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Current Trends in Robotic Surgery for Otolaryngology

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Abstract As minimally invasive surgery has become common in head and neck surgery, the role of robotic surgery has expanded from thyroid surgery and transoral robotic surgery (TORS) of the oropharynx and supraglottic to other areas. Surgeons have advanced the limits of TORS, adapting lasers to the Da Vinci robot for glottic cancer, and combining existing techniques for transoral supraglottic laryngectomy and hypopharyngectomy to perform transoral total laryngectomy. Skull base approaches have been reported with some success in case reports and cadaver models, but the current instrument size and configuration limit the applicability of the current robotic system. Surgeons have reported reconstruction of the head and neck via local and free flaps. Using the previously reported approaches for thyroidectomy via modified facelift incision, neck dissection has also been reported. Future applications of robotic surgery in otolaryngology may be additionally expanded, as several new robotic technologies are under development for endolaryngeal work and neurotology.

Keywords Transoral robotic surgery (TORS) · Lingual tonsillitis · Lingual tonsillectomy

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Introduction

As technology has grown exponentially since the 1980s, surgeons have pushed the limits of what was previously considered possible in the field of minimally invasive surgery. Surgical robotics, once only science fiction, has become a reality in modern medicine. The Da Vinci robot, initially approved by the Food and Drug Administration (FDA) for adult and pediatric general surgical procedures in 2000, was first introduced for head and neck procedures in 2003 by Haus et al. [1] in a porcine model for neck dissection and submandibular gland removal, and was shortly thereafter followed by Weinstein et al. [2] for transoral supraglottic laryngectomy in a canine model. Transoral robotic surgery (TORS) has now been widely adopted by head and neck surgeons for treatment of benign and malignant conditions of the oropharynx and larynx. The Da Vinci system is currently the only FDA approved robotic system for surgery in humans, although many new systems are currently being developed. The purpose of this article is to discuss new applications and technologies within the field of surgical robotics in otolaryngology-head and neck surgery.

TORS: New Applications

Indications of TORS have expanded from straightforward oropharyngeal and supraglottic surgeries for benign and malignant disease. Some physicians have found robotics to be useful in treating obstructive sleep apnea and sleep disordered breathing via robotic-assisted uvulopalatopharyngoplasty, lingual tonsillectomy, and partial glossectomy [3, 4]. Although these techniques can be performed without robotic assistance, proponents argue that the robotic technique allows more precise placement of sutures, and that the amount of tissue removed in partial glossectomy and lingual tonsillectomy can be better quantified than in coblation or radiofrequency ablation.

Base of tongue resection has also been reported to be an effective technique to identify the tumor in patients with unknown primary carcinoma [5]; nine of ten patients were localized to the base of tongue who had unknown primary tumors with negative imaging and failed traditional endoscopy in a study from our institution [6].

Laryngeal robotic surgery is also now commonly performed by robotic surgeons; Robotic supraglottic laryngectomy was first reported in patient by Weinstein and colleagues in 2006 and has since become an accepted technique [7]. Both benign and malignant disorders of the larynx may be treated with either TORS or transoral laser surgery based on surgeon preference, although some procedures may be better suited for the robotic technique. For example, Ciabatti and colleagues recently reported the removal of a large mixed (internal and external) laryngocele that previously would have required a cervical approach due to lateral extension [8]. Proponents argue that the articulated arms of the robot allow a greater degree of control than the line of sight needed for laser surgery, but the surgeon should keep in mind that the exposure afforded by currently available retractors may not allow sufficient working space in all patients. Additionally, the technique has yet to be widely adopted for glottic cancer, which may be due to inadequate exposure afforded by the Dingman or FK retractors for the glottis. However, Weinstein and colleagues have published a canine feasibility study that suggests that robotics may eventually be practical for endolaryngeal work [9]. Blanco et al. have published a single patient case of cordectomy for T1 glottic cancer using the Omniguide CO2 laser fastened to the Da Vinci robot arm. A Lindholm laryngoscope was used to suspend the patient, and the robotic arms were introduced lateral to the laryngoscope [10]. Park and colleagues in Korea has also reported three glottic cancers, T1–T2, that were completely resected using the FK retractor and monopolar cautery after tracheotomy was performed. All patients were decannulated within eight days of surgery and all resumed a normal diet within seven days [11]. More recently, Kayhan and colleagues have reported ten patients who underwent TORS cordectomy for T1 glottic cancer. Complete tumor resection was possible in all patients without tracheotomy, although one patient required tracheotomy for postoperative airway edema. With a mean follow-up of 9.1 months, there were no recurrences [12]. However, long-term oncologic outcomes and voice outcomes have yet to be published for transoral glottic robotic surgery.

