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Surgical Innovations and Instrumentation 3D Printed Human Laryngeal Model: A Tool for Laryngeal Framework Surgery Training

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ABSTRACT

Objective: To develop and pilot test a 3D-printed human laryngeal model designed for laryngeal framework surgery training, aimed at enhancing the skills of ENT specialists and residents.

Methods

Design: Surgical Innovation

Setting: Tertiary Government Training Hospital

Participants: Consultants and Residents of the Department of ORL-HNS

Results: This surgical innovation described the step-by-step production of a 3D-printed human larynx which was used as a model for an advanced laryngeal workshop by ENT residents, consultants, and phonosurgeons. It was evaluated to be easy to use and effective in simulating different laryngeal framework surgeries such as Isshiki Thyroplasty Types I to IV.

Conclusion: The 3D-printed human larynx may be used as a tool for laryngeal framework surgery training during workshops for ENT specialists.

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Introduction

Three-dimensional (3D) printing technology is currently used in different fields of medicine and has taken a key role in surgical planning, medical education, personalized surgery guides, and simulation practice [1]. Laryngeal framework surgery is done for patients with dysphonia caused by different conditions such as unilateral vocal cord paralysis or spasmodic dysphonia, wherein the laryngeal skeleton or the insertion of muscles to correct vocal fold positioning and/or tension are changed. It aims to improve the voice without directly coming in contact with the vocal folds. This surgery usually involves cutting and suturing the thyroid cartilage and cricoid cartilages which could be substituted by a 3D printed human laryngeal model.

After a thorough search of HERDIN Plus, MEDLINE (PubMed and PubMed Central), Google Scholar, and the Directory of Open Access Journals (DOAJ), there are few existing literatures on the use of 3D printed laryngeal models on laryngeal surgeries and we did not find any models used specifically for Isshiki thyroplasty types II-IV [2].

This study aims to develop and pilot test a 3D-printed human laryngeal model designed for laryngeal framework surgery training, aimed at enhancing the skills of ENT specialists and residents.

Methods

Preparation of the 3D printed larynx was done first by downloading an STL file for a 3D printed human larynx on Thingiverse (Ultimaker, Utrecht, Netherlands), a free website available from: https://www.thingiverse.com/ that allows users to create and share 3D printable items. (Figure 1)

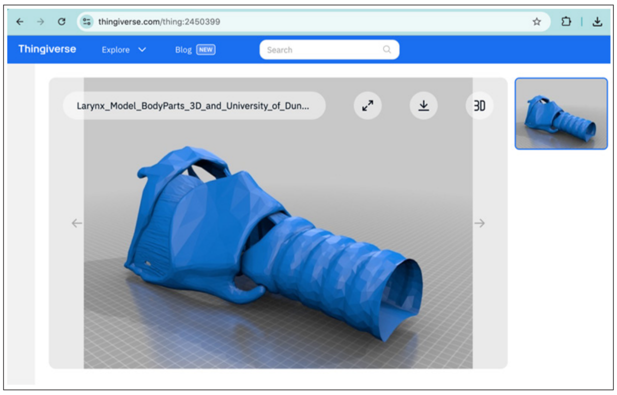

Figure 1: Download of a Laryngeal Model STL File from the Open-Source Website Thingiverse

Second, direct modeling or adjusting the 3D geometry of the larynx was edited using Tinkercad (Autodesk, San Francisco, CA, USA), a free open-source software available from: https://www.tinkercad.com for 3D design, electronics, and coding. (Figure 2) The transverse length at the level of the thyroid incisure used was 40.3mm and the transverse length at the level of the vocal cord used was 36.9 mm, based on dimensions for Asian men from a study of Isshiki [3].

