Robotic Surgery: Research and Reviews

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REVIEW

Potential of robotic systems in phonosurgery

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Abstract: There has been rapid growth in the utilization of robotic surgery in the head and neck. Its utilization in the phonosurgical space has lagged owing to difficulty with access and exposure to the laryngeal site, small working space due to the size of the larynx and the need to work around an endotracheal tube. The goal of this work is to explore recent developments in robotic microlaryngeal surgery. At this time robotic instrumentation is available; however, the range of instruments is not as extensive to match the current microlaryngeal instrumentation that exists for traditional endoscopic surgery. Studies have demonstrated the ability to perform phonosurgery safely with currently available robotic systems but exposure is less than ideal. Work is been undertaken to develop specialized transoral robotic retractors which will improve visualization and allow the robotic instrument to reach the glottis, which has traditionally been the most difficult to area to access. Additional studies will be needed to assess the application of these systems to more patient populations, and prospective research will be required to compare outcomes of traditional phonosurgery to robotic phonosurgery.

Keywords: phonosurgery, robotic, larynx, glottis, microlaryngeal, endoscopic transoral robotic surgery, transoral retractor

Introduction

Laryngeal surgery was first performed in the 1800s with the development of direct laryngoscopy and endolaryngeal surgery. Since then, advances in endolaryngeal surgery have focused on increasing surgical precision with the utilization of operating microscopes and endoscopes, CO2 lasers and microflap techniques. Endoscopic and microscopic techniques as well as new microlaryngeal instruments have allowed for more precision surgery and has improved outcomes. Phonosurgery involves the use of microscopes and microsurgical techniques to perform endolaryngeal surgery specifically of the glottic larynx, for the restoration and improvement of voice secondary to benign laryngeal conditions. The founding principles of phonosurgery, as with any laryngeal surgery, rests on optimal visualization of the pathology and surgical field, the ability to use two hands with precise tissue handling and preservation of normal tissue.[1]

Despite these current advancements, endolaryngeal surgery is still limited in many ways. The surgeon is required to operate at long distances from the true surgical field using twenty-two centimeter-long instruments. This leads to a reduction of sensory feedback, and the long working distances directly relates to amplification of surgeon hand tremor. The direct laryngoscope, of which there are multiple sizes and types, provides a very narrow working space and field of exposure. In addition, the instruments lack distal dexterity, which can contribute to inadvertent collateral damage to surrounding healthy tissue.[2]

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Robotic surgery within the head and neck is a relatively new and rapidly growing field. Transoral robotic surgery (TORS) has been described in the treatment of benign and malignant lesions of the oropharynx, hypopharynx, larynx, skull base and parapharyngeal space.[3] Indeed, TORS has FDA clearance for the treatment of T1 and T2 oropharyngeal carcinoma with larger tumors having been successfully treated as well. Robotic systems have the potential to overcome many of the limitations of more traditional endolaryngeal surgeries. Specifically, robotic systems provide improved 3D visualization, greater degrees of freedom at the surgical site and dissipation of surgeon tremor.[2] These factors all contribute to increased surgical precision. With the primary goal of laryngeal phonosurgery being the restoration and optimization of voice, surgical precision is key. Despite this, robotic phonosurgery has lagged behind other anatomical sites within the head and neck in which robotic usage has rapidly been growing, namely within the oropharynx. There are several reasons for the slow advancement of robotic use for phonosurgery. This area has been limited by poor visualization of the glottis due to poor access, 'large' robotic instruments and the narrow working space for these robotic arms. The robotic arms were primarily designed for larger resections in the abdomen, thorax, head and neck. Narrower and finer effector robotic arms modified for the glottis in the upper airway to allow delicate tissue handling required in phonosurgery had not been a focus of the robotics industry until recently with release of the Medrobotics Flex system.[4]

Robotic systems

Currently, there are two main robotic systems utilized in the head and neck space. The first robotic system to be developed, the DaVinci Surgical Robot (Intuitive Surgical Inc; Sunnyvale, CA), is used in many anatomical areas and specialties including within head and neck, cardiac, colorectal, gynecologic and urologic surgeries. The DaVinci S and Si platforms have been approved for use in the head and neck space, and in March 2019, the single port (SP) platform was partially approved for use in the head and neck space, specifically for radical tonsillectomy and tongue base resection. Given the limited approval of the SP platform, it will not be covered in this review. The DaVinci system utilizes a Master Control and Slave Robot system. The surgeon sits separate from the patient at the master control center. The robot itself has four independently controlled endoscopic arms; one robotically controlled endoscopic camera and three robotically controlled arms holding instruments.[5] In transoral surgery, only two instrument arms are utilized with the endoscopic camera. The DaVinci system does not have instruments specific for microlaryngeal surgery.

