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Three-Dimensional Printing of a Low-Cost, High-Fidelity Laryngeal Dissection Station

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INTRODUCTION

Micro-laryngeal phonosurgery requires a significant amount of operative precision to obtain desired voice outcomes.^{1,2} Residents have traditionally developed these skills via intraoperative experience; however, with growing duty-hour restrictions and relatively limited case volume, it has become more difficult to achieve mastery of these super-specialized procedures through operative experience alone. In fact, the majority of otolaryngology–head and neck surgery residents believe their training in phonosurgery would be enhanced by laboratory-based simulation sessions.³ Accordingly, several authors have described laryngeal dissection stations aimed at facilitating such simulations.^{2,4,5} All these have a role in increasing competence among trainees and in allowing for the instruction of phonosurgical technique.

Within the realm of surgical simulation, there is tension between high-fidelity and low-fidelity models. High-fidelity models more closely mimic clinical phonosurgery in equipment and task, but they often have a large cost associated with their manufacture and are not always readily available, especially if several stations are needed (personal conversation with Dr. Dailey and Dr. Jiang regarding availability of their teaching station for purchase by the senior author, LMA).^{5,6} To solve these issues, lower cost models have been described utilizing commonly available materials; however, as described, this lower cost model requires use of a clinical laryngoscope, something not feasible in institutions that do not allow instrumentation to be shared between patient-care and teaching lab environments.⁷ Also, this low-cost model offers lower fidelity in the modeling of micro-laryngeal surgery: rubber bands, bacitracin, and plastic wrap are used to simulate layers of the true vocal fold given that the system is not designed to hold an animal larynx.

A laryngeal dissection station that was simultaneously high fidelity and low cost would solve this tension and improve the teaching of phonosurgery in a simulation setting. Ideally, this station would closely mimic the conditions of operative micro-laryngoscopy in terms of dimensions, positioning, and stability of the laryngoscope; would allow for the use of animal larynges that make possible high-fidelity modeling of phonosurgery; would not require the

use of a clinical laryngoscope from the operating room; and would be readily available for those in any programs who wished to use it.^{6,8} Here, we describe a laryngeal dissection station constructed with a 3-dimensional (3D) printed laryngoscope that fulfills these criteria.

MATERIALS AND METHODS

A large universal modular glottiscope (Endocraft, Boston, MA) was chosen as the model for this 3D printed teaching station given its frequent use in microlaryngeal phonosurgery. The glottiscope was measured and modeled using computer-aided design tool Creo 2.0 (PTC, Needham, MA) for the purposes of 3D printing. Without the need for distal illumination or suction, and similarly without the need for any change from one laryngoscope size to another, the constructed model does not utilize a separate base-plate as does the clinical glottiscope. Instead, a single triangular laryngoscope was modeled, and the base was made thicker than what exists in its clinical counterpart such that the printed version would remain stable. Additional modifications include paired flanges extending from the base of the laryngoscope to accommodate connection to the rest of the dissection station, and the addition of hooks on each side of the laryngoscope to aid in securing a larynx for phonosurgery. Otherwise, dimensions and architecture of the modular glottiscope were preserved, including incorporation of proximal sideports that allow for stable instrument insertion.⁹ The design of the teaching laryngoscope is shown in Figure 1. Three-dimensional printing of the laryngoscope was accomplished by Xometry (Gaithersburg, MD), a commercial 3D printer. The blade was printed out of nylon and sanded to provide a smooth finish.

The rest of the teaching station was assembled to support this laryngoscope. A stainless-steel baseplate is utilized to provide a stable platform, and rubber feet glued to the corner of the base-plate provide a nonslip property when the teaching station is utilized. A series of three metal brackets connect the laryngoscope to the baseplate; the pivot point between each bracket allows the position of one bracket relative to the next to be changed, allowing for the laryngoscope to be positioned at variable heights and angles. The resulting jointed, moveable arm is secured to the laryngoscope at a midposterior location chosen to balance weight during use. A metal hook is attached to the front edge of the base-plate to aid in securing a larynx to the end of the laryngoscope. Steel components for the teaching station were purchased through McMaster-Carr (mcmaster.com, Robbinsville, NJ), an online retailer; similar parts would be available at a hardware store. The completed teaching station is shown in Figure 2A.

