Robot-Assisted Pharyngeal and Laryngeal Microsurgery: Results of Robotic Cadaver Dissections

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Objectives/Hypothesis: Robotic surgery has significant potential in pharyngeal and microlaryngeal surgery. We demonstrate the use of a surgical robot in pharyngeal and microlaryngeal surgery in a cadaver.

Study Design: Six experimental surgical dissections, modeled after commonly performed pharyngeal and microlaryngeal procedures, were performed in a cadaver with a commercially available surgical robot in an operating room suite to demonstrate proof of concept.

Methods: Using the daVinci Surgical Robot (Intuitive Surgical, Sunnyvale, CA), surgical procedures were performed on an edentulous, female cadaver. The procedures included 1) bilateral true vocal cord stripping, 2) rotation of a mucosal flap from the epiglottis to the anterior commissure, 3) partial vocal cordectomy, 4) arytenoidectomy, 5) partial epiglottectomy and thyrohyoid dissection and 6) partial resection of the base of tongue with primary closure. All procedures were timed and documented with still and video photography.

Results: The daVinci Surgical Robot, with currently available instruments, enabled performance of several laryngeal and pharyngeal surgical procedures on a cadaver. Laryngeal and pharyngeal exposure was excellent, instruments movement was unimpeded, tissue handling was delicate and precise, and endolaryngeal suturing was relatively easily performed. The duration of the different robotic cadaver dissections was comparable to procedure duration using conventional techniques.

Conclusions: Using the daVinci Surgical Robot, six different pharyngeal and microlaryngeal dissections were successfully performed in a cadaver. The recent development of surgical robotics has a potential role in pharyngeal and microlaryngeal surgery. Surgical robots offer the ability to manipulate instruments at their distal ends with increased freedom of movement, scaled movement, tremor buffering, and under stereoscopic three-dimensional visualization. Surgical robots may increase the precision with which we perform currently described procedures; additionally, surgical robots may advance the field of endoscopic laryngeal and pharyngeal surgery.

Key Words: Robotic, endoscopic, minimally invasive surgery, microsurgery, larynx, partial laryngectomy, lateral pharyngotomy, laryngeal cancer, daVinci.

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Robot-assisted cardiac and urologic surgery are revolutionizing the ways in which cardiac valvular disease and prostate cancer are being treated. Surgeries are being performed without large thoracotomies or laparotomies, morbidity is decreased, and patients are leaving the hospital sooner.1,2 These improved outcomes are the result of many assets of surgical robotics, including improved optics, increased freedom of endoscopic instrument movement, and tremor filtration.

The potential to apply the advantages of robot-assisted surgery to the pharynx and larynx is great, and previous work has demonstrated the technical feasibility of introducing the robotic instruments through the mouth into the pharynx and larynx.3 The breadth of pharyngeal and microlaryngeal surgical procedures and specific applications in which a surgical robot may be useful have not been identified. To assess potential applications of robot-assisted surgery in the pharynx and larynx, several cadaver dissections with the daVinci (Intuitive Surgical, Sunnyvale, CA) surgical robot were performed. Dissections performed included 1) bilateral true vocal cord stripping, 2) rotation of a mucosal flap from the epiglottis to the anterior commissure, 3) partial vocal cordectomy, 4) arytenoidectomy, 5) partial epiglottectomy and thyrohyoid dissection, and 6) partial resection of the base of tongue with primary closure.

MATERIALS AND METHODS

Using the daVinci Surgical Robot, cadaver dissections were performed on an edentulous, female cadaver. The cadaver...
weighed 43 kg and was 1.6 m tall. Operating room space constraints and laryngeal exposure were managed as previously described, with the operating room table rotated 30 degrees relative to the patient and with a mouth gag rather than a laryngoscope. Using a Dingman mouth gag, with its integrated cheek retractors, and a medium length tongue blade, the mouth was widely opened and the pharynx exposed. A 30-degree, upward facing, three-dimensional endoscope was inserted through the mouth gag to visualize the pharynx. A 2-0 prolene suture was placed through the midline of the oral tongue and was suspended on the outer ring of the Dingman mouth gag. The robotic instruments were then introduced through the mouth gag into the pharynx and larynx (Fig. 1). A 4-0 prolene suture was placed through the midline of the suprahypoid epiglottis, and this was also suspended on the Dingman mouth gag’s outer ring. Dissections were performed using a variety of 5 mm and 8 mm robotic instruments. All experiments were documented with both still and video photography. All dissections were timed. Dissections were performed from the most distal surgical sites to more proximal sites to ensure that exposure for each procedure best mimicked a true clinical setting. Dissections performed included 1) bilateral true vocal cord stripping, 2) rotation of a mucosal flap from the epiglottis to the anterior commissure, 3) partial vocal cordectomy, 4) arytenoidectomy, 5) partial epiglottectomy and thyrohyoid dissection, and 6) partial resection of the base of tongue with primary closure.