Lawson et al., have also recently reported a proposed surgical technique for transoral total laryngectomy. This technique combines techniques of TORS supraglottic laryngectomy and hypopharyngectomy with an external tracheal separation and stoma creation. The authors suggest that a horizontal pharyngeal closure would maintain good blood supply to the neopharyngeal mucosa, and the avoidance of carotid sheath dissection and an external incision would prevent postoperative pharyngocutaneous fistula formation [13]. In their initial report of three patients, two were able to successfully undergo TORS total laryngectomy. The first patient was converted to open total laryngectomy due to poor exposure; the authors recommend exposure with the FK retractor at initial endoscopy to determine whether the procedure is feasible. Additionally, one patient had a prolonged hospital course and delayed oral intake due to bleeding from the pharyngeal suture line on postoperative day 8. Neither of the successful cases had a postoperative fistula, and both underwent successful primary tracheoesophageal puncture [14••]. Further study may reveal the utility of this procedure in select patients, but it should not be performed in patients who require neck dissection.

Reconstruction

As surgeons have become more facile with the robotic technology, one problem that has arisen is reconstruction of the surgical defect, rather than the ability to resect. The use of robotics for local flap reconstruction is still in its infancy, but may be valuable in certain patients. Our group has reported on robot-assisted pharyngoplasty for pharyngeal stenosis and velopharygneal insufficiency via Z-plasty and pharyngeal flaps, as well as facial artery musculomucosal (FAMM) flap and microvascular free flap reconstruction of post-resection oropharyngeal defects [15, 16]. Others have also reported using robotic techniques for local flap reconstruction and inset of microvascular free flaps for pharyngeal defects [17–19].

Skull Base

Application of robotic surgery to surgery of the skull base is a logical step, as binocular vision and articulated instruments could potentially improve lateral access with less disruption of normal sinus anatomy and function, as well as obviate the need for two surgeons. However, studies using current instrumentation have shown only limited application of the technology. Transoral access to the parapharyngeal and retropharyngeal spaces developed from a better understanding of transoral anatomy via radical tonsillectomy. The technique was first described by

O'Malley et al., and several other groups have reported success with minimal complications [20–24]. Caution against this approach if the tumor is too large for en bloc resection, if there is inadequate oral exposure or cervical mobility, or if there is major vascular involvement. Resection of an isolated metastatic retropharyngeal node has also been reported for papillary thyroid cancer [24]. Although little has been published on the subject, TORS may prove to be useful in resecting post-treatment retropharyngeal nodes as an alternative to the traditional transcervical approach.

Robotic anterior and middle skull base approaches are still under investigation. A cadaver feasibility study by Ozer et al., using transnasal, transoral, and transpalatal camera positioning in combination with transoral, transpalatal, and transcervical instrument ports yielded variable access to portions of the skull base and clivus. A traditional endoscopic endonasal approach was needed to remove the posterior bony septum to allow introduction of the robotic camera transnasally. For the transpalatal approach, a bipedicled posteriorly-based flap was raised prior to resection of the hard palate and vomer for access. The study concluded that the transpalatal approach provided the best access to the anterior skull base, nasopharynx, and clivus [25••]. Transcervical port placement may allow increased mobility of the robotic arms [25••, 26]. Approaches to the nasopharynx have had similar limitations. However, robot-assisted transnasal endoscopic resection of small, recurrent, post chemoradiation nasopharyngeal carcinomas have recently been reported by Tsang et al. In one case the robot was used to completely resect the recurrence; when bony involvement of the sphenoid was noted in another case, traditional transnasal endoscopic surgery was used for the superior mucosal and bony cuts. Sagittal division of the soft palate and separation from the hard palate was necessary in both cases [27, 28]. Technological advances may expand the use of robotic surgery for the skull base as instruments become smaller, but tactile feedback is needed before more complex procedures can be undertaken. Furthermore, because these procedures generally involve two teams, the benefit of the new techniques will need to be proven to our neurosurgical colleagues.

Transcervical Approaches

Transaxillary robotic thyroidectomy was performed by endocrine surgeons and head and neck surgeons after its FDA approval in 2000, but this approval was subsequently revoked in 2011. Although many still practice the technique, it will not be discussed in this chapter.

