# Robotic Endolaryngeal Flexible (Robo-ELF) Scope: A Preclinical Feasibility Study

Kevin Olds, BE; Alexander T. Hillel, MD; Elizabeth Cha, BS; Martin Curry, DO; Lee M. Akst, MD; Russell H. Taylor, PhD; Jeremy D. Richmon, MD

**Objectives/Hypothesis:** This article presents a novel robotic endolaryngeal flexible (Robo-ELF) scope driver for minimally invasive laryngeal surgery. The Robo-ELF consists of a simple, robust robotic scope driver with three active and two passive degrees of freedom, allowing it to manipulate any standard flexible endoscope. The system is controlled by a joysticklike three dimensional mouse that interfaces with the scope driver via a laptop. Because the scope is supported and controlled by the robot, motor control and therefore visualization are enhanced. Additionally, because the robot remains stationary when the mouse is not being manipulated, the surgeon can position it and operate bimanually.

**Methods:** The system was validated by performing visualization and biopsy procedures on two human cadavers with the Robo-ELF and comparing this with standard rigid endoscopes with three different angles.

**Results:** The Robo-ELF outperformed the rigid scopes in both image quality and range of motion, overcoming line of site constraints, and allowing visualization of otherwise hidden anatomy. The system also demonstrated a rapid learning curve and enhanced motor control over a manually operated flexible endoscope.

**Conclusions:** The Robo-ELF is a novel robot to assist in driving a flexible endoscope for surgery of the upper aerodigestive tract.

**Key Words:** Robot, larynx, minimally-invasive, endolaryngeal, surgery, flexible fiberoptic scope. **Level of Evidence:** N/A.

Laryngoscope, 121:2371-2374, 2011

# **INTRODUCTION**

Transcervical laryngeal surgery results in disruption of the laryngeal framework with resultant sensory and motor deficits. Efforts to reduce the morbidity of external approaches have led to advances in endoscopic laryngeal surgery that access the endolarynx through the mouth. Technologic advances in binocular microscopy, rigid telescopes, microlaryngeal instrumentation, and lasers have led to dramatic improvements in the management of benign and malignant conditions of the larynx. Nonetheless, endolaryngeal surgery continues to have disadvantages, namely, reduced depth perception, relatively small exposure, and the operator's distance

From the Department of Otolaryngology–Head and Neck Surgery (A.T.H., M.C., L.M.A., J.D.R.), and Engineering Research Center for Computer Integrated Surgery (K.O., E.C., R.T.H.), Johns Hopkins Hospital, Baltimore, Maryland, U.S.A.

Editor's Note: This Manuscript was accepted for publication August 2, 2011.

This work was funded with Johns Hopkins Hospital Department of Otolaryngology and Johns Hopkins University internal funds. The authors have no other funding, financial relationships, or conflicts of interest to disclose.

Institutional approval for use of the cadavers was obtained prior to the study.

Kevin Olds, BE, and Alexander T. Hillel, MD, contributed equally to this study.

Send correspondence to Jeremy D. Richmon, MD, Assistant Professor, Otolaryngology-Head and Neck Surgery, Director of Head and Neck Robotic Surgery, 601 N. Caroline Street, 6th Floor, Baltimore, MD 21287. E-mail: jrichmo7@jhmi.edu

#### DOI: 10.1002/lary.22341

from the surgical field. These limitations restrict the surgeon's ability to manipulate instruments from outside the oral cavity, resulting in poor sensory feedback and magnification of the operator's tremor. In addition, the lack of distal dexterity risks injury to surrounding healthy tissue. Line-of-sight limitations inherent in microscopic or telescopic visualization limit the ability to view around corners, rendering areas such as the anterior commissure, subglottis, and ventricle challenging to visualize fully.