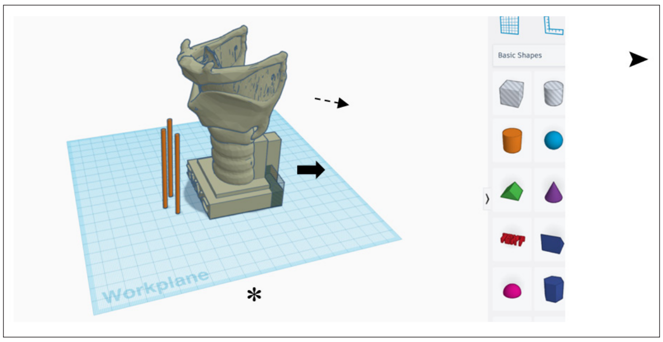

Figure 2: Editing the 3D Print file on an Open-Source CAD Software Website, Tinkercad. Work Plane Options and Basic Shapes (Arrowhead) can be Used on the Work plane (Asterisk) to Make Vertical Supports (Arrow) Which are Added to the Design of the Larynx to Support Overhang Parts like the Thyroid Prominence (Broken Arrow)

The third step was slicing the STL file in preparation for the 3D printer using UltiMaker Cura version 5.10 (Ultimaker, Utrecht, Netherlands) available from: https://ultimaker.com/software/ultimaker-cura/ Software. (Figure 3)

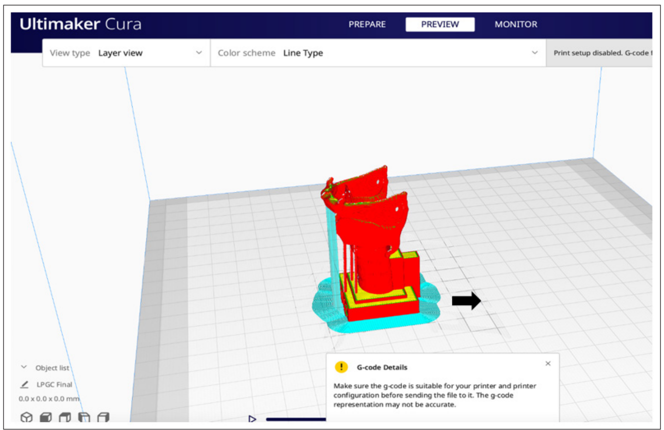

Figure 3: Slicing the Edited STL file on Ultimaker Cura Slicer Software Version 5.10 in Preparation for 3D Printing. The Preview Shows a Simulation How the Model will be Manufactured Layer by Layer. Support Structure and Build Plate Adhesion (Arrow) are Generated to Maintain the Shape of the Model During Printing.

The fourth step was printing of the model using Creality Ender 3 V3 SE 3D printer (Shenzhen Creality 3D Technology Co., Ltd., Shenzhen, China), a type of fused deposition modelling (FDM) that is an example of material extrusion-based 3D printing technology. (Figure 4) Thermoplastic polyurethane (TPU, Shenzhen Esun Industrial Co., Ltd., Shenzhen, China), a type of flexible and elastic filament was used to print the 3D larynx. This material has the nearest consistency with the human larynx and can be cut or sutured for simulation of surgeries.

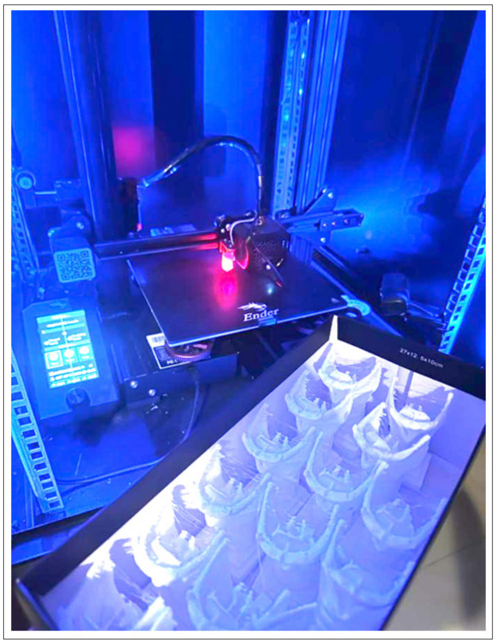

Figure 4: Printed Laryngeal Models on TPU using the Creality Ender 3 V3 SE 3D Printer