The success of transaxillary thyroidectomy in avoiding a cervical incision has, however, sparked interest in other "cosmetic" approaches to the central and lateral neck. The facelift incision popularized by Terris for parotidectomy is one such incision that is cosmetically well-hidden and lies within the region of interest [29]. Over the past two years, Terris and colleagues have developed robotic facelift thyroidectomy (RFT) from a preclinical cadaveric study to a series of eighteen patients with no complications [30]. The same group then did a comparative retrospective study of hemithyroidectomy via transaxillary robotic technique in five patients versus ten undergoing RFT; operative time was shorter for RFT, and patients in the RFT group were all managed as outpatients, while to the transaxillary group was made inpatient. All but one patient avoided a surgical drain in the RFT group, while all patients who had transaxillary hemithyroidectomy had drains [31].

Byeon and colleagues from Yonsei University have expanded the postauricular approach to the lateral neck, first proposing a combined transaxillary and retroauricular (TARA) approach for neck dissection in a series of seven patients with oral or laryngeal cancer [32]. This approach was also used to perform total thyroidectomy with selective neck dissection and a Sistrunk procedure in a 22 year old woman with synchronous thyroid carcinoma of the thyroglossal duct cyst and thyroid gland [33]. After performing several neck dissections, the surgeons noted that the transaxillary approach was not needed for supraomohyoid neck dissection, and subsequently reported a comparison of facelift approach robotic neck dissection versus standard supraomohyoid neck dissection. Surgical time was significantly longer in the robotic group (157 vs. 78 min), but postoperative drainage, hospital stay, complications and number of lymph nodes were comparable, and subjective scar satisfaction was higher in the robotic group [34]. The group has also reported success in seven patients treated with level II–V neck dissection through the modified facelift incision; three patients required only the retroauricular limb, and average nodal yield was 25.1. Complications in this study were minimal; three patients reported transient ear lobe numbness, and had a postoperative chyle leak that resolved with conservative nonoperative treatment. The surgeons recommend harmonic shears or clip application to control major vessels in this approach [35] .

The use of remote incisions for thyroidectomy and neck dissection is likely to spark some debate over its oncologic benefit and cost-effectiveness. The studies have demonstrated short-time oncologic completeness, but long-term follow up will determine whether these procedures are sound. Additionally, surgical times for the new approaches are significantly longer than traditional thyroidectomy and neck dissection via a direct approach. The surgical learning curve will need to be assessed to determine the ultimate impact on operative time and cost.

Technology

A widespread criticism of the currently available robotic systems for the head and neck applications has been the large camera and robotic instrument size. This is not surprising, since the Da Vinci System was designed for thoracoscopic and laproscopic surgeries. However, several groups, including Schneider et al. at [36] Vanderbilt University Medical Center, have worked to miniaturize robotic technology so that it is better suited for robotic skull base surgery with smaller instrumentation and image guidance, and have even shown feasibility for pituitary tumor removal in a cadaver model. The line-of-sight limitations associated with rigid endoscopy may eventually be overcome using flexible robotic technologies. Recently, Rivera-Serrano and colleagues have demonstrated a flexible robotic technology well-suited for endolaryngeal work. Preliminary cadaveric studies have demonstrated excellent access to the larynx, even without suspension, with an improvement in visualization compared to traditional line-of-sight surgery [37]. Olds et al., have also reported the development of a robotic system that may allow improved access to the larynx, the Robotic Endolaryngeal Flexible Scope (Robo-ELF). In cadaveric studies, visualization was superior to rigid endoscopy, and the robot provided steady visual field and the potential for bimanual operation [38].

In the field of neurotology, there is considerable interest in developing robotic technology for precision work. At Vanderbilt University, Kratchman and colleagues have reported the development of a robotic system that allows percutaneous placement of a cochlear implant in a cadaveric model with an accuracy of 0.4 mm using a microstereotactic skull-anchored frame that is fabricated according to the preoperative plan [39]. The same group has also reported on the use of an image-guided robot for performing mastoidectomy [40]. Bell and colleagues have developed a robotic system for percutaneous cochlear implantation based on a table-mounted robotic arm, an image-guidance system, and head immobilization. This system provides similar accuracy without the need for frame fabrication in cadaver models [41].

New instruments are also under development to expand the use of robotics in head and neck surgery. A new CO2 laser wave guide has been developed by Lumenis and has shown promise for head and neck applications [42].

Conclusion

There have been many advances in robotic head and neck surgery as surgeons have become more adept with robotic thyroidectomy and TORS. Cosmetic approaches to traditional head and neck surgery may become more commonplace with robotic assistance, and new robotic technologies may increase the applicability of robotic surgery to the skull base and glottis.

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