Robotic surgery offers potential advantages with steerable modular instrumentation and three-dimensional (3D) viewing that are lacking in traditional endolaryngeal surgery, improving the laryngologist's distal dexterity and suturing ability.<sup>1</sup> Currently, the da Vinci robot (Intuitive Surgical, Inc., Sunnyvale, CA) is U.S. Food and Drug Administration-approved for transoral surgery of benign and malignant early stage lesions of the upper aerodigestive tract. The da Vinci surgical robot's 3D optics system creates a high-definition, wideview image of the surgical field.<sup>2,3</sup> Furthermore, its maneuverable endoscope allows a high-fidelity view of the surgical field that can be rotated and positioned to enhance surgical precision. Motor control is enhanced by scaling movement, modulating tremor, and additional instrument freedom of motion.<sup>2,4-5</sup> Instrument control is further enhanced with distal articulation by the da Vinci's EndoWrist design, providing seven degrees of freedom for finer tissue manipulation.

Olds et al.: Robotic Endolaryngeal Flexible Scope

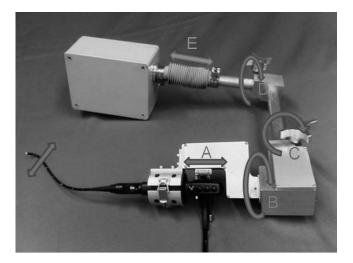


Fig. 1. The robotic endolaryngeal flexible scope with attached flexible fiberoptic laryngoscope. A = active scope tip manipulator; B = active axial rotation of the scope; C = passive lockable joint to adjust scope entry angle; D = passive lockable joint to adjust scope height; E = active in-out translation.

Unfortunately, there have been limited reports of successfully utilizing the da Vinci robot within the endolarynx.<sup>4,5</sup> This is because the current da Vinci robot was designed for opposing arms via widely spaced ports of entry for abdominal and thoracic surgery with large diinstruments predicated ameter on laparoscopic instruments. The arms of the robot were designed to mimic the opposition of a surgeon's hands in conventional surgery, a task quite different from parallel ports of instrument entry with manipulation coaxial with the lumen of a laryngoscope. Development of laryngeal robotic surgery is further limited by the endotracheal tube occupying space in the operative field, laryngeal suspension allowing for sufficient exposure, and manipulation of the robotic instrument arms in the crowded, narrow oral, pharyngeal, and laryngeal spaces.<sup>6</sup>

A collaborate effort between the otolaryngology and engineering departments of Johns Hopkins University led to the development of a simple robotically controlled endoscope system that may overcome some of the challenges faced today with transoral endoscopic laryngeal surgery.

# MATERIALS AND METHODS

A robotic endoscope driver was designed to have the potential to connect to a variety of commercially available endoscopes. The scope of choice for these experiments was the Pentax VNL-1570STK distal-chip flexible laryngoscope (Pentax Corp., Golden, CO). To give the surgeon adequate control of this otherwise unmodified clinical endoscope, it was determined that at least three active degrees of freedom were needed. These include manipulation of the scope's tip, rotation of the scope about its axis, and linear translation of the scope in and out of the patient. To increase the versatility of the system, two passive lockable degrees of freedom were also included to assist with positioning the scope in relation to the patient (Figs. 1 and 2). The active degrees of freedom are powered by brushed coreless 12 V, DC motors with planetary gearheads and integrated magnetic encoders (Micromo Micro Motion Solutions, Clearwater, FL). Each active degree of freedom also has a

potentiometer directly on the joint. This redundant sensing allows for greater safety and better control of the robot. The active joints all have limit switches to prevent them from exceeding the desired range. The scope holder portion of the robot is highly adjustable, and has a custom molded urethane rubber scope gripper, which can be easily changed to fit other commercially available scope models. To improve control of the scope while operating, we added a stiffening attachment to give the otherwise flexible scope shaft more "memory" so that it could maintain its own position and be easier to control. The entire robot is built to satisfy Johns Hopkins Hospital clinical engineering specifications, including waterproof seals, operating room-safe materials, proper electrical grounding with fusing, and an isolated power supply with no voltages greater than 12 V. The robot is operable in wet environments and pending a final clinical engineering inspection.