RESULTS

The 3D printed laryngoscope blade costs \$46.90 when printed in durable white nylon. The remaining materials (brackets, base screws, arm screws, locking nuts, hook, wing nuts, angle stock metal, low carbon steel baseplate, and rubber feet) cost \$41.60, and the machining time costs \$30, bringing the total cost to \$118.50. Printing time for the 3D laryngoscope was 7 to 8 days between order and delivery. The only machining required before assembly is drilling holes in the base for the hook and angle brackets, and drilling holes in the angle

brackets themselves. Machining time was less than half an hour, and once all parts are machined, assembly itself was less than 2 minutes. Total time from model completion to finished product was less than 10 days. The final product weighs 7 pounds, two ounces.

DISCUSSION

We present a novel solution to the problem of assembling a high-fidelity dissection station at a low cost. The laryngoscope is the only part of the teaching station that requires complex shaping. By using 3D printing for this portion of the teaching station, costs are low; availability is high; and a laryngoscope is created that very closely mimics clinical phonosurgery—including the ability to create sideports and angles with gently curved corners. When used within a teaching lab that uses an operating microscope and animal larynx, this station facilitates high-fidelity simulation of phonosurgery.

The baseplate is heavy enough to provide a stable platform for phonosurgery, and rubber feet prevent slipping of the station during use. The system remains light enough, however, to be easily portable. The use of hooks on the laryngoscope and baseplate aid in securing an animal larynx to the scope itself (Figs. 2B and 2C), using suture proximally to hold the larynx relative to the scope and using suture distally to the baseplate, which increases stability of the larynx and improves angle of the laryngotracheal complex relative to the laryngoscope. A finish that has been sanded smooth allows for easy cleaning of the laryngoscope after use. The ability of the brackets to change in configuration allows for laryngoscope positioning at whatever height and angle are necessary for microlaryngoscopy (Fig. 3), and for the laryngoscope to be positioned vertically to hold a larynx for framework dissections.¹⁰

The total cost of the device can be further reduced by ordering the 3D printed portion of the device in bulk (cost based on 10 units) and by internally machining the base. This would reduce the cost of each model by approximately \$42, bringing the total price of each station to \$77.50. Cost further can be decreased with use of a wooden base instead of a stainless-steel base. In planning for a fleet of teaching stations using each of these cost-saving maneuvers, it is possible to bring the cost per station down to a very reasonable \$48.00 per device.

To our knowledge, this is the first application of 3D printing to create a laryngeal dissection station. Three-dimensional printing is an additive process in which thin layers of plastic are laid on top of each other. The plastic cools quickly, and the layers adhere together to form a solid object. A thinner, web-like material often is included during printing as a support matrix while it is assembled; this support material typically is polyvinyl alcohol, which is water-soluble, allowing it to be removed postproduction, leaving only the desired material. Three-dimensional printing is being used in an increasing number of clinical and educational applications given its ability to create complex architecture in a rapid, reproducible fashion at reasonably low costs. Within otolaryngology, recent applications include scaffolds for microtia repair, nasal reconstruction, and tracheal grafts, as well as construction of sinus surgery simulators.^{11,12}

CONCLUSION

The benefits of learning phonosurgery in a simulated teaching environment are well documented; further categorization of these is beyond the scope of this submission. However, past descriptions of laryngeal teaching stations either had relied on high-cost models with limited availability, which limited generalizability to large numbers of teaching programs and other educational settings, or had utilized a low-cost system that was low fidelity. Using the inherent advantages of 3D printing to create complex shapes inexpensively, we describe a way to create a low-cost, high-fidelity laryngeal teaching station that allows for teaching both microlaryngoscopy and framework surgery. This system easily can be assembled, as well as scaled up so that any single program can have multiple stations. In addition, stations can be distributed widely over a variety of residency programs. As such, we encourage readers to request our design files to help facilitate integration of this device within resident education initiatives.

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Fig. 1.

The teaching laryngoscope design in Creo 2.0 (PTC, Needham, MA). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Fig. 2.

(A) The assembled teaching station, combining metal hardware with three-dimensional printed laryngoscope. (B) Teaching station with suspended porcine larynx in place. (C) Closeup view of the larynx in suspension, showing proximal and distal sutures holding the larynx in place. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Fig. 3.
View through an operating microscope of the teaching station and suspended porcine larynx.
[Color figure can be viewed in the online issue, which is available at
www.laryngoscope.com.]