RESULTS

Initial setup of the surgical suite was achieved in less than 30 minutes. This included draping of the robot, placement of the mouth gag, and insertion of the endoscope and robotic instruments.

Procedure Details

Bilateral true vocal cord stripping. With a 5 mm fine forceps in the left-handed robotic arm, the mucosa overlying the right true vocal cord was gently grasped just anterior to the vocal process. Using a 5 mm round tip scissors in the right-handed robotic arm, the mucosa was incised and bluntly dissected from the underlying lamina propria. The dissection was carried to within 5 mm of the anterior commissure and then sharply truncated with the scissors and removed. The forceps were then switched from the left- to the right-handed robotic arm and the scissors from the right- to the left-handed robotic arm. The procedure was repeated on the left true vocal cord in a similar fashion. Both procedures were performed without tremor and surgical specimens were each removed in a single bloc. The right vocal cord stripping was performed in 8 minutes and the left in 6 minutes (Fig. 2).

Rotation of a mucosal flap from the epiglottis to the anterior commissure. With a 5 mm fine forceps in the left-handed robotic arm, the mucosa overlying the epiglottis was gently grasped approximately 1 cm superior to the anterior commissure, just to the right of midline. With a 5 mm round tip scissors a thin mucosal flap was elevated and pedicled just above and to the right of the anterior commissure. The flap was rotated onto the left true vocal cord, extending from the anterior commissure to approximately the mid-cord. The right-handed instru-
ment was then changed to a 5 mm fine forceps and a 7-0 prolene suture was passed into the surgical field. The mucosal flap was then sutured to the vocal fold. The procedure was performed in 28 minutes (Fig. 3).

**Partial vocal cordectomy.** With a 5 mm fine forceps in the left-handed robotic arm, the right true vocal fold was grasped just anterior to the vocal process. Using a 5 mm round tip scissors in the right-handed robotic arm, the vocal fold was incised perpendicular to its free edge. The incision was carried to the inner perichondrium of the thyroid cartilage. The scissors were then rotated and the incision was carried anteriorly to the mid-cord. This portion of the vocal fold was then excised. The partial vocal cordectomy was performed in 6 minutes (Fig. 4).

**Arytenoidectomy.** With a 5 mm fine forceps in the left-handed robotic arm, the right arytenoid cartilage was gently palpated and its outline was better visualized through the overlying, redundant mucosa. The mucosa overlying the most superior aspect of the arytenoids was then grasped with the forceps and using a 5 mm round-tip scissors in the right-handed robotic arm, the mucosa was incised just posterior to the vocal process. The anterior and lateral muscular attachments were then incised and the cricoarytenoid joint was bluntly separated. The medial muscular attachments were then freed and the arytenoid

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Fig. 3. (A) The 5 mm instruments are used to elevate a mucosal flap from the laryngeal surface of the epiglottis. (B) Flap is rotated and draped from the anterior commissure to the left vocal fold. (C) Flap is secured with 7-0 interrupted sutures.

Fig. 4. (A) Right vocal fold is grasped with a 5 mm forceps and a posterior incision is made perpendicular to the vocal fold, extending to the inner perichondrium of the thyroid cartilage. (B) Portion of vocal fold just prior to resection.
cartilage and overlying mucosa was removed. The arytenoidectomy was performed in 13 minutes (Fig. 5).

Intubation. The above procedures were performed without endotracheal intubation. For the remaining procedures, the cadaver was endotracheally intubated with a standard 6-0 endotracheal tube. Intubation was performed under endoscopic visualization without altering the laryngeal exposure.

Partial epiglottectomy and thyrohyoid dissection.

The suture, which had been used to suspend the epiglottis, was cut and removed. With a 5 mm Debakey forceps in the right-handed robotic arm, the epiglottis was grasped and both the lingual and laryngeal surfaces were examined. On the laryngeal surface, an approximately 1 cm² lesion was created using a 5 mm cautery hook held in the left-handed robotic arm. Using the cautery hook, the epiglottis was then bisected in the sagittal plane to the petiole and the resection was then carried laterally through the aryepiglottic fold. Partial resection of the epiglottis was performed in 4 minutes. An assistant surgeon, viewing the procedure on a video monitor, evacuated smoke with a rigid suction catheter. The endotracheal tube did not interfere with the dissection (Fig. 6). After removal of a
portion of the epiglottis and aryepiglottic fold, the superior aspect of the hyoid bone was dissected with the cautery hook. A round-tip scissor was then placed in the left-handed robotic arm. Using scissor dissection, the superficial and deep aspects of the hyoid bone were identified and the greater horn was dissected free. Dissection continued along the superficial aspect of the hyoid bone, across the thyrohyoid membrane to the thyroid cartilage. The strap muscles were then bluntly dissected from the outer perichondrium of the thyroid cartilage on the right side. Dissection of the hyoid bone and thyroid cartilage was performed in 22 minutes (Fig. 7).