The Flex Robotic System (Medrobotics, Raynham, MA) has FDA approval for use in the head and neck and colorectal sites. The Flex Robotic system has the surgeon positioned at the patient's head rather than at a separate console (Figure 1). This system employs a flexible endoscopic camera which can be advanced towards the supraglottis in a non-linear fashion (Figure 2). Once the camera is positioned, the robotic system functions as a stable surgical platform through which the flexible surgical instruments can be passed through the side ports into the surgical field. These surgical instruments are manually operated through two side ports by the surgeon compared to the off-set robotic manipulation seen in the DaVinci system.[6] The direct physical connection of the instruments in the Medrobotic Flex system provides the surgeon direct haptic feedback. The Flex Robotic System has microlaryngeal surgical instruments developed specifically for the Flex Robotic system, which provides a comparative advantage over the DaVinci system. The available microlaryngeal instruments for the Flex Medrobotic system include a CO2 laser holder, alligator graspers, triangle forceps, Flex sickle and Flex scissors available in all directions; however, some specific endolaryngeal instruments are lacking at this time (Figure 3). As interest in robotic phonosurgery continues to evolve, the available instrumentation continues to improve.

Surgical advances

In 2005, Hockstein et al demonstrated the ability to utilize the DaVinci robotic system in cadaver models to perform microlaryngeal surgery. In order to visualize the larynx with their technique, they required a Dingman retractor and retracting sutures on both the oral tongue and the epiglottis, and they were able to show that the robotic system could be utilized to perform various microlaryngeal procedures. Specifically, they were able to perform vocal cord strippings, endolaryngeal microflaps, partial vocal cordectomy and arytenoidectomy. With their complex retraction system, they demonstrated good visualization of the larynx. The robot demonstrated the ability to delicately handle the tissue without tremor; however, this model was limited by the lack of an endotracheal tube use during these microlaryngeal procedures which limits the ability to generalize their results to live patients.[7]

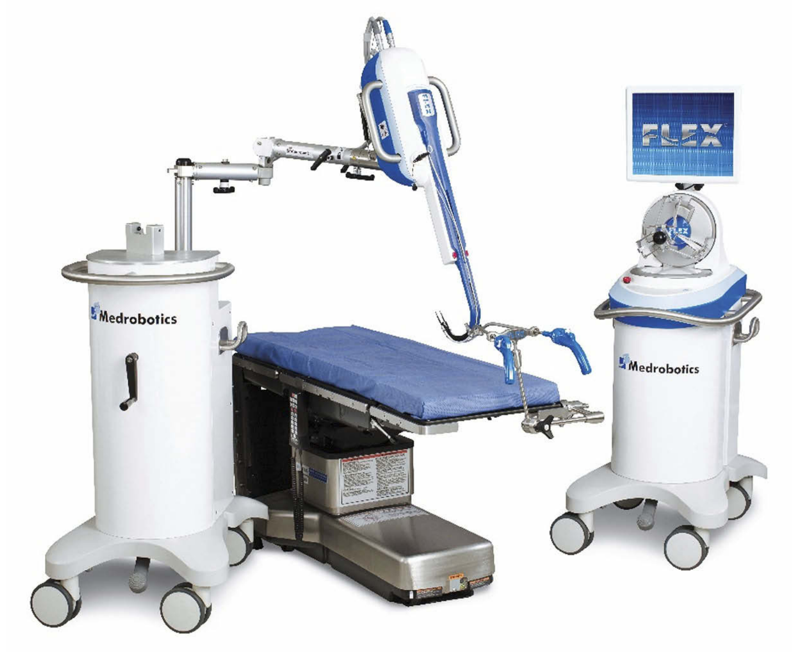

Figure 1 Medrobotic Flex 3D scope with alligator grasper and triangle forceps which demonstrates the ability for the robot to manipulate in a non-linear fashion.
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Subsequent to this, O'Malley Jr. et al in 2006 applied the DaVinci robotic system to perform robotic glottic microsurgery in live canine models. In this series, the surgeons were able to successfully utilize the robotic system to perform a submucosal vocal cord dissection in an orotracheal intubated canine model without adverse events. The authors note excellent visualization of the operative field, significant reduction of surgeon tremor and removal of the fulcrum effect noted in traditional endolaryngeal surgery given the wristed instruments. In addition, they noted improved operative time with the 5-mm instruments as compared to the 8-mm instruments.[8] Following these proof of principle studies, the ability to apply robotic techniques shown in cadaveric and animal models was applied in live human laryngeal surgeries.

