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# Evaluation of a Telerobotic System for Transnasal Surgery of the Larynx and Airways in Cadavers

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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## Abstract

**Objectives.** Minimally invasive, transnasal endoscopic approaches to the larynx have been utilized but are limited by the precision and accuracy afforded to the surgeon. The objective of this study is to analyze the feasibility of a rapidly deployable telerobotic system for enabling transnasal microsurgery of the larynx and upper airways, specifically injection laryngoplasty.

**Study Design.** This is a feasibility study.

**Setting.** This study was conducted at a laboratory in the Department of Mechanical Engineering at Vanderbilt University.

**Subjects and Methods.** A feasibility study was conducted in which a telerobotic system was transnasally inserted in both a human intubation trainer mannequin and a cadaver. A flexible needle was passed through an instrumentation port and targeted specific areas of the vocal folds of our models to simulate injection laryngoplasty. The experiments were recorded with both still and video photography. Average forces exerted on surrounding tissue and times of deployment were measured.

**Results.** Our robot was able to expeditiously gain access to the glottis with an average manual insertion time of 5.87 seconds while exerting minimal forces on the surrounding tissues with an average force of 4.45 Newtons. The onboard fiberoptic endoscope conveyed images of adequate quality for the completion of a simulated injection medialization laryngoplasty. The experiment was successfully completed in both mannequin and cadaveric models.

**Conclusion.** This telerobotic system proved to be capable of being rapidly deployed to the upper airways while exerting minimal forces to the surrounding structures and successfully simulated injection medialization laryngoplasty.

## Keywords

telerobotic transnasal surgery, minimally invasive surgery, injection medialization

## Introduction

The trend toward minimally invasive surgery (MIS) has been an historic force driving the development of new surgical techniques, and this theme has been pervasive throughout all surgical disciplines. Otolaryngology has been no exception, with trans-oral endoscopic surgery of the larynx and upper airways dating to the early twentieth century.<sup>1</sup> Trans-oral minimally invasive surgery of the throat has been a preferred surgical modality because it preserves the integrity of the laryngeal framework, eliminates visible scars, and promotes a faster recovery.<sup>2</sup> These advantages come at the price of limited access, visualization, depth perception, and distal dexterity. Trans-oral robotic surgery (TORS), one of the newest additions to the head and neck surgeon's armamentarium of MIS techniques, has been extensively investigated to overcome some of the aforementioned disadvantages.<sup>3–5</sup>

Though TORS continues to be an active surgical modality in head and neck surgery, there are several disadvantages associated with this method. These include the required use of a laryngoscope and thus general anesthesia, failure to achieve adequate exposure, and collateral damage to surrounding structures (eg, lingual and hypoglossal nerves, teeth, and mucosa).<sup>6–7</sup> The surgeon and patient also have to accept the potential complications and costs associated with general anesthesia.

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At our institution we have constructed a novel telerobotic system that is capable of providing transnasal surgical access to the larynx and upper airways. Previous research conducted with our telerobotic system has shown that the compliant insertion algorithm utilized by this platform is effective in assisting the surgeon as the robot is being inserted through the nasopharynx to the level of the glottis.<sup>8</sup> In the current paper, our aim was to investigate the feasibility of our system in providing transnasal surgical access to the larynx and upper airways in 2 experimental models: an intubation trainer mannequin and a cadaver. Simulated injection medialization laryngoplasty was conducted in our experimental models, and the efficacy of our system at completing this task was evaluated. We believe this approach paves the way for low-cost office-based surgery of the upper airways and therefore circumvents several of the disadvantages associated with current minimally invasive trans-oral techniques.

## Methods

In accordance with Vanderbilt University Medical Center's Institutional Review Board policy, cadavers are not considered human subjects, thus IRB approval was not needed for the current study.

