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A Novel Laryngoscope With an Adjustable Distal Tip

Adam Honeybrook, MBBS; Walter Lee, MD; Seth Cohen, MD, MPH

Objectives: Various laryngoscopes are currently available for supraglottic, glottic, and cervical esophageal exposure, yet none allow for adjustable articulation of the laryngoscope distal tip. We sought to create a new laryngoscope to improve anatomic field of view exposure.

Study Design: Novel laryngoscope device validation study.

Materials and Methods: Three-dimensional printed plastic and titanium prototype designs were created using Solidworks. Validation testing was performed in a cadaveric model. Optimal exposure of the cadaveric larynx and supraglottis was determined by ensuring the endoscope tip was exactly 2.5 cm from the level of the vocal cords. The prototype exposure (22-cm adjustable tip laryngoscope) was compared to the Weerda (18-cm distending laryngoscope) and Dedo (18-cm operating laryngoscope) laryngoscope exposures. Anteroposterior (AP) and lateral (L) exposure measurements were obtained from analysis of endoscopic images. Objective millimeter quantification was performed by pixel calibration to the known width of the vocal cord.

Results: The prototype provided 77.3-mm AP and 40.6-mm L exposure of the cadaveric larynx and supraglottis. These measurements were then compared to the exposure provided by the Weerda (49.9-mm AP, 40.4-mm L) and Dedo (15.7-mm AP, 18.6-mm L) laryngoscopes. The investigators found the prototype had similar handling characteristics to the Weerda laryngoscope and laryngeal instrumentation was enhanced due to a wider field of view.

Conclusion: This novel laryngoscope with an adjustable distal tip provides improved exposure of the supraglottis and glottis in a cadaveric study and has the potential to be used for both supraglottic/glottic and proximal esophageal procedures.

Key Words: Laryngoscope, novel, innovation, medical device.

Level of Evidence: 5

INTRODUCTION

Laryngoscopes are important devices that have various clinical applications and are essential for several procedures including endotracheal intubation, direct laryngoscopy/microlaryngoscopy, supraglottic, glottic, subglottic, and proximal esophageal pathologic diagnosis and surgery. As discussed by Best et al., many variables affect the surgeon’s ability to achieve adequate glottic exposure. Models have been used to identify various patient characteristics that are associated with difficult laryngeal exposure which broadly encompass soft tissue factors (neck circumference, modified Mallampati index, body mass index), and anatomic or cephalometric measurements. Common cephalometric measurements include incisal opening and the distances and angles between the relevant bony and cartilaginous landmarks of the neck (thyroid cartilage, hyoid bone, sternum, and mandibular}


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mentum),1 with the most important landmark being the position of the mental prominence.4–6 Its usefulness as a landmark is derived from the mental prominence’s relationship to the inner table of the mandible. The inner table of the mandible has the most relevance to vocal fold exposure, as the inner table defines the limit of anterior displacement of the laryngoscope.1

Many laryngoscopes are rigid, static, devices that do not have the ability to distend or articulate. The concept of adjustable laryngoscopes was advanced with the introduction of the Weerda laryngoscope. Weerda et al. published details of a new laryngoscope design between 1981 and 1983, which was a modification of the Kleinsasser laryngoscope.7,8 This device offers 2 degrees of freedom; one which increases the angle between the blades and the other increases the volume between blades. Weerda et al. outlined the benefits of the new scope, including individual adaptation after the scope is inserted into the patient, improved visualization of the larynx and space for instrumentation, and an additional suction port for smoke evacuation.7 The Weerda Laryngoscope has been previously published as a device that is particularly useful for endoscopic Zenker’s diverticulectomy procedures,9 however, it is also used for laryngeal procedures.

