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

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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.

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 computed tomography (CT) and magnetic resonance imaging of the head and neck, which revealed left temporal jugulotympanic paranglioma 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
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 mm². Soft tissue deficiency of the left vocal cord was further evaluated using previously described volumetric measures. 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. 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,
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