The 3D Printing of the Paralyzed Vocal Fold: Added Value in Injection Laryngoplasty

*Abdul-Latif Hamdan, *Ghassan Haddad, †Ali Haydar, and ‡Ramsey Hamade, *†‡*Beirut, Lebanon*

Summary: Introduction. Three-dimensional (3D) printing has had numerous applications in various disciplines, especially otolaryngology. We report the first case of a high-fidelity 3D-printed model of the vocal cords of a patient with unilateral vocal cord paralysis in need of injection laryngoplasty.

Methodology. A case report was carried out.

Results. A tailored 3D-printed anatomically precise models for injection laryngoplasty has the potential to enhance preoperative planning, resident teaching, and patient education.

Conclusion. A 3D printing model of the paralyzed vocal cord has an added value in the preoperative assessment of patients undergoing injection laryngoplasty.

Key Words: 3D printing–Vocal cord–Paralysis–Injection laryngoplasty–Larynx.

INTRODUCTION

In the early 1980s, Charles Hull invented and built the first three-dimensional (3D) printer which he calls at the time the "stereolithography apparatus, SLA" printer. It is the translation of digital information into a fusion or compilation of suitable materials, layered together to produce a 3D tangible object. The field of 3D printing has been evolving tremendously ever since, with applications in a multitude of disciplines, including engineering, industrial manufacturing, business, fashion, and art among others.[1]

Many surgical disciplines such as craniofacial plastics and head and neck reconstructive surgery have specifically benefited from the translation of imaging data into tailored and anatomically precise models for preoperative planning, which reduce operative time and increase the operations' success rate.[2–7] Numerous otolaryngology residency programs have introduced 3D printing models as cost-efficient, low biohazard, and realistic models for resident training and rehearsal before surgeries such as rhinoplasties, auricular reconstructions, and temporal bones among others.[3,4,6] 3D-printed models have also helped surgeons better visualize certain organs that are not very accessible during examination, such as the diseased trachea in tracheomalacia.[5]

To the authors' best knowledge, no previous report has described the usage of 3D printing technology in the assessment of patients with unilateral vocal cord paralysis undergoing injection laryngoplasty. The aim of this paper is to report on the usage of 3D printing technology in a patient with unilateral vocal cord paralysis undergoing injection laryngoplasty.

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From the *Department of Otolaryngology and Head & Neck Surgery, American University of Beirut-Medical Center, Beirut, Lebanon; †Department of Diagnostic Radiology, American University of Beirut- Medical Center, Beirut, Lebanon; and the ‡Department of Mechanical Engineering, American University of Beirut, Beirut, Lebanon.

Address correspondence and reprint requests to Ramsey Hamade, Department of Mechanical Engineering, American University of Beirut, P.O.Box: 110236, Riad El Solh, Beirut 11072020, Lebanon. E-mail: rh13@aub.edu.lb

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CASE REPORT

Mr. A.F. is a 60-year-old gentleman who presented with tinnitus and dysphonia of 3 months' duration. He describes the tinnitus as roaring in nature, pulsatile and persistent, and associated with hearing loss and aural fullness. The patient describes the incidence of hoarseness as sudden, associated with pitch breaks and vocal fatigability. The patient also reports occasional and intermittent respiratory discomfort. He was initially treated for laryngopharyngeal reflux disease with omeprazole 40 mg once daily for a period of 1 month, with no noticeable improvement. Perceptual voice evaluation revealed a grade 3 dysphonia with a breathy and weak voice. Physical examination revealed an erythematous mass behind the left tympanic membrane. Flexible fiber laryngoscope showed an immobile left vocal cord in the paramedian position with incomplete closure of the vocal cords during phonation. Further evaluation included a computerized tomography (CT) and magnetic resonance imaging of the head and neck, which revealed left temporal jugulotympanic paraganglioma eroding and widening the left jugular foramen and extending along the vein course, with intracranial extension to the left sigmoid sinus, and invasion of the left hypotympanum and the mastoid portion of the facial nerve. The patient underwent excision of the left temporal mass and left neck dissection via an infratemporal approach and C-shaped incision with neck extension. Postoperatively he had injection laryngoplasty for the left vocal cord using the transoral fiberoptic injection approach. Restylane (cross-linked hyaluronic acid (20 mg/mL) 0.6 cc was used as a filling material. 3D printing of the glottic region during phonation and normal breathing was performed before the injection to enhance the preoperative planning.