Lastly, preparation of the laryngeal mount was done using a whole ordinary plywood measuring 4 feet by 8 feet with a thickness of 0.5 inches or 12.0 mm. The plywood was cut into 12 in x 8 in size using a wood saw. One whole plywood could provide 48 pieces of laryngeal mount. The edges were sanded using wood or metal sandpaper with a grit of 100 until a smooth feel was achieved. A hole on the laryngeal mount was cut then a sticker paper with a printed image of the neck was placed prior to mounting of the 3D printed human laryngeal model. (Figure 5) A total of 20 3D printed human laryngeal models on laryngeal mounts were produced.

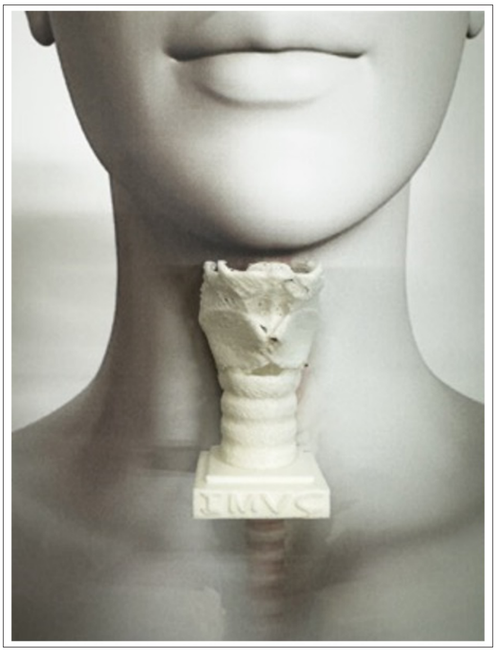

Figure 5: 3D Printed Human Larynx on the Laryngeal Mount

Evaluation of the 3D printed larynx with laryngeal mount was done in an In-House Advanced Laryngeal Framework Surgery Workshop. There were four ENT residents, three general otolaryngologists, and two phonosurgeons from the Department of ORL-HNS of the Veterans Memorial Medical Center. One phonosurgeon from the department who underwent Laryngology fellowship in Isshiki Memorial Voice Center in Kyoto, Japan, conducted the workshop. The participants performed Type I to IV Isshiki thyroplasties during the workshop using two 3D printed human laryngeal models for each participant. Isshiki thyroplasty types I and II were done on the first model and types III and IV were done on the second model.

In Type I Isshiki thyroplasty, an implant was inserted through a window in the thyroid cartilage lateral to the thyroarytenoid muscle ipsilateral to the side of weakness or atrophy [4]. During the workshop, the participants performed Type I Isshiki thyroplasty by making an incision on the 3D-printed thyroid cartilage and inserting a small rubber eraser which served as an implant. (Figure 6A)

In Type II Isshiki thyroplasty, the anterior midportion of the thyroid cartilage was exposed by 1/2 cm in width, and a vertical incision was made exactly along the median line, cutting carefully through the cartilage only. The underlying soft thin tissue was left intact by not entering the airway, especially at the anterior commissure [5]. During the workshop, the participants created an incision on the midline of the 3D printed thyroid cartilage and inserted 2 metal implants which were sutured to the cartilage using prolene 4-0 sutures. (Figure 6B)

In Type III Isshiki thyroplasty, an incision was made on the lateral side of the thyroid cartilage and overlapped to reduce its anteroposterior diameter. This caused the vocal folds to shorten and relax. During the workshop, the participants excised a vertical strip on one side of the 3D-printed thyroid cartilage and fixation was done by two mattress sutures using prolene 4-0. (Figure 6C)

In Type IV Isshiki thyroplasty, an increase in the fundamental frequency of the voice was aimed for by bringing the thyroid cartilage closer to the cricoid cartilage [6]. During the workshop, the participants performed cricothyroid approximation by applying sutures from the inferior portion of the cricoid at the midline then to the thyroid cartilage at 3 points. (Figure 6D)

