A Shifting Paradigm for Patients with Head and Neck Cancer: Transoral Robotic Surgery (TORS)

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The evolution of surgical oncologic technology has moved toward reducing patient morbidity without compromising oncologic resection. In head and neck surgery, organ-preserving techniques have paved the way for the development of transoral techniques that remove tumors of the upper aerodigestive tract without external incisions and potentially spare the patient adjuvant treatment. The introduction of transoral robotic surgery (TORS) improves upon current transoral techniques to the oropharynx and supraglottis. This review will report on the evolution of robotic-assisted surgery: We will cover its applications in head and neck surgery by examining early oncologic and functional outcomes, training of surgeons, costs, and future directions.

Over the last two decades, the introduction of robotic-assisted surgery has revolutionized minimally invasive surgery in multiple surgical specialties; the successful use of robotics in these other specialties has led to an examination of the potential application of robotic assistance in head and neck surgery. Robotic surgery offers distinct advantages over traditional open and laparoscopic surgical procedures, including smaller incisions, decreased hospital stays, better optics, and improved range of motion of the surgical arms; thus emerging as a standard operation for many procedures in urology, gynecology, general surgery, and cardiothoracic surgery.[1-5] The advantages that robotic-assisted surgery has shown in these fields are achieved without compromising oncologic outcome.

Background

The concept of robots appears to have originated with Aristotle, who imagined independently functioning tools as a means to achieve equality. In the 1960s, General Motors unveiled the Unimate, the first fully functional industrial robotic system.[6] However, it would be another two decades before robots made the transition between the world of manufacturing and that of medicine; when, in the 80’s, robots were introduced in rehabilitative medicine, where they were used to assist patients with day-to-day tasks.[7]

The first robotic surgery system, the PUMA 560, was developed in 1985 to perform greater precision in performing image-guided intracranial biopsies. The PUMA 560 was also used to perform a transurethral resection of the prostate.[8] Further refinement in the early 1990s led to ROBODOC, which improved hardware manipulation in hip replacement surgery. ROBODOC was the first system to receive FDA approval for arthroscopic hip surgery in 1994.[8]

Interest in medical robots led to a collaboration between the National Aeronautics and Space Administration (NASA) and Stanford Research Institute (SRI) in the early 1980’s. Virtual reality consoles were employed to develop telepresence surgery, the virtual placement of a remotely located surgeon in the operative field. The United States military took an interest in this work in an effort to develop a remotely operated robotic system with a dexterous telemanipulator that could stabilize injured soldiers in the battlefield.[9]

Experience with minimally invasive laparoscopic procedures helped surgeons understand the limitations of rigid equipment and two-dimensional views, and this resulted in the development of semi-rigid robotic equipment with three-dimensional views for the operative setting. Combining these tools with telepresence surgery led to the development of the Automated Endoscopic System for Optimal Positioning (AESOP), a robotic arm (controlled by a surgeon’s voice commands) that manipulated an endoscopic camera.[4,9] Shortly thereafter, Intuitive Systems (Sunnyvale, CA) released the SRI Telepresence Surgery System that was recently updated to the current daVinci Surgical System, the most common robotic system in use today.[10] FIGURE 1
Basic robotic surgical setup. (A) Robotic console with three-dimensional viewer, micromanipulators are situated in front of arm rest. Foot pedals are used to control electrocautery and switch controls of robotic arms. (B) View of surgeon sitting at robotic console controlling micromanipulators. (C) Panoramic view of operating room with robotic cart positioned with arms placed transorally. Surgeon is seen at console in back left corner of room.

The daVinci system is a comprehensive master-slave robot with multiple arms operated from a remote console with three-dimensional endoscopic views. To operate this system, the surgeon sits at the console and manipulates the instruments on a patient-side robotic cart, which is cable-driven and provides six degrees of freedom. In the daVinci system, robotic arms are capable of docking 8-mm and 5-mm instruments. The system displays its three-dimensional image above the hands of the surgeon, giving the illusion that the tips of the instruments are extensions of the control grips and creating the impression of being at the surgical site.[10] (Figure 1)

