Robotic Microlaryngeal Surgery: A Technical Feasibility Study Using the daVinci Surgical Robot and an Airway Mannequin

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Objectives/Hypothesis: The trend toward minimally invasive surgery has led to the development and mastery of endoscopic and laparoscopic surgical techniques. These minimally invasive approaches, which only two decades ago were either novel or experimental, are now mainstream. More recently, robot-assisted surgery has evolved as an adjunct to open and endoscopic techniques. Surgical robots are now approved by the United States Food and Drug Administration for a variety of thoracic and abdominal/pelvic surgical procedures. The purpose of this study is to demonstrate the technical feasibility of robot-assisted microlaryngeal surgery. Study Design: Experimental surgical manipulation of the larynx in an airway mannequin with a surgical robot. Methods: A variety of laryngoscopes and mouthgags, coupled with the daVinci Surgical Robot’s (Intuitive Surgical, Sunnyvale, CA) 0-degree and 30-degree, two-dimensional and three-dimensional endoscopes, were utilized to optimize visualization of the larynx in an airway mannequin. Five millimeter and 8 mm microinstruments compatible with the daVinci robot were utilized to manipulate different elements of the larynx. Experiments were recorded with both still and video photography. Results: The endoscope and robotic arms of the daVinci robot are well suited to airway surgery. Conclusions: Robot-assisted laryngeal surgery can be performed with currently available technology. The potential for fine manipulation of tissues, increased freedom of instrument movement, and endolaryngeal suturing may increase the precision of endoscopic laryngeal microsurgery and offers the potential to increase the variety of laryngeal procedures that can be performed endoscopically. Key Words: Robotic, endoscopic, minimally invasive surgery, microsurgery, larynx, daVinci.

INTRODUCTION

Over the last century, surgical innovation has benefited from discovery in other fields of study. Perhaps the greatest improvement in outcome after total laryngectomy resulted from the discovery of antibiotics.1 In the field of rhinologic surgery, the development of surgical telescopes and the computed tomography scanner have led to revolutionary advances in the treatment of diseases of the paranasal sinuses.2 The recent advances in surgical robotics emerged after the development of robotic technology for industrial and aerospace applications. Surgical robotics required miniaturization of both the mechanical robotic components and the solid-state components. These miniaturized robots coupled with improved three-dimensional optic technology have paved the way for advancement and application of surgical robotic technology.

The advantages that surgical robots have brought to abdominal and thoracic surgery can be applied in the head and neck as well. The primary obstacles to the performance of robotic-assisted pharyngeal and laryngeal surgery are 1) the introduction of the robotic arms and instruments into the narrow funnel created by the oral cavity, pharynx, and larynx, 2) the means of suspending and exposing the larynx to allow for adequate exposure without interfering with introduction of the robotic arms, and 3) a means of managing the airway. To assess the potential to overcome these obstacles, we simulated several endoscopic pharyngeal and laryngeal procedures using the daVinci surgical robot.

MATERIALS AND METHODS

Using the daVinci Surgical Robot (Intuitive Surgical, Sunnyvale, CA) and a Laerdal Airway Management Trainer 250000 (Wappingers Falls, NY), different combinations of retractors, laryngoscopes, endoscopes, and microinstruments were used to identify the optimal setup for robot-assisted microsurgical surgery. The different combinations are listed in Table I. Angles between the operating room bed and the robot, between the lateral robotic arms and the camera (positioned in line with the mannequin), and between the robotic arms and the horizon were
RESULTS

All experiments were photographed and video recorded. Procedures were performed with and without endotracheal intubation. Endolarynx were performed using 6-0 prolene sutures. Procedures were performed with a Lindholm laryngoscope, with the endoscope passing through the lumen of the laryngoscope, the pharynx and larynx could be well visualized with both the two-dimensional and three-dimensional 0-degree and 30-degree endoscopes. Movement of the endoscope was limited by the lumen of the laryngoscope; therefore, exposure of different elements of the larynx required repositioning of the laryngoscope, rather than just movement of the endoscope. Exposure of the pharynx, supraglottis, and glottis could be achieved with both the 0-degree and 30-degree endoscopes, but the view of the anterior commissure was superior with the 30-degree endoscope. The movement of the 8 mm robotic instruments was restricted by either the lips or the laryngoscope, except in the hypopharynx and supraglottis, where there was good excursion of the instruments. With the 5 mm instruments, movement was markedly less restricted. Because the endoscope passed through the laryngoscope, there was no difference in exposure or instrument excursion with either the two-dimensional or the three-dimensional endoscopes.