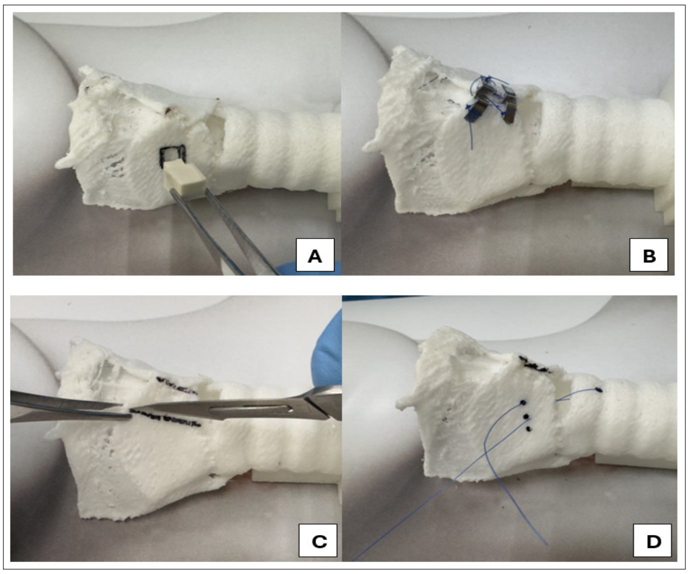

Figure 6: Laryngeal Framework Surgery; Isshiki Thyroplasties:
A. Isshiki Thyroplasty Type I (Vocal Cord Medialization)
B. Isshiki Thyroplasty Type II (Vocal Cord Lateralization)
C. Isshiki Thyroplasty Type II (Vocal Cord Shortening
D. Isshiki Thyroplasty Type IV (Vocal Cord Lengthening)

Evaluations were obtained from participants using an individually-administered survey form with a 5-point Likert scale (Strongly Agree, Agree, Neutral, Disagree, Strongly Disagree). (Figure 7) The scores from the evaluation and participants' data were recorded using Microsoft Excel 2022 version 16.66.1 (Microsoft Corporation, Redmond, WA, USA) to generate simple descriptive statistics.

Rating Scale Survey
Name of Respondent
Institution
Please describe your evaluation for each statement based on the following Rating Scale Below. Mark check on the desired rating.
5 - Strongly Agree
4 - Agree
3 - Neutral
2 - Disagree
1 - Strongly Disagree

Criteria	1	2	3	4	5
Functionality					
The 3D printed larynx can be a good substitute for a thyroid and cricoid cartilage					
The 3D print can be sutured like a thyroid and cricoid cartilage					
The 3D print can be cut like a thyroid and cricoid cartilage					
Usability					
3D print larynx may be used for simulation of Laryngeal framework Surgery					
The 3D print larynx is easy to use					
I was able to perform the thyroplasties using the 3D printed larynx					

Figure 7: Evaluation form of 3D Printed Human Laryngeal Model

Results

We were able to produce 20 3D printed human larynx models based on the average size Asian male larynx which were used as models for an advanced laryngeal workshop by ENT residents, consultants, and phonosurgeons. Each participant had two models. (Figure 8) There were a total of nine participants who evaluated the use of the 3D printed larynx based on its functionality and usability. Of the nine participants, there were four ENT residents, three general otolaryngologists, and two phonosurgeons. There were 7 females and 2 male participants. Their ages ranged from 32-47 years old (M=37; SD=5.67).

Seven of the participants answered that they "Strongly Agree" that the 3D print larynx can substitute a thyroid and cricoid cartilage, can be sutured like a thyroid and cricoid cartilage, can be cut like a thyroid and cricoid cartilage, it may be used for simulation of laryngeal framework surgery, and it is easy to use. While two of the participants answered "Agree" that the 3D print can be sutured and cut like a thyroid and cricoid cartilage. All participants answered "Strongly Agree" that they were able to perform the thyroplasties using the 3D printed larynx. (Figure 9) It was evaluated to be easy to use and effective in simulating different laryngeal framework surgeries such as Isshiki Thyroplasties Types I to IV.