3D Printing

The methodology for constructing the 3D print is summarized as follows:

CT scan (Phillips Brilliance iCT, Amsterdam, Netherlands) was employed in producing dicom files using slice thickness and spacing between slices of 0.67 and 0.335 mm, respectively, and resulting in pixel spacing of 0.578 mm. Utilized were 893 such slices (dicom files 520 kB each) in each of the normal breathing and phonation modes. For construction of the CT data, these

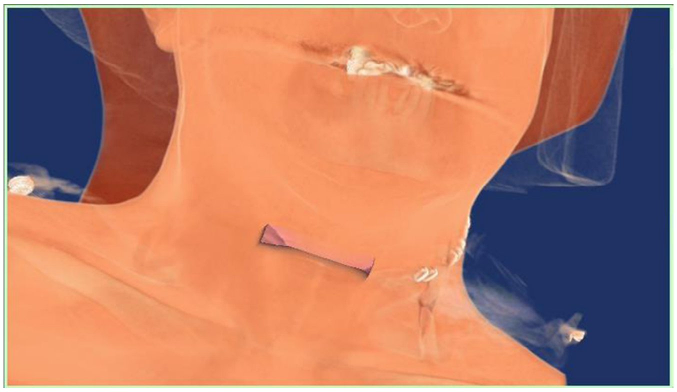

FIGURE 1. Isometric rendered view showing location of segmented anatomy of interest.

files were imported into *Mimics* (Materialize, Leuven, Belgium). Upon importing the dicom data into *Mimics*, the three CT views (sagittal, coronal, and axial) of the segmented anatomy were visualized. Figure 1 shows an isometric rendered view that highlights the location of the segmented anatomy with respect to the overall scan.

To segment the relevant anatomy, a custom mask was created using lower and higher threshold values of −331 and 201, respectively. Additional surface smoothing and further processing was performed on *3-Matic* (Materialize) to create digital 3D solid models.

Segmentation was followed by creation of .stl files for the purpose of printing. A 3D printer was used (Ultimaker 2 + (Ultimaker B.V., Geldermalsen, The Netherlands; https://ultimaker.com/)) with the following dimensional accuracy: 12.5 µ in X and Y, 5 µ in Z. Printing material was polylactic acid in filament form (https://s3-eu-west-1.amazonaws.com/prod.ultimaker.com/download/materials/Ultimaker-PLA-(TDS).pdf)

With the 3D printing model at hand, the glottal configuration as well as the soft tissue defect of the immobile left vocal cord was visualized and palpated to assess the best site for injection and the amount to be injected (see Figure 2). The gap between the vocal cords during phonation was 4.96 mm and the area of glottic insufficiency was 81.02 mm^2. Soft tissue deficiency of the left vocal cord was further evaluated using previously described volumetric measures.[8] Measured volumes were 3.78 mL for the right thyroarytenoid muscle and 3.16 mL for the left thyroarytenoid muscle. The volume difference between both cords is then 0.62 mL.

DISCUSSION

Unilateral vocal fold paralysis is a very challenging condition, both to the otolaryngologist and to the patient. Despite the advances in technology as far as intraoperative monitoring of the recurrent laryngeal nerve during thyroidectomy, and chest or base of skull surgery, iatrogenic injury remains to be the leading cause of paralysis.[9] The clinical presentation is usually that of a change in voice quality often described as breathiness, vocal fatigue, loss of power and range, in addition to aspiration and dysphagia. On laryngeal video-stroboscopic examination there is incomplete closure of the vocal cords during phonation with decrease or absence of mucosal waves. Depending on the width and shape of the glottal gap and the severity of the clinical presentation,