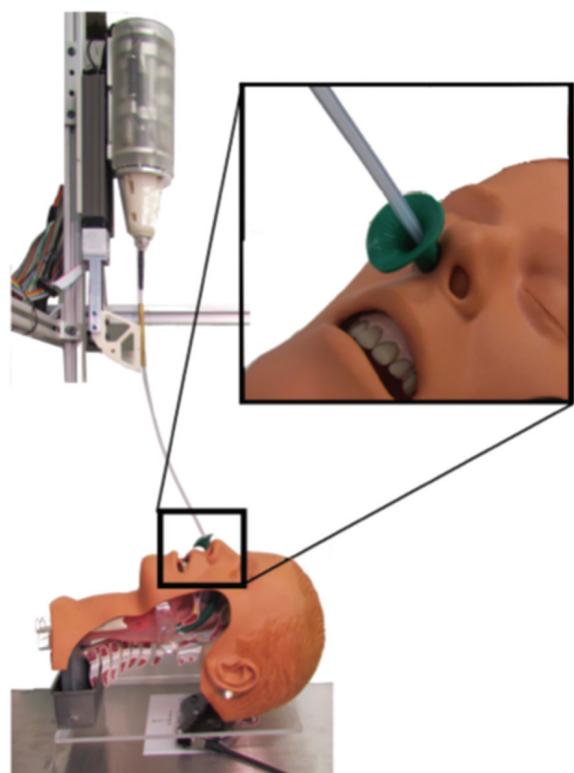
A system composed of a 5 degree of freedom (DoF) continuum manipulator robot with three 1.8 mm instrumentation ports, 1 of which contained a 1.2 mm fiberoptic endoscope and another contained a flexible 22 gauge needle. Other components of the telerobotic system include a Phantom Omni master interface, an actuation unit, and an Ascension 3D Guidance trakSTAR 2 with flat metal immune transmitter (**Figure 1**). The actuation unit has 7 controlled axes, 6 of which are used for actuating the 2 segments of the snake-like manipulator and 1 that is used to control the axial insertion of the continuum robot into the nasopharyngeal tube. The actuation unit has force sensing capabilities on all the axes that control the continuum robot. The trakSTAR 2 flat magnetic field transmitter was placed under the patient's head and it provided the position and orientation of the base of the proximal actively bending segment.

An intubation trainer mannequin (Nasco Atkinson, Wisconsin) was used for 1 set of experiments. A 34 French nasopharyngeal tube was inserted through the naris, and its tip reached the supraglottis (**Figures 1, 2**). The telerobotic system was then deployed through this conduit.

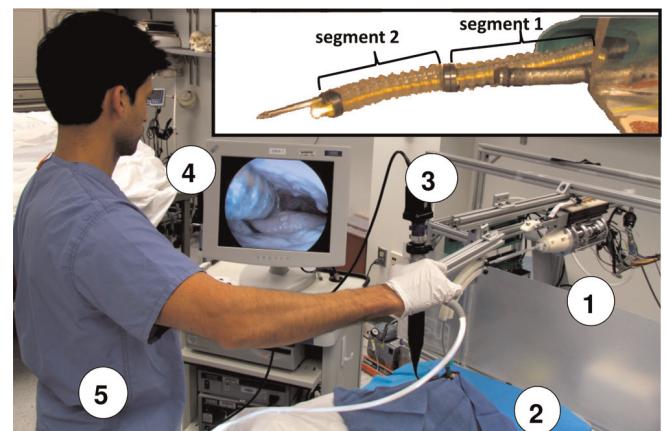
Five cadavers were obtained through the Vanderbilt Anatomical Donation Program, 3 females and 2 males. One cadaver was compatible with our experiments. Similar to the intubation trainer mannequin, a nasopharyngeal tube was inserted through the naris until the tip reached the supraglottis. The robot was then deployed through this conduit. A fiberoptic endoscope was inserted in the contralateral naris and was used to photo document the experiments (**Figure 2**).

## Results

Ten insertions through the nasopharyngeal tube in the intubation trainer were performed and insertion time and forces exerted on the mannequin were recorded. The average

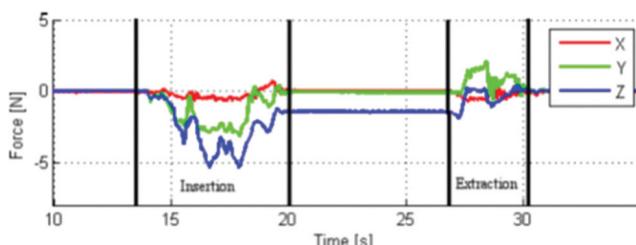


**Figure 1.** Experimental setup. Depicted is a 5 mm flexible robot passing through a 34 French nasopharyngeal tube that has been inserted in an intubation trainer mannequin.