Figure 8: In House Advanced Laryngeal Workshop Using the 3D Printed Human Larynx

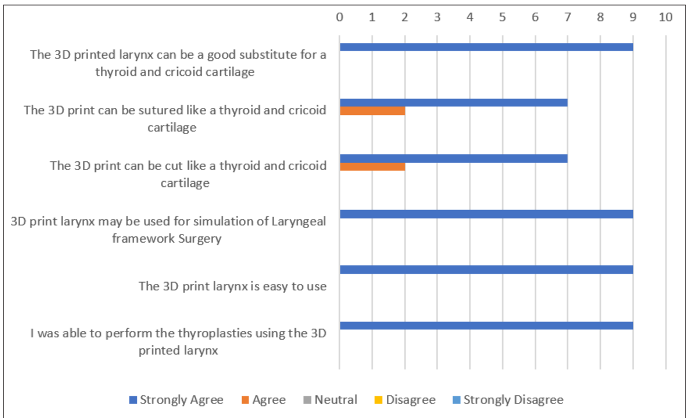

Figure 9: Summary of Responses of the Rating Scale Survey

Discussion

We successfully developed 20 3D-printed human laryngeal models and pilot tested them in an In-House Advanced Laryngeal Framework Workshop involving nine participants.

Our study had similar results with the study made by Villegas et al. done in Colombia, wherein they were able to develop a low-cost, anatomically accurate, and useful 3D printed laryngeal model for resident education by applying it in Medialization Laryngoplasty. They also used FDM type of printing which showed an advantage of being highly precise and at a low cost. In our study, four types of thyroplasties were done using the 3D-printed human laryngeal model.

Three-dimensional printing needs high quality materials that meet consistent specifications to build consistent high-quality devices. Furthermore, 3D printing technology has the potential to create fully functional parts in a wide range of materials including ceramic, metallic, polymers and their combinations in form of hybrid, composites or functionally graded materials [7]. In the study of Villegas et al., polylactic acid (PLA) filament was used in printing their laryngeal model which had realistic features regarding a similar anatomic detail, visual, sound, and tactile sensation compared to cadaveric or real laryngeal drilling. In another study by Kostas et al., they also made a 3D printed larynx model using heat-treated polylactic acid (HTPLA), a material chosen for its thermal stability, allowing drilling for medialization thyroplasty. In contrast, we used Thermoplastic polyurethane (TPU) in printing the 3D human larynx model. It is a type of flexible and elastic filament which has the nearest consistency with the human larynx and can be cut or sutured for simulation of Isshiki Type I-IV thyroplasties. TPU is a suitable material for the thyroid and cricoid cartilages. On the other hand, soft tissues such as the vocal cords, silicone could be used to achieve a closer consistency.

Different types of 3D printing technologies have been developed such as binding jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photopolymerization. We used the Creality Ender-3 V3 SE 3D printer. This method used polymer as the main material and it built parts layer-by-layer from the bottom to the top by heating and extruding thermoplastic filament. The Creality Ender printer provided a remarkable ease of use and print quality at a low cost.

One limitation of our study was the small number of participants who evaluated the 3D printed larynx model and only two of them were phonosurgeons. All participants had experience in live or cadaveric laryngoplasty procedures, however, the phonosurgeons rated their experience lower than the residents and general otolaryngologists did. This can be attributed to their having more experience in handling human larynges in surgeries and comparing the difference from a 3D printed version. It is recommended that larger number of ENT specialists, specifically phonosurgeons, can evaluate the ease of use of the 3D printed models in future studies. Another limitation was the use of only 1 filament material (TPU) for the laryngeal model. Other 3D printing methods and 3D materials may be explored for a more detailed model and a more accurate consistency with the laryngeal framework cartilages. We recommend that 3D printed human larynx model may be used for preoperative planning of patients who will undergo laryngeal framework surgeries. It may also be used in simulating other airway procedures such as tracheostomy or tracheal resection surgeries.

In conclusion, the 3D-printed human laryngeal model may be used as a tool for laryngeal framework surgery training during workshops to enhance the skills of ENT specialists and residents.

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