The Laryngoscope

Robot-Assisted Transnasal Laryngoplasty in Cadaveric Models: Quantifying Forces and Identifying Challenges

Kelly Groom, MD; Long Wang, MSc; Nabil Simaan, PhD; James Netterville, MD

Objectives/Hypothesis: We expanded our prior work with transnasal robotic surgery (TNRS) in this study with the following aims: 1) use a cadaveric model to evaluate the feasibility of laryngoplasty with TNRS, 2) measure robot insertion times and forces, and 3) identify operational challenges to further guide the development of a flexible robotic system.

AQ1 **Study Design:** Cadaveric study.

Methods: A 5-mm robot was guided to the larynx via a transnasal approach. Insertion times and forces using TNRS and a 4-mm flexible fiberoptic laryngoscope (FFL) were measured. Target sites on the true vocal cords were marked, and the TNRS was telemanipulated to perform injection laryngoplasty.

Results: Insertion times averaged 5.05 seconds (range, 3.8–10.4 seconds) for the TNRS and 7.97 seconds (range, 6.2–11.6 seconds) for the FFL. Insertion forces averaged 2.06 newtons (range, 1.56–5.55 newtons) for the TNRS and 0.43 newtons (range, 0.157–1.138 newtons) for the FFL. The unpaired t test between times and forces revealed P values of .0024 and .0000658, respectively. Seven target injection sites on three vocal cords in two cadaveric larynxes were successfully injected. In two out of nine sites marked, we were unable to access the vocal cord due tongue base collapse that obscured the posterior airway.

Conclusions: TNRS is able to effectively access the larynx, although in a supine model may be limited by tongue base collapse. Forces with TNRS were significantly higher than with the FFL, albeit within the same scale. Despite increased forces, there was no evidence of tissue trauma using TNRS.

Key Words: Laryngoplasty, minimally invasive surgery, robotic.

Level of Evidence: NA

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INTRODUCTION

Robotic surgery is rapidly becoming accepted as a standard and often a preferred surgical method. Robotic surgery in the larynx with current technology is difficult because the equipment consists of robotic instruments attached to rigid rods that must be angled far apart from each other. This is unfeasible in the small confines of the larynx and has limited robotic surgery of the upper aerodigestive tract largely to the oropharynx, hypopharynx, and supraglottis.[1,2] The need for more dexterous manipulating robotic hands to work within the larynx has prompted a search for different robotic configurations.[3] The ideal tools for robotic laryngeal surgery would involve small grasping instruments on flexible arms that do not require angulation, such as with a snake-like robot. Variants of these robots were reported in a study[4] demonstrating knot tying within the confines of transoral access. In Bajo et al.,[5] we proposed transnasal robotic surgery (TNRS) and demonstrated the feasibility of accessing the larynx on a mannequin using a snake-like robot in a model. In another study,[6] we demonstrated the feasibility of transnasal access in a cadaver. This experiment expanded our prior experience resulting in the following goals: 1) evaluate the feasibility of laryngoplasty with TNRS using a cadaver model, 2) measure robot insertion times and forces, and 3) identify operational challenges to further guide the development of a flexible robotic system.

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MATERIALS AND METHODS

We performed injection laryngoplasty with standard injection materials on two fresh cadavers using a transnasal approach with the robot. In our initial trial (attempts 1–4) an intact cadaver was used. In our second trial (attempts 5–9) a decapitated head was used. The reason for switching to a decapitated cadaver was twofold. First, rotating the head of the intact cadaver body to allow introduction of the robot was difficult due to the stiffness of the cadaver. The decapitated head was easily rotated to suit introduction of the robot. Second, the decapitated head was easily placed on our force sensor, a task that was not possible with the intact cadaver. Using methylene

Fig. 1. Transnasal robotic surgery depolyed in cadaver model with external recording camera and tower to the right. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

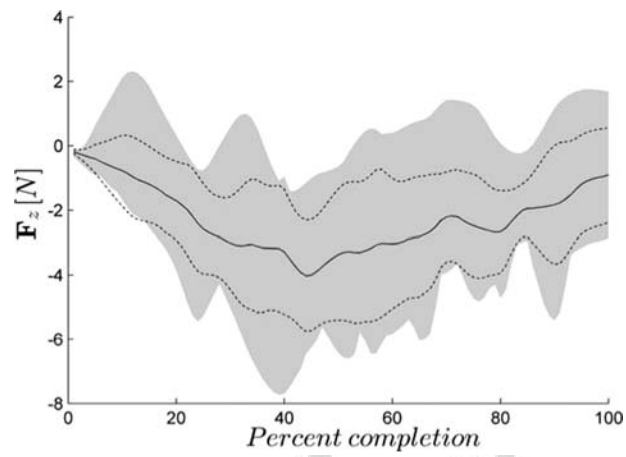

Fig. 2. Forces measured with insertion of the transnasal robotic surgery. Shaded area = maximal and minimal insertion forces during each insertion; x-axis = time in the form of percent completion of the insertion; y-axis = forces.

blue on a hollow bore needle, we marked out target injection sites on the vocal cords of fresh cadavers via direct laryngoscopy. A 0° Hopkins rod was inserted into the larynx via a lateral transcervical incision at the level of the hyoid to enable external recording. An 8-mm nasopharyngeal airway tube was inserted in the cadaver nostril to protect the tip of the fiberoptic
F1 camera from debris during insertion (Fig. 1).