Since Weerda first published details of his new innovative laryngoscope, other laryngoscopes have been created which include Zeitels’ adjustable supraglottiscope,10 the Steiner laryngoscopes,11 and other similar variations12 including the Fehn-Kastenbauer retractor. One major limitation of devices that only have proximal articulation
functionality, is that the angle of articulation between the blades can be limited by the interincisal opening and the inner table of the mandible which thereby limits the degree of distal opening and field of anatomic exposure. Thus far, a laryngoscope has not yet been created that allows for adjustable distal tip articulation. We therefore sought to create a novel laryngoscope to improve supraglottic/glottic and proximal esophageal exposure by allowing for adjustable distal tip articulation.

MATERIALS AND METHODS
A collaborative multidisciplinary team was established between members of the Duke Department of Head and Neck Surgery & Communication Sciences and Duke Pratt School of Engineering. Three-dimensional (3D) printed plastic and titanium prototype designs were created using Solidworks 3D computer-aided design engineering software. The goal was to create a laryngoscope that allows surgeons to articulate the distal tip of the laryngoscope with each individual blade of the laryngoscope after insertion into the patient. As such, the design process focused on the addition of a distal articulating tip 5.5 cm from the distal tip of the laryngoscope. This length was chosen as the ideal length based on cadaveric anatomic analysis to overcome the epiglottis for laryngeal exposure and to provide improved distal exposure and instrument working space. This distal blade length also theoretically ensured enough length to provide improved exposure of a proximal esophageal diverticulum pouch when opened. Figure 1 illustrates the final design of the adjustable distal tip laryngoscope.

Mathematic calculations were performed to determine the increase in volume created by adding a distal articulating tip to a proximal distending laryngoscope. Two of the calculations are based on the existing Weerda laryngoscope design. The first of these is the downwards vertical displacement of the bottom blade. This is represented by H in Figure 2. The second method is the rotation of the bottom blade away from the top blade, represented by the angle $\Phi$ at the rear of the device. The novel method of volume creation, here represented by $\Theta$, are the articulating blades at the distal end of the device. Calculation variables and volume calculations are found in Tables I and II.

To create a novel laryngoscope with adjustable distal tip articulation, power screws were fashioned within custom housings which were attached to flexible metal rods which when manipulated allowed for each individual distal blade to articulate to the desired angle. The custom housing was designed to allow the power screw to rotate freely without applying a
torque to the metal rods. The superior distal blade was longer (5.5 cm) than the inferior distal blade (4.0 cm) to allow for easier insertion. The distal blades can articulate up to an angle of 90°, however, in clinical practice an angle of this magnitude would not be necessary. After significant refinement of the prototype, final prototypes were 3D printed using various materials (Fig. 3).

RESULTS
After final prototypes were created, we performed a device validation study in a cadaveric model. We compared the prototype (22-cm adjustable tip laryngoscope) with the Weerda (18-cm distending scope; Karl Storz Endoscopy-America, Inc., Culver City, CA), and Dedo (18-cm operating laryngoscope) laryngoscopes. The aim of the study was to compare the optimal exposure of each device.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dimension (unit)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Θmax</td>
<td>Maximum tip flare angle (°)</td>
<td>37.5°</td>
</tr>
<tr>
<td>Φmax</td>
<td>Maximum blade rotation angle (°)</td>
<td>22.5°</td>
</tr>
<tr>
<td>l_t</td>
<td>Average tip length (inches)</td>
<td>1.92 in</td>
</tr>
<tr>
<td>l_b</td>
<td>Average blade length including lt (inches)</td>
<td>8.13 in</td>
</tr>
<tr>
<td>ΔHmax</td>
<td>Maximum vertical displacement (inches)</td>
<td>0.95 in</td>
</tr>
<tr>
<td>W</td>
<td>Average blade width (inches)</td>
<td>1.125 in</td>
</tr>
</tbody>
</table>

**TABLE I.**
Variables and Values for Volume Calculations.

**TABLE II.**
Calculations Indicating Potential Volumes Created by Angulation Adjustment.

<table>
<thead>
<tr>
<th>Vertical displacement adjustment</th>
<th>(VH)<em>{max} = H</em>{max} \times W \times l_b = 8.7 \text{ in}^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base angle adjustment</td>
<td>(ΔV_Φ)<em>{max} = \pi \times \frac{Θ</em>{max}}{360} \times W \times \left(\frac{l_t}{2}\right)^2 = 3.7 \text{ in}^3</td>
</tr>
<tr>
<td>Addition of the distal articulating tip</td>
<td>(ΔV_Θ)<em>{max} = 2 \times \pi \times \frac{Θ</em>{max}}{360} \times W \times \left(\frac{l_b}{2}\right)^2 = 0.7 \text{ in}^3</td>
</tr>
</tbody>
</table>

Fig. 3. Plastic and titanium 3D printed models of the final prototype.