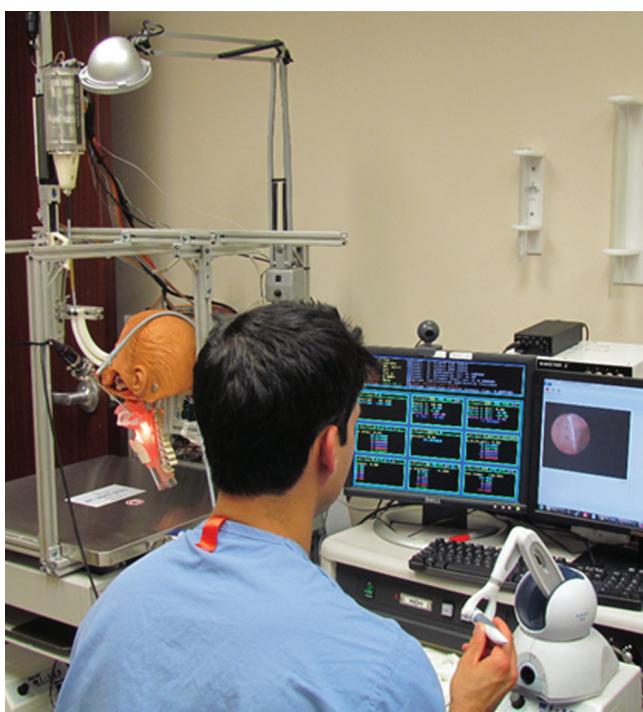


**Figure 2.** Cadaveric experimental setup. (1) actuation unit, (2) magnetic tracker, (3) fiberoptic endoscope, (4) monitor, (5) surgeon.

insertion time to reach the pharynx was 5.87 seconds (range, 4.32-11.05 seconds). The average maximum insertion forces in the x, y, and z directions were 0.855 N (range, 0.648-1.219 N), 2.685 N (range, 2.407-3.144 N), and 4.551 N (range, 3.743-5.396 N), respectively (**Figure 3**). The vector of force in the x direction describes forces in the horizontal plane, y describes forces in the craniocaudal plane, and z describes forces in the anteroposterior (AP) plane. The greatest force was exerted in AP plane as the robot was in contact with the posterior wall of the nasopharyngeal tube.



**Figure 3.** Graphical depiction of forces being exerted on the intubation trainer mannequin with time on the x axis and force exerted on the y axis.



**Figure 4.** Experimental setup. Depicted here is the surgeon using a joystick to remotely operate the robot in the intubation trainer mannequin (shown in the top left of the picture) utilizing a live feed from the onboard fiberoptic endoscope.

In order to evaluate the ability to perform a teleoperated injection medialization of the vocal folds, a flexible needle (described previously) was inserted into 1 of the instrumentation ports of the robot and targeted 6 predetermined points on the vocal folds of the mannequin. All 6 points represented injection sites that are typically targeted *in situ* for vocal fold medialization. The surgeon utilized a live video feed from the onboard fiberoptic endoscope to guide the robot to the assigned targets (**Figure 4**). The surgeon had no previous experience with the robot or the joystick and underwent 15 minutes of training prior to the experiments. As shown in **Figure 5**, the surgeon was able to direct the needle toward all the predetermined points.

Next the experiment was replicated in a cadaver (**Figure 2**). **Figure 6** shows a sequence of pictures as the distal tip

of the robot passes along the posterior pharyngeal wall, to the supraglottis, and finally to the level of the glottis.

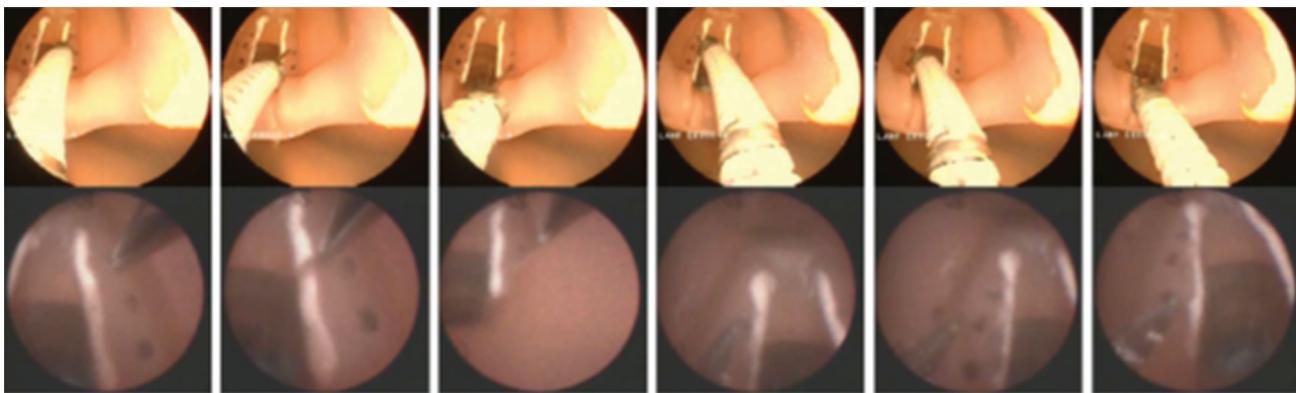
## Discussion

Currently available MIS techniques of the glottis and upper airways may not only be technically challenging but also have other associated disadvantages. In general, MIS transoral procedures, due to their requirement of general anesthesia and use of a laryngoscope or equivalent retractor, are associated with a higher cost and potential for collateral soft tissue trauma. Also, patients with multiple comorbidities who are poor candidates for general anesthesia are at an even greater risk while undergoing transoral surgery.