In this same parallel orientation, the larynx was exposed with a McIvor mouthgag. With the mouthgag, movement of the endoscope was not restricted and the entire hypopharynx, supraglottis, and glottis could be visualized without repositioning of the mouthgag. The anterior commissure was better visualized with the 30-degree endoscope. Trials using the 5 mm two-dimensional endoscope and the 10 mm three-dimensional endoscope yielded similar endoscope and instrument excursion, but with the 5 mm two-dimensional endoscope, depth perception and three-dimensionality were lost. With the 8 mm instruments, there was relatively unrestricted movement in the hypopharynx and supraglottis, but left- and right-hand instruments could not work in tandem in the glottis due to sheer space limitations. With the 5 mm instruments, there was relatively free movement throughout the pharynx and larynx and endolaryngeal suturing between the vocal folds was performed without difficulty with 6-0 prolene sutures. The only limitation in this setup occurred when working at the extremes of the exposed operative field. In these far lateral, anterior, and posterior locations, movement was restricted when the back of the instrument arms contacted the ring of the mouthgag.

Attempts to visualize the pharynx and larynx using only a 10 mm standard abdominal trocar (Ethicon Endo-Surgery, Cincinnati, OH) and the endoscope were largely unsuccessful. Endoscope movement, without another device on which to suspend the larynx, resulted in movement

### TABLE I.

<table>
<thead>
<tr>
<th>Retractor</th>
<th>Scope</th>
<th>Instrument</th>
<th>Exposure</th>
<th>Instrument Excursion</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0-degree 2-D</td>
<td>8 mm</td>
<td>HP, SG, G—limited view of AC</td>
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2-D = two-dimensional; 3-D = three-dimensional; HP = hypopharynx; SG = supraglottis; G = glottis; AC = anterior commissure.
of the entire head and neck and seemed to be dangerous. Additionally, the proximity of the tip of the endoscope to the surgical field made for a very narrow field of view.

Having identified the optimal configuration to include suspension with the McIvor mouthgag combined with the three-dimensional 30-degree endoscope and the 5 mm instruments for work at the glottic level and either the 5 mm or the 8 mm instruments for work in the hypopharynx or at the level of the supraglottis, attempts were made to identify the best angle between the operating room table and the robot. The ideal set-up would place the patient perpendicular to the robot (as is done for thoracic and abdominal procedures), but this severely limited movement of the endoscope and the far robot arm. Rotating the bed to an angle of 30 degrees to 45 degrees allowed for freedom of movement of the endoscope and both robotic arms, but the far arm was slightly more restricted at the extremes of the operative field (Fig. 1). Using this configuration, manipulation of the mannequin's epiglottis, arytenoids, cartilages, and vocal folds was performed (Fig. 2).
Endolaryngeal suturing and knot tying between the mannequin's vocal folds was also successfully performed using the 5 mm instruments and 6-0 prolene sutures (Fig. 3).

Finally, having identified an operating room setup that would enable robotic-assisted microlaryngeal surgery in a patient without an endotracheal tube, instrument manipulation was performed after endotracheal intubation with a standard 6-0 endotracheal tube. The tube did not significantly interfere with instrument excursion in the hypopharynx or the supraglottis, and in the glottis, the tube was easily manipulated with the robotic arms. Only its space-occupying effect in the glottis interfered with manipulation of the glottic structures.

**DISCUSSION**

Currently, surgical robots are used in abdominopelvic and thoracic surgery. Cardiac procedures are being performed without thoracotomy and abdominal procedures with significantly reduced blood loss and decreased operating time. These improvements are the result of several features of robotic surgery. First, surgical robots offer the advantage of true three-dimensional endoscopic vision. This is accomplished with dual endoscopes feeding separate video cameras and eyepieces. The endoscopes are configured to converge on a focal point in the same way in which our eyes do, and this provides the surgeon with true depth perception (Fig. 4). Second, surgical robots allow increased freedom of movement of endoscopic instruments, including simulated flexion, extension, pronation, and supination of instruments at their distal tips (Fig. 5). Third, surgical robots allow for scaling of movement, translating large movements of the hands into small movements of the instruments. Additionally, surgical robots can filter tremor.