In 2009, Park et al. performed a prospective study to demonstrate the feasibility of the DaVinci robotic system for the resection of glottic cancer in 4 patients. Park et al. were able to completely resect these malignancies en bloc with clear margins; however, they did require tracheostomy for their patients.[9] In 2011, Blanco et al demonstrated the ability to use the DaVinci robotic system for the oncologically sound

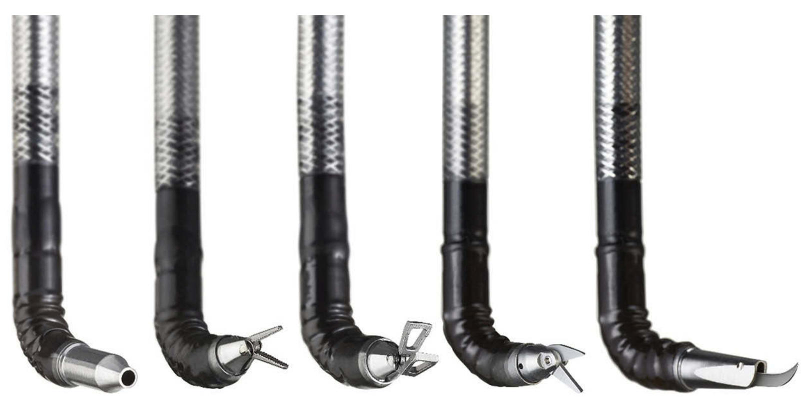

Figure 2 Microlaryngeal Instrumentation available for the Flex robotic system including laser attachment, alligator grasper, triangle forceps, micro-scissors and sickle knife.
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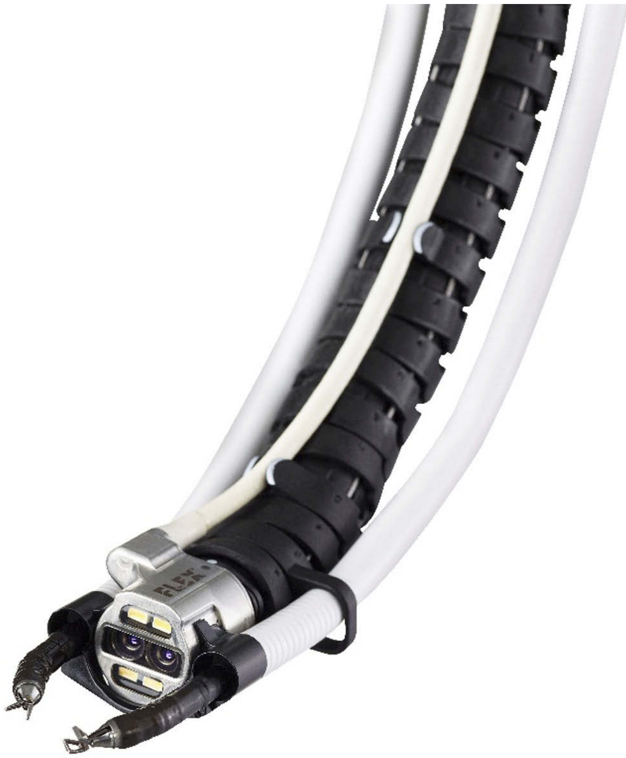

Figure 3 Medrobotics Flex robotic system.
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resection of T1 glottic squamous cell carcinoma. The robot surgical arms were placed outside the bounds of a Lindholm laryngoscope, and the robotic camera was passed through the laryngoscope. Blanco et al were able to resect the carcinoma en bloc with adequate 2 mm margins and they were able to perform this operation with a 6–0 endotracheal tube in place; however, restricted access to the anterior commissure was noted with their use of a Feyh-Kastenbauer (FK) retractor.[10] In 2017, Remacle et al. published their case series involving four patients treated for benign glottic lesions with the Flex Medrobotic system. The patients presented with vocal cord polyps, vocal cord keratosis and amyloidosis. For the vocal cord keratosis patient, a type 1 subepithelial cordectomy was performed. The vocal cord polyps and the amyloid lesion cases were resected with the CO2 laser. These patients were all able to be successfully treated, with orotracheal intubation, utilizing the Medrobotic system and discharged home on the same day.[11] In 2018, Persky et al. published their multi-center retrospective review of patients undergoing transoral surgery utilizing the Medrobotic Flex system. Their study highlighted 68 patients who underwent trans-oral robotic surgery of the oropharynx, hypopharynx and larynx. At the supraglottic subsite, 88% of patients were able to successfully undergo robotic resection, while in the glottic subsite only 50% of patients were able to successfully undergo robotic resection utilizing the Flex system.[12] This finding underscores the difficulty of performing microlaryngeal and phonosurgical operations on the glottis.