Applications in Other Specialties

Currently, the most common uses of robotic surgery are in general surgery, urology, cardiothoracic surgery, and gynecology. In general surgery, multiple case reports have been published on cholecystectomy, Heller myotomy, Nissen fundoplication, bowel resection with re-anastomosis, splenectomy, and distal pancreatic surgery.[4,5] These reports endorse the benefits of stable visualization and improved dexterity of the robotic arms with suturing and dissection. Gynecologists utilize robotic surgery in hysterectomies, myomectomies, and tubal reanastomoses, and show similarly positive results.[2] Oncologic outcomes were similar to laparoscopic and open methods. However, both specialties noted a disadvantage — the length of setup time both for exposure and for the docking of the robotic arms. Surgeons also observed another major disadvantage; the lack of haptic feedback, which is a virtual tactile feedback technology that provides mechanical feedback to the surgeon.[2,4,5]

Cardiothoracic surgeons have used robotic surgery since 1998, when a German group first performed a series of coronary revascularization procedures and mitral valve replacements.[3] Since that time, multiple other case series have been published describing valve replacements, revascularizations, atrial fibrillation ablations, and congenital cardiac anomalies. Results were encouraging, with evidence demonstrating fewer blood transfusions, shorter hospital stays, faster returns to preoperative function levels, and improved qualities of life compared to data in patient series in which patients underwent a sternotomy.[3]

The field of urologic surgery has perhaps seen the greatest incorporation of robotic surgery: In 2008, nearly two-thirds of prostatectomies were performed with robotic assistance.[13] High-volume centers have shown equivalent positive margin status and reduced PSA levels.[11] Surgeons noted
Evolution of Robotic Applications in Otolaryngology

Traditional surgery of tumors of the upper aerodigestive tract has required external approaches that bring the oral and pharyngeal contents into the closed neck space, requiring either local or free flap reconstruction. The addition of a mandibulectomy, which increases visualization and access unfortunately contributes to greater morbidity and poor aesthetic outcomes. These approaches have left patients with varying levels of speech and swallowing dysfunction as well as cosmetic deformity depending on the size and location of the tumor and the extent of resection. Often patients required tracheotomies and feeding tubes, and postoperative recovery included intensive functional rehabilitation that was further slowed by adjuvant chemotherapy and/or radiation.[9,14,15] In the late 1980s and early 1990s, multiple institutions investigated alternative treatment protocols based on organ preservation without compromising survival. The VA larynx trial and RTOG 91-11 showed that survival rates after following chemotherapy and radiation protocols while preserving the larynx were equivalent to those seen when patients underwent surgery followed by radiation. By preserving the functional laryngopharyngeal complex, these protocols became the standard of care in the treatment of squamous cell carcinoma of the larynx.[16,17] Organ preservation protocols were also applied to other primary sites of the upper aerodigestive tract, with similar survival outcomes. Mendenhall et al reviewed over 6,000 patients treated for oropharynx squamous cell carcinoma (OPSCC) at multiple institutions and found that patients treated with surgery had similar survival rates to those who received radiation as the primary modality.[18] More importantly, he found that patients undergoing surgery first were ten times more likely to have a severe complication or fatality compared to those who had radiation first as part of their treatment. Although the review compiled data from multiple retrospective reviews, the conclusion of this study was that radiation is superior to surgery in OPSCC. This data supports the role of radiation therapy as the primary modality for treatment of this patient population.

Over the last decade, there has been an increase in young, otherwise healthy patients with OPSCC caused by the human papilloma virus (HPV); Fortunately, there is data that shows that these tumors are highly responsive to radiotherapy.[19] Patients with HPV-positive tumors must endure intensive radiation treatments, just as those with HPV-negative tumors do, and since the HPV-positive patients are younger, there is a greater potential for long-term sequelae from radiation, such as osteonecrosis or radiation-induced malignancy.[20,21] Head and neck surgeons are then faced with a dilemma of providing oncologic cure without affecting functional performance in this era of organ preservation. While it is unclear whether these HPV-positive tumors are more susceptible to all types of treatments or whether we are simply identifying patients at an earlier stage, the development of successful minimally invasive surgical techniques may serve to control the tumor locally and spare patients from undergoing radiotherapy, which can be used later if the patient develops either a local recurrence or a second primary.