The robotic arm was manually inserted through one nostril down to the level of the larynx. The robot controller actively bent the robot's tip to facilitate insertion by using the active compliance algorithm described by Goldman.[7,8] The robotic telemanipulation controls were used to guide the robot to the injection sites. A 25-gauge needle tip modified by soldering it to a hollow superelastic nickel titanium (NiTi) tube of the same diameter was passed through one port of the robotic arm. Both Cymetra (trials 1–7) and Radiesse (trials 8 and 9) were injected through the needle into the true cords at the marked injection sites in standard injection laryngoplasty technique.

Insertion times and forces were recorded and averaged for both the TNRS system and with a 4-mm flexible fiberoptic laryngoscope (Karl Storz, Tuttlingen, Germany). Forces were recorded using a six-axis force/moment sensor (Gamma; ATI Industrial Automation, Apex, NC). Forces were measured by placing the cadaver head on the force sensor. After zeroing the force sensor to cancel out the weight of the head, we were able to record the insertion force data at a frequency of 1,000 Hz with a moving average of 25 points.

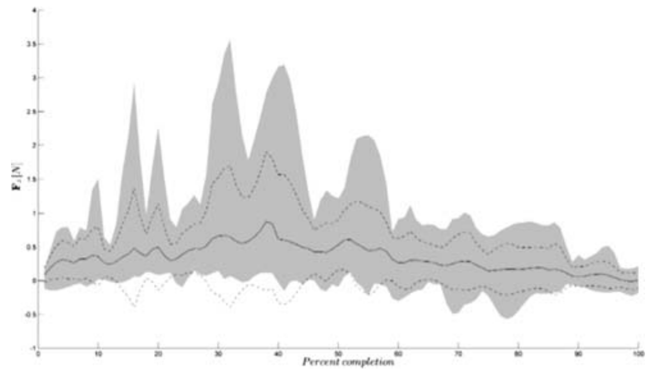

Fig. 3. Forces measured with insertion of the flexible fiberoptic laryngoscope. Shaded area = maximal and minimal insertion forces during each insertion; x-axis = time in the form of percent completion of the insertion; y-axis = forces.

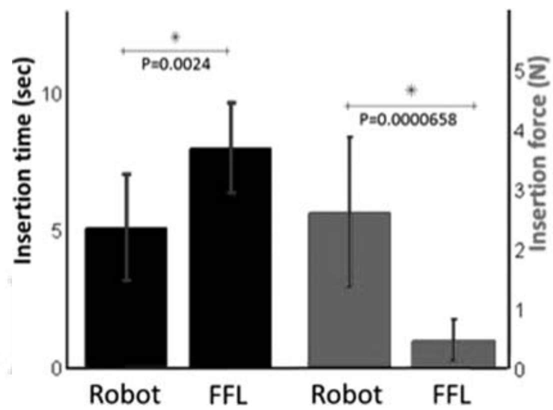

Fig. 4. Unpaired t test comparing insertion times (left) and forces (right). FFL = flexible fiberoptic laryngoscope. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

RESULTS

Insertion times for the TNRS ranged from 3.8 to 10.4 seconds. The average insertion time was 5.05 seconds. Insertion times for the flexible fiberoptic laryngoscope ranged from 6.2 to 11.6 seconds, with an average insertion time of 7.97 seconds.

With each insertion, forces on the cadaveric head were recorded. Insertion forces for the TNRS ranged from 1.56 to 5.55 newtons, with an average of 2.06 newtons (Fig. 2). Insertion forces for the flexible fiberoptic F2
laryngoscope ranged from 0.157 to 1.138 newtons, with an average of 0.43 newtons (Fig. 3). An unpaired t test F3
between the times and forces revealed P values of .0024 and .0000658, respectively (Fig. 4). There was a significant difference between the two datasets. F4

A total of seven injection sites on three vocal cords in two cadaveric larynxes were marked and injected.

TABLE I.
Cadaveric Injection Results.

