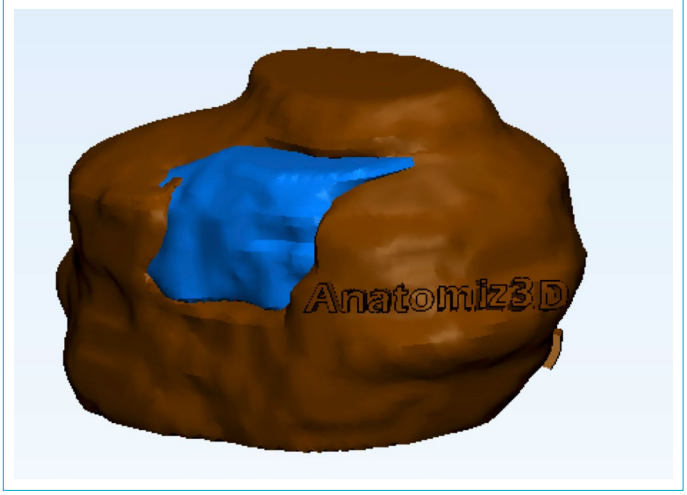


Figure 2. 3D reconstituted tongue.

Data Acquisition

A team of head-and-neck surgical oncologists, reconstructive surgeons, anesthesiologists, physician, and speech-language pathologists preoperatively evaluated the patients. The 3D biomechanical patient-specific tongue model (Fig. 3) was used by the team to frame a treatment and rehabilitation plan taking into account the patient preferences and needs.

All the surgeries were performed by the same head-and-neck surgical oncology and reconstructive team. These patients underwent a partial/hemiglossectomy with neck dissection. The 3D model served as a guide for planning the margins. Intraoperatively, clear surgical margins were confirmed in each case using frozen section analysis. The formalin-fixed resection specimens were processed for final histopathological examination. As the assessment of volume loss and estimation of the surgical defect were possible preoperatively with the 3D model, the reconstructive team could simultaneously start the appropriate flap harvest.

Speech and Swallow Evaluation

Post-reconstruction, patients routinely underwent speech and swallow evaluation by the oral swallow and speech rehabilitation team which was initiated from post-operative day 3. Once the patient was able to take orally adequately, the nasogastric tube was removed.



Figure 3. 3D printed biomechanical tongue model.

Statistical Analysis

Descriptive statistics were done using standard methods. Demographic data were analyzed. Data analysis was done using SPSS Statistics for Windows, version 22.0 (IBM Corp, Armonk, NY).

Results

The two patients had biopsy-proven SCC of the lateral border of the tongue. Both patients were male. Based on clinical evaluation, the patients were staged T3N0M0 (Stage III) as per the AJCC 8th Edition.

Demographic Details and Surgery

Patient 1 underwent a partial glossectomy with the left selective neck dissection (I-III). The margins estimated by the 3D model were reconfirmed intraoperatively, and the partial glossectomy was done with the planned margins. Using the frozen section analysis, clear surgical margins were confirmed. Preoperatively, the reconstructive surgeon assessed the surgical defect with the help of the 3D model. According to the defect dimensions estimated by the 3D model, the reconstructive surgeon planned a left radial artery forearm flap to reconstruct the surgical defect. The flap harvest was started simultaneously according to the dimensions estimated by the model and the tongue is reconstructed. The surgical defect in the patient was reconstructed with a.

Patient 2 underwent a hemiglossectomy with the right selective neck dissection (I-III). The 3D model assessed margins were reconfirmed, and the patient underwent a hemiglossectomy. Clear surgical margins were confirmed using frozen section analysis. The reconstructive surgeon simultaneously started a left lateral arm flap harvest and the tongue defect is reconstructed as planned.

The frozen section reported the margins to be safe (>5 mm) in both cases. The final histopathological margin was clear in both cases (Table 1). The 3D model also enabled accurate molding and inset of the flap into the surgical defect.

Table 1. Patient demographics

Patient Demographics	Side	Tumour Dimension on MRI (cms)	TNM (Stage)	Closest Margin	Furthest Margin
Patient 1					
Male	Left	2.2x1.1x1.6 cm	$T_3N_0M_0$ (III)	7	10
Patient 2					
Male	Right	2.1x2.8x2.2 cm	$T_3N_0M_0$ (III)	6	9

Speech and Swallow Evaluation

Post-surgery, from day 3, the patients underwent the routine speech and swallow evaluation by the oral swallow and speech rehabilitation team. The clinical assessment by the rehabilitation team was done by routine objective and subjective assessment tools of speech and swallowing. In all the patients, superior functional outcomes were recorded and it supports the hypothesis of sulcus preservation benefitting the functional outcome. The model helped in addressing the discordance between patient expectations before the surgery and surgical outcomes. The rehabilitation for both the patients was achieved as planned and explained to the patient.

Discussion

The tongue being a dynamic organ has often tricked the surgeon. A close or positive margin has adverse implications on treatment outcome and overall survival.[6] With better imaging modalities, the surgeon can better assess the tumor extent. However, a real-time assessment of tumors intraoperatively is far from reality. The decision as to how much to resect is taken based on clinical judgment. Over resection and margin positivity in the third dimension is always a threat.[7] The biomechanical 3D model helps the surgeon to get a real-time three-dimensional extent of the tumor. In the present study, the pre-operative assessment with the 3D model led to more accurate resection and resulted in lesser chances of over resection.

Until recently, reconstructive surgeons designed free flaps by visually estimating the defect and using basic geometric shapes. However, defects following the ablative procedure are considerably more complex. Today, CAD-CAM 3D printed models have increased the accuracy of reconstruction in the management of buccoalveolar complex tumors. A similar guide for tongue tumor resection can help improve the efficacy of reconstruction.[8] Due to the dynamic nature of the tongue, the extent of functional restriction often relates to the extent of resection.[9] With a real-time model, the patient and family can better visualize the tumor and understand the concept of safe margin and the possible extent of resection. This helps them better prepare for the outcomes and functional deficits. With a wealth of information available at a click of a button, the patients also prefer to be fully prepared for the deficits to make an appropriate decision.

Due to incessant tobacco use among youngsters, the disease is now more prevalent in the younger population. Functionally rehabilitating these young patients accurately has definitive implications on quality of life personally and professionally. Often, the resected specimen is used as a benchmark to plan the flap volume. Common problems encountered by patients' post-reconstruction are often due to preventable causes. The flap bulk can restrict tongue movements, impair swallowing, and also compromise vocalization.[10] A patient-specific 3D model can help in optimizing the extra flap bulk, which, in turn, can reduce the chances of such problems.

Using the 3D model, the rehabilitative team can have a better understanding preoperatively about the extent of resection and the possible functional restriction. This, in turn, helps the rehabilitative team in developing better rehabilitative strategies.[9] The usage of a 3D model also helps the rehabilitative team in better communication with the patient and can prepare the patient before the surgery.

One of the limitations of the study is the lesser sample size. Furthermore, the functional outcomes could not be compared due to the sample size.

Conclusion

Although the current technology is not yet advanced enough to create a dynamic model to exactly mimic the tongue, the 3D biomechanical model might help bridge the existing deficiencies in our treatment to deliver the best outcomes. In conclusion, the realistic 3D reconstructed image model helps the oncologist in planning the resection, enables the reconstructive surgery to more precisely predict the defect volume, and lastly the rehabilitative team in developing better rehabilitation strategies.

Disclosures

Ethics Committee Approval: The Institutional Ethical Committee approved the present study (1365/12.05.19).

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Conflict of Interest: None declared.

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