Transoral laser microsurgery (TLM) was introduced in the 1970s for ablation of laryngeal papillomas. It has since evolved to encompass treatment of early laryngeal cancers, showing excellent local control rates without compromising vocal function. TLM has only recently been evaluated for its clinical efficacy in OPSCC.[22] While there have been no randomized trials comparing surgery versus radiation, small series from various institutions have shown success at achieving local control in using TLM as the primary modality for OPSCC. At the Mayo Clinic, 69 patients with OPSCC (T-stage 1-3) were treated with TLM without adjuvant therapy and after a 44-month follow-up period, local control was achieved in 66 patients.[23] In Germany, a team led by Wolfgang Steiner showed an 85% local control rate at five years when using TLM for OPSCC, with 52% of the patients not requiring adjuvant radiotherapy. However, the rigid equipment and the narrow-field view through the laryngoscopes used in TLM make it a challenge to maneuver within the complex anatomy of the oropharynx.[24] Robotic surgery provides a unique advantage by introducing optics and instrumentation with multiple degrees of rotation that allows for access to the entire pharyngeal surface. In addition to this, the three-dimensional camera can be positioned close to the tumor, which provides an excellent view of the surgical bed.[15] In the following sections, we will discuss the development of TORS and review the early data on oncologic and functional outcomes.

Feasibility
The first application of robotics in otolaryngology was reported at Stanford University in 2003, where a group performed robotic assisted salivary gland surgery and neck dissection in a porcine model. The surgeons described the elimination of hand tremor and superior visualization as significant advantages of robotic surgery. Robot set-up time did not significantly slow down the operation; on average the required set-up time was 12.5 minutes. This group also observed that the normal lack of tactile sensation was compensated for by superior optics, which provided clearer views of the tissue planes.[25]

The concept of TORS was established at the University of Pennsylvania, when Hockstein et al demonstrated wide access to the laryngopharynx using mouth gag retractors in an airway mannequin and cadaver.[26] Weinstein et al later performed a supraglottic laryngectomy in a canine model. He demonstrated increased exposure with the mouth gag, with adjustable visualization of the larynx to facilitate the resection, a technique not possible with conventional TLM.[27,28] Additional series from this institution in canine and cadaver models provided information regarding use of five-mm instruments and other mouth retractors, which established a foundation to begin live human patient operations.[29]

The first supraglottic laryngectomy in a single patient using robotic assistance with a CO2 laser was reported by a group from the Cleveland Clinic in 2007.[30] While they showed the ability to incorporate the CO2 laser with the robotic arm, they also demonstrated the importance of evaluating variable patient factors such as oral opening and neck extension; failure to adequately evaluate these factors led to aborting two attempted robotic laryngeal resections in their series.

The first case series of patients undergoing TORS for OPSCC was reported from the University of Pennsylvania.[31] Three patients with early stage, base of tongue squamous cell carcinomas (2 T2, 1 T1) had complete en bloc resection of their tumors with negative margins. No immediate complications were noted and patients were able to return to a full diet within six weeks of surgery. With the feasibility of TORS established in OPSCC, institutions have begun recruiting patients for clinical trials to compare efficacy with traditional TLM and radiation therapy with or without chemotherapy.

Oncologic and Functional Outcomes

Long-term oncologic outcomes of TORS are not possible at this point because of the relative infancy of the procedure. However, several institutions have published short-term data from small series, and this data is promising.

Surgeons at the University of Pennsylvania reported a phase I study of 27 patients with early-stage tonsillar squamous cell carcinoma undergoing TORS in 2007.[32] Negative margins were attained in 25 of 27 patients and the two patients with positive margins were later cleared. Local control was achieved in all patients at six months follow-up. One patient developed distant metastasis. Three other institutions have also reported their data on the efficacy of TORS for OPSCC. These institutions reported achieving negative margins of resection in patient series ranging from 20 to 45 patients.[33-35] In the Mayo Clinic series, 12 of 45 patients (27%) were able to avoid adjuvant radiation, and at one-year follow-up in this series, no local recurrences were detected.[34] Functional evaluation of organ-preserving minimally invasive techniques involves the preservation of swallowing and airway function without long-term dependence of enteral feedings and tracheotomies. The University of Alabama at Birmingham evaluated functional outcomes in 54 patients undergoing TORS.[36] They found only five of 54 patients needed temporary tracheotomy, with decannulation occurring at a mean of eight days. 69% of patients initiated an oral diet after TORS and did not require enteral feedings. Only nine patients required a gastrostomy tube at the end of the study period and a statistically significant association was found with T4 stage primary site disease and primary disease located in the oropharynx or larynx.

Similar functional data was seen in the series reported by Moore, et al at the Mayo Clinic.[34] His group reported tracheotomies in 31% (14 of 45) of patients, with average time to decannulation seven days. 48% (22 of 45) of the patients had feeding tubes and all but five patients had their tubes out within 20 days. The other five patients had their feeding tubes removed by four months after surgery.