The robot uses a simple proportional-integral-derivative velocity controller implemented using a Galil model DMC 40x3 motor controller (Galil Motion Control Inc., Rocklin, CA). The motor controller interfaces with a laptop via ethernet, allowing joystick-like control using a SpaceNavigator 3D mouse (3DConnexion, Rochester, MI) [Fig. 3]. This configuration allows for rapid setup and adjustment. The software is based on the open source CISST libraries developed by the Engineering Research Center for Computer Integrated Surgical Systems and Technology at Johns Hopkins University.

#### **Clinical Validation**

Two fresh human cadavers were obtained from the University of Maryland State Anatomy Board after approval by the Johns Hopkins Hospital Minimally Invasive Surgical Training Center. Both were male with full dentition. Each cadaver was suspended with a Steiner laryngoscope to afford visualization of the endolarynx. Standard microlaryngoscopy was performed initially using 0°, 30°, and 70° rigid scopes. Representative photographs were taken of the endolarynx with each scope. The robotic endolaryngeal flexible (Robo-ELF) scope was then mounted to the bedside and advanced through the scope.

#### Task 1

The goal of the first task was to demonstrate comparable if not superior field of vision with the Robo-ELF scope. After



Fig. 2. The robotic endolaryngeal flexible scope mounted to a cart with an airway phantom. Controlling joystick is present in the mid-lower portion of the photo.

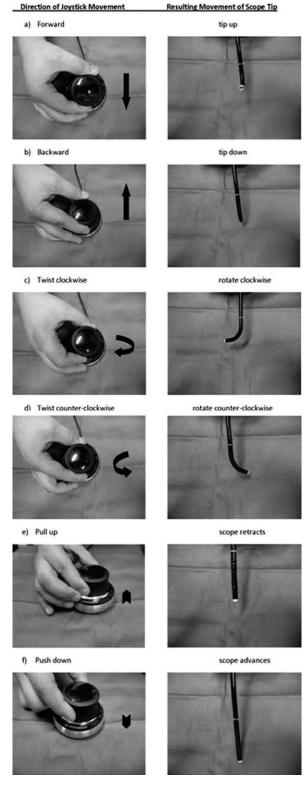


Fig. 3. The primary directions of scope movement are demonstrated by joystick control.

the Robo-ELF was positioned, the 3D mouse was used to manipulate the scope to obtain the same endoscopic views afforded by the rigid scopes. The entire field of vision navigated by the Robo-ELF was then compared to that of the rigid scopes.

#### Task 2

The goal of the second task was to achieve optimal visualization of normally challenging anatomical areas with precise biopsy sampling. With one hand controlling the joystick and the other manipulating a laryngoscopic biopsy forceps, attempted biopsies were taken of the subglottis, anterior commissure, and ventricle.

### Task 3

The goal of the third task was to demonstrate the ability to perform two-handed microlaryngoscopic procedures with the Robo-ELF in a fixed position. The Robo-ELF was driven to an optimal position above the vocal cords and left in position such that two-handed microlaryngeal surgery could be performed.

Photo and video documentation of the above tasks were reviewed by the authors to compare the effectiveness of the Robo-ELF to the traditional rigid scopes.