Alongside these robotic surgical advancements, additional research has been undertaken to further improve access to the glottis. One of the most troublesome aspects for robotic laryngeal phonosurgery is difficulty with exposure. The larynx has been a difficult anatomic site to address because of visualization and the small space and size requirements. In robotic laryngeal surgeries multiple different types of retractors have been employed to improve glottic exposure. These include FK retractors, Laryngeal Advanced Retractor System (LARS) and Dingman retractors (Table 1). These retractors suffer from closed, rigid frames, limited blade rotation and limited frame articulation. The FK retractor is especially cumbersome in its use, and its exposure of the larynx is very limited, particularly for the anterior glottis. Prior studies had noted the need for a complex system involving multiple instruments and tongue suture retraction in order to access the glottis.[7] Vasan et al. demonstrated the benefit of a modular oral retractor (MOR) to improve access to the glottis.[4] The MOR retractor (US and International Patent) has two pivot points on the frame and various tongue blades which can be utilized to improve access to the glottis (Figures 4 and 5). The maxillary brace pivot point augments the ability of the retractor to push the tongue and epiglottis forward, allowing improved visualization of the glottis. The 360° axis of rotation also gives the retractor a more stable purchase on the maxilla. The ability to rotate multiple parts of the retractor around an axis to maximize exposure is not possible with other retractors currently available for robotic laryngeal surgery. The maxillary brace is very similar to a Crowe-Davis retractor in that it widely distributes dental pressure from canine to canine across the superior alveolus as well as protecting the upper teeth from robot arm collision; whereas, the Dingman has two narrow dental braces that anchor on one tooth on each side of the superior alveolus. In their study, Vasan et al. were able to achieve full visualization of the glottis, and in one case, prolapsed, redundant arytenoid tissue was easily resected with the CO2 laser. This was accomplished without a retracting the tongue using a suture.[13] In their follow-up case series, this retractor system was noted to be effective in providing an easy to use, highly effective retractor system that may be used to facilitate access to the glottis with the robotic systems currently available. In this case series, they were able to adequately resect the

Table 1 Characteristics of currently available retractors for robotic microlaryngeal surgery

Retractor	Face Frame	Narrow Laryngeal Blade	Blade Anterior-Posterior Advancement	Blade Rotation Around Central Axis	Frame Articulation	Used in Live Humans
Dingman	Closed: Rectangle	No	No	No	Fixed	Yes
Crowe-Davis	Open: Oval	No	No	Yes	Fixed	Yes
Feyh-Kastenbauer (FK)	Closed: Square	No	Yes	Yes	Fixed	Yes
Feyh-Kastenbauer Weistein-O'Malley (FK-WO)	Closed: Rectangle	No	Yes	Yes	Fixed	Yes
Laryngeal Advanced Retractor System (LARS)	Closed: Curved Rectangle	Yes	Yes	Yes	Fixed	Yes
Lalich Microlaryngeal Robotic Retractor	Closed: Curved Rectangle	Yes	Yes	No	Articulates relative to the handle	No
Modular Oral Retractor (MOR) System	Open: Oval	Yes	Yes	Yes	Articulates relative to the handle	Yes
Flex retractor	Closed: Curved Rectangle	Yes	Yes	Yes	Articulates relative to the handle	Yes

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patients' supraglottic lesions with full visualization of both the lesions and the glottis. This was performed without the need for a complex retractor set-up or a retracting suture in the tongue (Figure 6).[4]

Conclusion

There has been a rapid growth in the utilization of TORS in the head and neck site; however, its utilization in the phonosurgical space has lagged owing to difficulty with access and exposure to the laryngeal site, small working space and the need to work around an endotracheal tube. Robotic instrumentation is available; but the range of instruments is not as extensive to match the current microlaryngeal instrumentation that exists for traditional endoscopic surgery. Research has demonstrated the ability to perform phonosurgery safely with robotic systems currently available, i.e. DaVinci Robotic System and Medrobotics Flex System. In addition, further