Partial resection of the base of tongue with primary closure. The suture used for retraction of the tongue was removed. The right base of tongue was grasped with an 8 mm round-tooth forceps in the left-handed robotic arm and a 5 cm × 3 cm × 2 cm portion of the tongue base was excised using an 8 mm Potts scissors in the right-handed robotic arm. After resection, a needle driver was placed in the right-handed robotic arm and the tongue base was closed primarily with 3-0 Vicryl sutures. Resection and closure was performed in 17 minutes (Fig.

Fig. 7. (A) A forceps in the right-handed robotic arm is used to retract the hyoid bone medially and a round-tipped scissor in the left-handed robotic arm is used to free the greater horn of the hyoid bone. (B) The scissors in the left-handed instrument are used to retract the hyoid bone and thyroid cartilage medially, and the forceps in the right-handed robotic arm are used to bluntly dissect the strap muscles free from the outer surface of the thyroid cartilage.

Fig. 8. (A & B) The base of tongue is grasped with an 8 mm round-toothed forceps, and an 8 mm Potts scissors is used to resect a 5 cm × 3 cm × 2 cm portion of the base of tongue. (C) The tongue base is closed primarily, under endoscopic visualization, with 3-0 Vicryl suture.
Summary of Results

Prior to the initiation of the above dissections, the Dingman mouth gag was placed and the cadaver was placed in suspension. No subsequent repositioning of the mouth gag was required. Under robotic control, the endoscope was manipulated through the oral cavity, pharynx, and larynx. Upon completion of the dissections, the robotic instruments, the endoscope, and the mouth gag were removed. There was no trauma to the cadaver’s lips, gums, or tongue.

DISCUSSION

Surgical robotics offers several potentially advantageous features to the microlaryngeal or pharyngeal surgeon. When comparing robot-assisted surgery to conventional endoscopic surgery, these advantages relate to improved optics with three-dimensional visualization, tremor filtration, and increased freedom of instrument movement. Each of these may allow increased surgical precision and more delicate handling of tissues. Additionally, robot-assisted surgery, with its wristed instruments, may allow the performance of procedures that otherwise would necessitate an open approach. The improved endoscopic visualization, wristed instruments, which include both monopolar and bipolar cautery, and the potential for relatively easy endoscopic suturing may facilitate the resection of tumors of the base of tongue with relative ease. Potentially, lesions traditionally approached through a lateral pharyngotomy may be managed endoscopically. With the angled telescopes and wristed instrument, issues of line of sight required for carbon dioxide laser surgery are eliminated. The application of surgical robotics to tumor resection may expand the scope of lesions, which can be managed endoscopically and therefore may improve functional outcome relative to open procedures, which require transection of the strap muscles.

These advantages of surgical robotic technology can be applied to a wide variety of procedures in the pharynx and larynx. The most delicate of endolaryngeal procedures, including the elevation of microflaps, the treatment of anterior commissure webbing, and the treatment of benign mucosal lesions of the vocal folds, may be managed with a high degree of precision. At the other extreme, large tumors of the larynx and pharynx can be resected endoscopically with relative ease. Robotic surgery may also offer speed advantages over laser surgery. While we did not compare the duration of robotic dissections to either sharp dissection or dissection with a laser, we believe the robotic dissections were performed in times that were, at least, comparable to other modalities. Further study into procedure duration is warranted.

The initial challenges of laryngeal exposure and introduction of the robot arms with their associated instruments through the oral cavity are manageable, and several strategies for the management of operative bleeding have been described. Additional research, potentially with an animal model, would be valuable in demonstrating these strategies and is also warranted.

As surgical robotic technology advances, instruments will become smaller and less expensive, and the technology will become available at more medical centers. With the improvement of the technology, opportunities to treat disorders of the larynx and pharynx will increase and, ideally, patients will reap the benefits from this technology in the form of equivalent or improved surgical outcomes with more rapid recovery and improved function.

CONCLUSIONS

The application of surgical robotic technology to microlaryngeal and pharyngeal surgery shows much promise. We have demonstrated in a cadaver that exposure with the Dingman mouth gag and a 30-degree endoscope is at least comparable to that obtained by conventional methods and that robot-assisted surgery offers the advantage of three-dimensional vision. Both fine procedures at the glottic level and larger resections in the larynx and pharynx were performed with relative ease, and endoscopic suturing was performed with a high degree of precision. The potential advantages of robot-assisted surgery lie not only in its ability to improve upon procedures currently performed, but also to expand surgical endoscopy to include performance of procedures not yet envisioned. Future research into the application of robotic technology to pharyngeal and microlaryngeal surgery is warranted.

BIBLIOGRAPHY