These assets are particularly useful for microlaryngeal surgery. The potential for increased precision with robotic surgery with a very favorable learning curve will allow surgeons more rapid mastery of technically difficult surgical procedures. Endolaryngeal suturing, a very challenging task with conventional endoscopic instruments, is made relatively easy for the robotic surgeon. Additionally, the tremor filtration offers potentially much more gentle handling of tissues.

The currently available technology, which has been developed for use in the abdomen and the chest, lends...
itself reasonably well to use in the pharynx and larynx, in that all of these surgical fields involve primarily muscle, gland, and connective tissues. Scissors, tissue-grasping forceps, cautery, and needle holders, the instruments required for microlaryngeal surgery, are all commercially available and in clinical use.

The primary hurdle to the application of the daVinci surgical robot for microlaryngeal surgery is the means of introducing large robotic arms into the narrow funnel created by the mouth. Traditional means of laryngeal exposure with laryngoscopes is not adequate for robot-assisted microlaryngeal surgery. Most laryngoscopes are closed tubes, which severely limit endoscope movement. Even with modification of the laryngoscopes to open the lumen, the mouth is not kept widely open. With use of a mouthgag with a long tongue blade and a 30-degree endoscope, both laryngeal exposure and oral aperture are improved. A potential improvement on the McIvor mouthgag may be the Dingman mouthgag, with its integrated cheek retractors. With the use of the wristed instruments and a 30-degree endoscope, issues of line-of-sight required for CO₂ laser surgery are obviated. For procedures in which laser surgery is the current standard of care, the benefits of robotic assistance are unknown. Robotic surgery may offer speed advantages over laser surgery and, with angled endoscopes and wristed instruments, allow for improved exposure and the ability to work around corners.

Another potential obstacle to the performance of robotic-assisted microlaryngeal surgery is the lack of availability of suction instruments. Robotic surgeons in other fields have handled the issues of bleeding in the surgical field in a variety of ways. Primarily, the use of bipolar cautery forceps combined with the excellent optic technology allows for the prevention of bleeding by identification and cauterization of small vessels and the identification and ligation of larger vessels. In laparoscopic and thoracoscopic cases, an assistant surgeon can use a rigid, nonrobotic suction catheter to assist the robotic surgeon. A novel approach to the problem of suctioning could be the placement of a flexible suction catheter in the surgical field, which could be grasped and manipulated by the robotically controlled instruments, depending on the surgeon’s needs. Finally, if none of these strategies work, the development of instruments with integrated suction could alleviate these problems. For maintenance of hemostasis, a variety of monopolar cautery, bipolar cautery, ultrasonic shears, and clip appliers are commercially available. Animal modeling will be valuable in studying the ability to maintain hemostasis in the excision of larger lesions.

**CONCLUSIONS**

Microlaryngeal and pharyngeal surgery is the most fitting otolaryngologic application of robotic surgery at the present time. The application of surgical robotics to other areas of the head and neck (paranasal sinuses, tem-
poral bone, skull base) may require further instrument development, including drills, curettes, and bone-cutting forceps. Robot-assisted microlaryngeal surgery is technically feasible using currently available technology. We have identified the optimal setup to include the use of a mouthgag, rather than a laryngoscope and a degree three-dimensional endoscope with either 5 mm or 8 mm instruments at the level of the hypopharynx or the supraglottis and 5 mm instruments at the level of the glottis. With rotation of the operating room table by 30 degrees to 45 degrees relative to the robot, patient-device space constraints are manageable. Based on these preliminary experiments, management of the airway in patients who do not have tracheotomies is not an insurmountable obstacle. Additionally, we believe that there are several viable strategies to handle intraoperative bleeding. Robotic-assisted microlaryngeal surgery offers advantages to the endoscopic laryngeal surgeon, including increased precision, increased freedom of movement, filtration of tremor, and potential speed advantages over the CO₂ laser. Further study into this technology is warranted.

**BIBLIOGRAPHY**