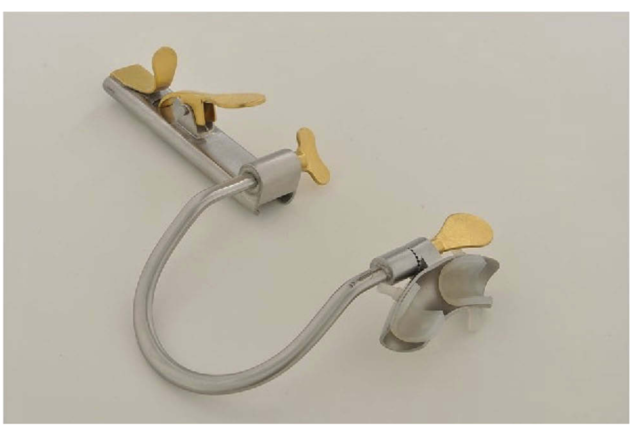

Figure 4 The MOR system allows the frame to be rotated relative to the handle and for blade rotation around the central access. It is shown here without a tongue blade. The superior pivot allows for change in pitch while the inferior pivot allows for adjustment in the roll of the tongue blade. There are right and left sided frames.
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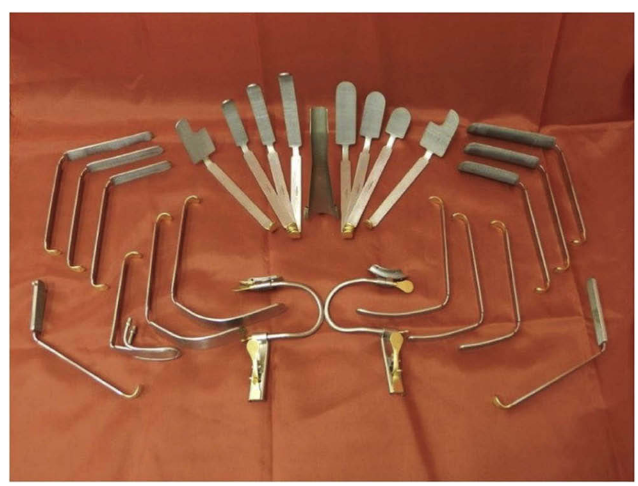

Figure 5 The different blades available to use with the MOR system. Various blades are available which allow for improved exposure of the tongue base, supraglottic larynx and glottis.

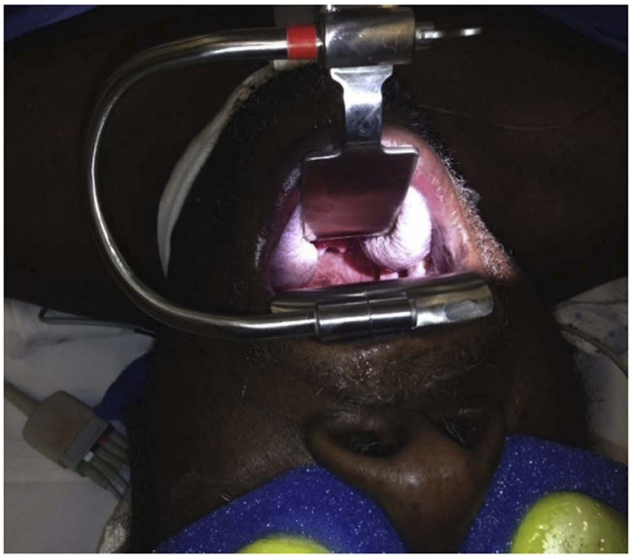

Figure 6 The MOR system in place demonstrating the access available to the supraglottic and glottic regions of the throat for surgery.

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research has been undertaken to develop specialized transoral retractors which allow optimal visualization of the glottis without the need for retraction sutures in the oral tongue or epiglottis. Further research will be needed to assess the application of these systems to more patients including those with less favorable anatomy as well as within the pediatric population. Moreover, prospective research will be required to compare outcomes of traditional phonosurgery compared to robotic phonosurgery.

Disclosure

Nilesh R. Vasan MD is the inventor of the MOR system and holds US patent US 9,993,148B2 with the Board of Regents at the University of Oklahoma. The authors report no other conflicts of interest in this work.

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