These early evaluations of the oncological and functional outcomes of TORS illustrate a minimally invasive technique that permits resection of the tumor en bloc while preserving patients’ swallowing ability. The promising results of the data from these multiple institutions led to FDA approval of TORS for use in selected benign and malignant tumors of the head and neck in December 2009. Using transoral techniques, a mandibulotomy and/or pharyngotomy is avoided. As additional information regarding HPV status in patients undergoing primary surgical therapy emerges, TORS may play a
significant role in the application of surgery as the first and possibly only treatment for select patients with OPSCC.

Cost

At institutions where robotic surgery has only recently been introduced, skeptics point to the significant costs associated with performing robotic-assisted cases. The console itself costs approximately 1.5 million dollars and requires at least one hundred thousand dollars in annual maintenance fees. Disposable equipment such as graspers, cautery arms, and other surgical instruments total approximately two hundred dollars per case.[10, 15] A recent cost analysis at a single institution showed that a hospital will lose money if fewer than 78 robotic prostatectomies are performed annually.[35]

Implementation of a robotic program solely for TORS is unlikely at any institution because of the low volume of existing cases. However, at higher volume centers where the robot console is used primarily for urology and general surgery, a head and neck surgeon may add to the value of the robot by performing additional procedures each year.[15]

Training

With the popularity of robotic surgery growing and more patients demanding robotic surgery as part of their treatment, practitioners are seeking out training and certification in this area. Currently, Intuitive Surgical provides a training curriculum on their website that details a curriculum involving didactic lectures on the daVinci console, cadaver dissections, and live case observation. Representatives for the company will also provide surgeon proctoring during a practitioner’s initial procedures.[10]

As more and more training programs perform robotic surgery, the implementation of a standardized curriculum into residency and fellowship education will be vital. The University of Medicine and Dentistry at New Jersey recently published a robotic training module for its otolaryngology residents.[38] The authors found that performing simple tasks such as grasping inanimate objects and suturing on latex introduces residents to basic robotic surgical skills, easing their transition to live patient cases. As a result, many training programs now provide cadaver dissection courses using the robot as part of their training.

Future Directions

With the knowledge that TORS is a safe, efficacious procedure to use in head and neck oncologic surgery, attempts at using TORS in innovative ways and in other areas in the head and neck are now being reported. For example, as finer, more flexible instrumentation is developed, transoral robotic-assisted surgery on the glottic larynx can be more easily accomplished. Current instrumentation is too bulky to access the narrow space of the glottis.

Another intriguing and increasingly popular area of application for robots is in transaxillary thyroidectomy. Avoiding an incision in such an aesthetically important area as the neck while still being able to safely and fully remove the thyroid gland is an attractive alternative to many patients. In Korea, Dr. Chung popularized this procedure, with his report of over 300 patients.[39] After assessing its feasibility in cadavers, we have also adopted this procedure at our institution.[40] The success of this procedure may revolutionize minimally invasive neck surgery, especially as surgeons attempt to transition this technique to cervical lymphadenectomy.

Another application for robotics is in the field of skull base surgery, which requires precise motions with a steady hand, an advantage of robotic arms. Surgeons at the University of Pennsylvania illustrated an approach to the midline and anterior skull base using two trocars inserted transcervically and placing the camera head in the oral cavity. They were able to successfully perform dissections of the skull base in canine and cadaver models.[41] At M.D. Anderson, the regions of the anterior skull base and sella were accessed and dissected via bilateral Caldwell Luc incisions and maxillary antrostomies.[42] Both groups found precision dissection with improved dural repairs without a natural tremor.

A more recent trend in robotic-assisted surgery is in microvascular free tissue transfer. Microvascular anastomosis with non-tremulous arms has been shown to be faster and more effective. Introduction of a free flap into a large oropharyngeal defect provides improved functional recovery and avoids the need for long-term healing by secondary intention of the oropharyngeal defect.[43,44] The flexibility of the robotic arms also allows suture placement transorally in areas of decreased visibility using traditional open methods.
Conclusion

Robotic surgery in head and neck oncology is an exciting innovation that provides significant advantages. Patients have an *en bloc* removal of their tumors via a minimally invasive surgery without a cervical incision, while preserving function and potentially avoiding adjuvant radiation and its long-term sequelae. While long-term oncologic and functional data are needed to fully validate its use, early results are promising.

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