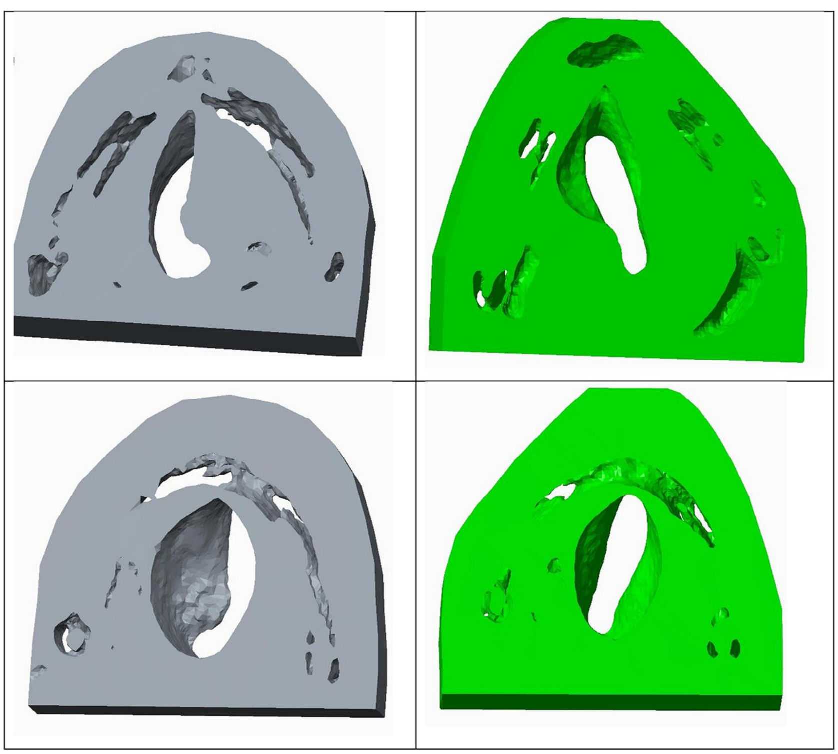

FIGURE 2. Two renderings of the digital 3D solid models: (Up) Superior and (Down) inferior views of the anatomy; phonation mode (Left) and normal breathing mode (Right).

two types of surgical interventions have been endorsed by otolaryngologists, namely, medialization thyroplasty and injection laryngoplasty. Other accepted surgical procedures include arytenoid adduction and laryngeal reinnervation.[10]

With the advances in technology, injection laryngoplasty as an office procedure has become the first therapeutic choice to both patients and physicians, more so when the glottic gap does not exceed 5 mm.[10] The main challenges have been the route of injection, the material to be injected, the site of injection, and the amount to be injected. 3D printing carries some added value to respond to those challenges:

(1) It allows superior visualization and palpability of the surgical object. As 3D printing allows the creation of a tangible and anatomically accurate model based on digital data derived from imaging, the surgeon can better understand the complex anatomy of the paralyzed cord in relation to the normal side, both during phonation and inspiration. When injection laryngoplasty is planned as an office procedure, the surgeon is limited to the two-dimensional endoscopic view which limits the perception of the surgical field from above and not in 3D perspective. With 3D printing, vocal cord atrophy and tissue deficiency in both the anteroposterior and cephalocaudal dimensions can be localized, thus facilitating the decision where and how deep to place the needle for injection. In this particular case, the atrophy was more pronounced in the middle and posterior aspect of the left vocal cord with a gap of around 5 mm. The injecting needle was placed just anterior and lateral to the vocal process and was inserted 2–3 mm in depth.

(2) The application of 3D printing coupled with 3D volumetric measures allowed us to better estimate the amount needed for injection which is one of the main challenges of injection laryngoplasty. Although the recommendation is to overcorrect by 30% depending on the material used for injection, prior knowledge of the difference in the volume between the two sites is valuable. In this particular case, the volumetric difference in the measurements of the vocal cords was 0.62 mm.

(3) With respect to the medical team, 3D printing is an exceptional opportunity to learn and examine the vocal cord, the change in its position secondary to the paralysis, and the alterations in its length, height, and volume compared with the normal cord. Simulation of the injection procedure on the printed object can also be performed with the purpose of guiding the residents where to place the needle and how deep to go with the injection. Last but not least, the 3D printing model can foster the patient's knowledge of the case and help educate family members about the medical condition of the patient. With this technology at hand, the patient can have a better grasp of the complexity of his or her case and the procedure to be done. This better understanding is crucial in patient's engagement, which is key in health-care reform nowadays.

CONCLUSION

3D printing is a rapidly growing technology that is gaining widespread applications in the medical field. It is based on the creation of a 3D object out of a computer design using a variety of materials. It is in alignment with personalized medicine which aims at providing individualized care through tailored approaches and therapy. In patients with unilateral vocal cord paralysis, 3D printing can assist the surgeon in preoperative planning. The tangibility of the model at hand may improve the decision-making process and subsequently improve the surgical outcome, in addition to its educational value for both residents and patients. A large case series using this technology will probably allow the development of guidelines as to where and how much to inject, the purpose of which is obviously better patient care.

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