## RESULTS

The Robo-ELF was easily positioned through the Steiner laryngoscope and movement in all three active degrees-of-freedom was smooth, consistent, and reproducible. The speed of robotic movement was reliably translated by the amount of force placed on the joystick. No erratic or sudden movement was present. The Robo-ELF provided a wider field of vision than that of the three rigid endoscopes. The flexible tip was capable of driving around the arytenoids into the piriform sinuses and through the vocal cords into the subglottis, thereby overcoming limitations of line-of-sight. The distal chip scope provided a high-resolution image, and navigating the scope was intuitive with virtually no learning curve. The scope is controlled by a single hand joystick allowing instrument manipulation with the other hand. Visualization of the intended biopsy sites was successful in both cadavers. However, in the first cadaver the larynx was anteriorly positioned, and despite a clear view of the subglottis and anterior commissure with the Robo-ELF in a flexed position, the straight laryngoscopic forceps were unable to reach these areas. Finally, it was established that after positioning the Robo-ELF above the vocal cords there was still ample room to use two instruments to perform bimanual endolaryngeal surgery. A video demonstration of the Robo-ELF is available online (http://www.youtube.com/watch?v=66KSw0pt5IY).

## DISCUSSION

In this study we demonstrated the advantages of a robotically controlled endolaryngeal flexible scope. The Robo-ELF is manipulated with a single hand on the 3D mouse and maintains its position when released, allowing for both one-handed and two-handed surgery. The flexible distal-chip scope allows for a high-resolution image that can curve around corners, thereby bypassing line-of-sight limitations inherent in rigid telescopes and microscopes. Furthermore, the Robo-ELF is able to achieve a field of vision wider than that achieved with multiple rigid telescopes all within a single instrument without having to exchange scopes. The flexible endoscope has the added advantage of a working port with which to operate a  $CO_2$  or potassium-titanyl-phosphate laser fiber for the rapeutic purposes. As this study demonstrates, the learning curve to use the system is minimal.

The technologic advantages of the Robo-ELF are substantial. This robot is inexpensive compared with other microscopic and robotic techniques, with an anticipated cost of \$30,000 to \$50,000, and will accept any standard commercial flexible laryngoscope. Because the robot does not contact the patient, sterilization is not necessary and it can be quickly wiped down with alcohol facilitating equipment maintenance in the operating suite. The actual flexible scope is processed according to existing practices. Of great promise is the ability to eventually adapt the Robo-ELF to other flexible surgical endoscopes, such as bronchoscopes, esophagoscopes, and colonoscopes where more complex manipulation can be achieved with a single joystick. There is potential for microvascular surgery at the base of the skull, as well as single port gastrointestinal and thoracic access surgery. Furthermore, the Robo-ELF can be married with other technology, such as image overlay, ultrasound, optical coherence tomography, and can be manufactured with two distal chips for 3D vision, greatly expanding its applications.

# CONCLUSION

We have developed a novel robotic endoscope driver to be used in procedures of the upper aerodigestive tract. This robot has potential to overcome some of the challenges of traditional laryngoscopic surgery, such as lineof-site constraints, single-hand instrument manipulation, and tremor. Additionally, its use may be expanded to include other endoscopes and much broader clinical applications.

## BIBLIOGRAPHY

- Plinkert P, Lowenheim H. Trends and perspectives in minimally invasive surgery in otorhinolaryngology-head and neck surgery. *Laryngoscope* 1997;107:1483-1489.
- Mack MJ. Minimally invasive and robotic surgery. JAMA 2001;285: 568–572.
- Weinstein GS, O'Malley BW, Snyder W, Hockstein NG. Transoral robotic surgery: supraglottic partial laryngectomy. Ann Otol Rhinol Laryngol 2007;116:19-23.
- Rahbar R, Ferrari LR, Borer JG, Peters CA. Robotic surgery in the pediatric airway: application and safety. Arch Otolaryngol Head Neck Surg 2007;133:46-50.
- McLeod IK, Mair EA, Melder PC. Potential applications of the da Vinci minimally invasive surgical robotic system in otolaryngology. *Ear Nose Throat J* 2005;84:483–487.
- Hockstein NG, Nolan JP, O'Malley BW, Woo YJ. Robotic microlaryngeal surgery: a technical feasibility study using the daVinci surgical robot and an airway mannequin. *Laryngoscope* 2005;115:780-785.