Trial	Cadaver Type	Insertion Times Recorded?	Insertion Forces Recorded?	Injection Material	Result	Reason for Failure
AQ6 1	Intact cadaver	Yes	No	Radiesse	Successful	
2	Intact cadaver	Yes	No	Radiesse	Successful	
3	Intact cadaver	Yes	No	Radiesse	Successful	
4	Intact cadaver	Yes	No	Radiesse	Successful	
5	Cadaver head	Yes	Yes	Radiesse	Failure	Tongue base collapse interfered with access
6	Cadaver head	Yes	Yes	Radiesse	Failure	Tongue base collapse interfered with access
7	Cadaver head	Yes	Yes	Radiesse	Successful	
8	Cadaver head	Yes	Yes	Cymetra	Successful	
9	Cadaver head	Yes	Yes	Cymetra	Successful	

One cadaveric vocal cord was deemed unsuitable for injection due to previous vocal cord trauma. In two out of nine sites marked, we were unable to access the vocal cord due to tongue base collapse that obscured the posterior airway, making it difficult to manipulate the robot to our goal site. The seven successful injection sites were
T1 injected with either Radiesse or Cymetra (Table I).

DISCUSSION

Current upper aerodigestive robotic surgery is generally limited to the oropharynx, and in some cases the supraglottis. To enable access to any region at the glottis or below, flexible and dexterous robotic arms that can be manipulated within the small confines of the larynx are needed.

The TNRS robot developed by our team is made of a flexible snake-like unit with 5 degrees of freedom. The unit contains three 1.8-mm ports. One port contains a 1.2-mm fiberscope with 10,000 imaging fibers and light delivery fibers. In our experiment, we used the second port to house a 25-gauge needle that was welded to a hollow-bore wire of the same diameter. This was connected via a luer lock to a syringe containing standard injection laryngoplasty material.

During insertion, the robot is in a semiactive mode as the operator manually inserts the robot while the robot tip autonomously complies with the anatomy. This automatic compliance is facilitated by using measurements of forces on three superelastic NiTi backbones used to actuate the robot tip. An Ascension Trackstar (Ascension Technology Corp., Shelburne, VT) magnetic tracker was used to track the pose of a 0.9-mm electromagnetic coil attached to the base of the snake robot. This magnetic coil provided information for correcting the telemanipulation mapping between the robot and the telemanipulation master device.

The average insertion times of the TNRS and flexible fiberoptic laryngoscope were 5.05 seconds and 7.97 seconds, respectively. The average insertion forces of the TNRS and flexible fiberoptic laryngoscope were 2.06 and 0.34 newtons, respectively. There was a significant difference in the times and forces, with the robotic insertion being faster but also exerting more force. Despite the increased force, no visible trauma from the robot was observed in the cadaveric tissue.

CONCLUSION

The goals of this study were first to test the feasibility of vocal cord injection with our robot. As shown in Table I, we were able to access and inject the vocal cords in 7/9 (78%) of the cadavers. Our second goal was to measure robot insertion times and forces. We identified a significant increase in insertion time between the robot and a standard flexible fiberoptic scope, but this did not appear to come with any increase in tissue trauma. Insertion time with the robot was approximately 5 seconds. Insertion forces with the robot, although significantly higher than those of the flexible fiberoptic laryngoscope, were still within the same scale. Our third goal was to identify operational challenges to further guide the development of a flexible robotic system. We discovered that even with a dexterous robot, surmounting tongue base collapse in a supine model is difficult without the aid of a retractor such as a laryngoscope. Continued development of flexible robotic arms will enhance our ability to perform robotic surgery of the larynx.

BIBLIOGRAPHY

1. Weinstein GS, O'Malley BW, Hockstein NG. Transoral robotic surgery: supraglottic laryngectomy in a canine model. *Laryngoscope* 2005;115:1315–1319.
2. Weinstein GS, O'Malley BW, Magnuson JS, et al. Transoral robotic surgery: a multicenter study to assess feasibility, safety, and surgical margins. *Laryngoscope* 2012;122:1701–1707.
3. Rivera-Serrano CM, Johnson P, Zubiate B, et al. A transoral highly flexible robot: novel technology and application. *Laryngoscope* 2012;122:1067–1071.
4. Hillel AT, Kapoor A, Simaan N, Taylor RH, Flint P. Applications of robotics for laryngeal surgery. *Otolaryngol Clin North Am* 2008;41:781–791.
5. Bajo A, Dharamsi LM, Netterville JL, Garrett CG, Simaan N. Robotic-assisted micro-surgery of the throat: the trans-nasal approach. In: *2013 IEEE International Conference on Robotics and Automation*. 2013:232–238. AQ2
6. Bajo A, Dharamsi LM, Netterville JL, Garrett CG, Simaan N, Tn N. Trans-nasal robotic micro-surgery of the throat: a cadaveric feasibility study. In: *Hamlyn Symposium on Medical Robotics*. 2013:27–28. AQ3
7. Goldman RE, Bajo A, Simaan N. Compliant motion control for continuum robots with intrinsic actuation sensing. In: *2011 IEEE International Conference on Robotics and Automation*. 2011:1126–1132. AQ4
8. Goldman RE, Bajo A, Simaan N. Compliant motion control for multisegment continuum robots with actuation force sensing. *IEEE Trans Robot*. In press. AQ5

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AQ6: "Yes" and "No" okay added to the table? Yes, OK.

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