Fig. 4. Laryngeal exposure comparisons of the prototype laryngoscope (upper image), Dedo laryngoscope (middle image), and the Weerda Laryngoscope (lower image).
A set distance of 2.5 cm from the true vocal cords was measured in a cadaveric larynx which acted as the “optimal exposure” distance to expose both the glottic and supraglottic anatomy. In other words, the tip of the laryngoscope was placed 2.5 cm away from the true vocal cords. Endoscopic images were captured using a 4-mm Hopkins Rod Endoscope (Karl Storz Endoscopy-America, Inc.) to allow for comparison of each laryngoscope. To objectively compare the exposure of each laryngoscope, Bersoft imaging software version 7.25 (Bersoft Software and Technology, First South, Nova Scotia, Canada) was used to compare pixilation measurements with a known set measurement. The use of this software to perform airway measurement analysis has been previously reported in the literature.13 We used the width of the true vocal cord as the known set measurement which measured 4.21 mm in this cadaveric larynx. After pixel calibration was performed, objective millimeter quantification of the anteroposterior (AP) and lateral (L) exposure measurements were obtained from analysis of the endoscopic images (Fig. 4).

The prototype provided 77.3-mm AP and 40.6-mm L exposure of the cadaveric larynx and supraglottis. These measurements were then compared to the exposure provided by the Weerda laryngoscope, which provided 49.9-mm AP and 40.4-mm L exposure, and the Dedo laryngoscope, which provided 15.7-mm AP and 18.6-mm L exposure (Fig. 3). The prototype laryngoscope used in this study was a titanium printed adjustable distal tip laryngoscope. As expected, the primary investigator found the prototype had similar handling characteristics to the Weerda laryngoscope but was slightly lighter as titanium was used as the 3D printing material. The larynx was then instrumented using a variety of microlaryngeal instruments and, subjectively, instrumentation was enhanced due to the wider distal field of view particularly when accessing the anterior commissure.

DISCUSSION

Direct laryngoscopic techniques and instrumentation have evolved significantly over the last several decades, particularly with the introduction of video laryngoscopy. However, operative laryngoscopes have been relatively slow to evolve. An ideal laryngoscope is one that can be inserted into a patient safely, provide the greatest possible anatomic exposure, allow the largest space for instrumentation, be adjusted after insertion into the patient, be lightweight to allow for easier handling and maneuverability, and be durable and long lasting. Additional features such as smoke evacuator port/s, jet ventilation port/s, and a well-placed, ergonomic, light adapter groove/tunnel are also desirable features.

We present our prototype laryngoscope that aims to address each of these desired elements, but most importantly, to improve anatomic field exposure and adjustability. This theoretically allows for improved surgical efficiency and, potentially, surgical outcomes. Our novel adaptation of distensible laryngoscopes combines the advantages of traditional laryngoscopes while preserving the ability to suspend and improve distal exposure, as demonstrated in our cadaveric study. We believe this novel device could also be useful for performing endoscopic Zenker’s diverticulectomy procedures, particularly in patients with challenging anatomy, as an additional 26-cm diverticuloscope length is planned for development and has the added benefit of distal tip articulation to expose the esophagus, common esophageal wall, and esophageal diverticulum.

CONCLUSION

This novel laryngoscope with an adjustable distal tip provides improved exposure of the supraglottis and glottis in a cadaveric study and has the potential to be used for both supraglottic/glottic and proximal esophageal procedures.

BIBLIOGRAPHY