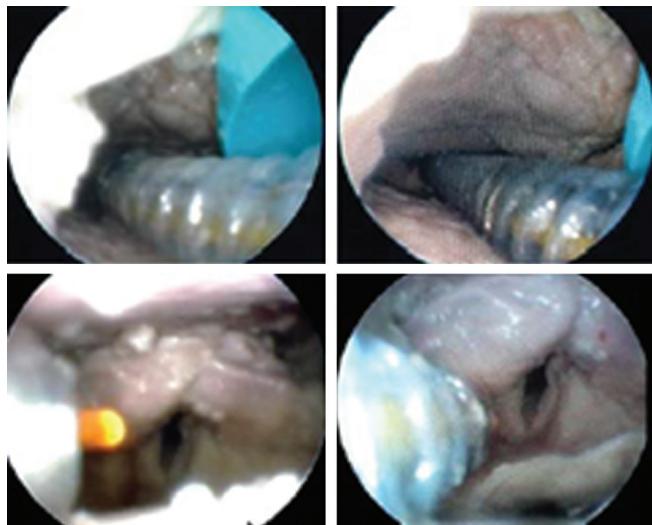
The concept of conducting transnasal procedures utilizing flexible fiberoptic endoscopes with operative ports is not new to otolaryngology and has been used to treat various glottic pathologies, including the paralyzed vocal fold and papilloma.<sup>9-11</sup> The lack of dexterity when using fiberoptically guided transnasal techniques significantly limits the breadth of this approach to single-instrument procedures requiring minimal tissue manipulation.

The presented telerobotic system proved to be capable of being expeditiously deployed to the upper airways while exerting minimal forces on the surrounding structures. Injection medialization laryngoplasty was successfully simulated in both the intubation trainer mannequin and cadaver.

The technology discussed in this paper does have several limitations that need to be addressed prior to its application in the clinical setting. One limitation of the current study is the image quality. As depicted in **Figure 5**, the resolution of the picture provided by the onboard fiberoptic endoscope is not as high as that provided by traditional high definition systems. In retrospect, the image from the fiberoptic endoscope was limited by an incorrect ratio between illumination and imaging fibers. Our fiberscope has 10,000 imaging fibers in 0.6 mm core while the rest are dedicated for illumination. Upon re-evaluation of the technology we discovered that the illumination is too powerful. In subsequent experiments, image quality was dramatically improved after this adjustment was made. Another limitation is conducting these proposed procedures in the awake patient who not only has a dynamic airway that requires local anesthesia but may also produce excessive secretions. Conventional means of obtaining topical anesthesia and decongestion such as lidocaine, tetracaine, oxymetazoline, and phenylephrine would be anticipated to provide adequate comfort in the awake patient undergoing transnasal robotic surgery. Secretions would be managed by either placing a suction catheter through 1 of the instrument ports, removing the endoscope from the robot and manually cleaning the lens, or pharmacologically with secretion-reducing medications. Experience in the clinical setting will determine the best means to maintain visualization. Lastly, though our system was shown to gain access to the upper airway in a time-efficient fashion and accurately target areas of operative interest in the mannequin and cadaver, experiments in the



**Figure 5.** Picture sequence of the surgeon targeting predetermined points on the true vocal folds using 2-D vision through the onboard fiberoptic endoscope. Top row: view from the fiberoptic endoscope inserted in the contralateral nare. Bottom row: view from the onboard fiberoptic endoscope.



**Figure 6.** View from accessory fiberoptic endoscope in order to observe robotic arm. Sequence of pictures showing the distal tip of the robot passing along the posterior pharyngeal wall, in the supraglottis, and finally at the level of the glottis.

awake and active patients would provide true performance metrics.

The current study exhibits 1 surgical application of our system. Presently underway is the development of various end effector devices including a new wrist design that will allow for finer manipulation of tissues, expanding the capabilities of our robotic platform beyond simple single-instrument tasks.

Our telerobotic system has the ability of completely shifting the paradigm of how surgery on the upper airways is approached. With the advent of such technology, treating various glottic and supraglottic pathologies under general anesthesia transorally may one day be an item of the past with this and similar procedures being conducted transnally in an office-based setting.

### Author Contributions

**Latif M. Dharamsi**, acquisition of data, drafting article, final approval of version to be published; **Andrea Bajo**, acquisition of

data, drafting article, final approval of version to be published; **James L. Netterville**, conception and design, acquisition of data, drafting article, final approval of version to be published; **C. Gaelyn Garrett**, conception and design, acquisition of data, drafting article, final approval of version to be published; **Nabil Simaan**, conception and design, acquisition of data, drafting article, final approval of version to be published.

### Disclosures

**Competing interests:** Nabil Simaan, inventor on patents with Intuitive Surgical and Titan Medical.

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