Transoral robotic surgery: does the ends justify the means?
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Introduction
In recent years, robotic surgery has increased in popularity in various surgical specialties, including cardiac surgery, urology, general surgery, and gynecology [1–4]. Nonetheless, recent media coverage has led some skeptical physicians to question whether the benefits of robotic surgery outweigh the potential negatives. The high initial cost of the robotic system (over a million dollars) and cost of instruments have also led to skepticism about robotic surgery in general. Specific concerns that have been expressed about transoral robotic surgery (TORS) include the issues such as feasibility of TORS; safety and efficacy; ‘teachability’ of complex new techniques; and competition with the recent trend of nonsurgical treatment for equivalent cancers. In the following article, we will discuss the various controversies and limitations described in the literature by reviewing the current clinical experience with TORS at various institutions.

Background
For the reader who may not be familiar with the term ‘robotic surgery’, it is performed utilizing the da Vinci surgical system. The surgeon sits at the console and controls micromanipulators, which in turn are connected to a robotic cart at the patient’s bedside. In TORS, three arms are used. The central arm has a double-video endoscope with high-quality video that gives the surgeon a three-dimensional view of the operative field via the console. The other two arms carry interchangeable instruments (approximately 5 mm wide and 2 feet long) with miniaturized tools on the end that mimic standard surgical instruments (i.e. electrocautery, pickups, etc.). The tips of the double-video endoscope and the instrument arms are ‘wristed’, so when surgeons move their wrist and hands at the console, the entire motion is scaled down to the miniaturized ‘robotic’ instruments, with benefits such as tremor filtration (Fig. 2a and b). Traditional nonrobotic transoral surgery can at times be surgically awkward secondary to (1) the instruments, which are long and of limited functionality; (2) the microscopic optics, which are outside the oral cavity; or (3) the laser, which is a line of sight beam far from the lesion. In contradistinction, the robotic optics are in the oral cavity and the miniaturized
surgical instruments move exactly as the surgeons’ hands, making the experience more like an actual open surgical experience.

The concept and development of TORS using the da Vinci surgical robot (Intuitive Surgical, Sunnyvale, California, USA) was first successfully studied at the University of Pennsylvania through a series of technical and feasibility trials. Initial studies included preclinical experiments involving manikin and cadaveric models in which it was proven that the optimal way to perform TORS was to work through mouth gags rather than through traditional laryngoscopes [5,6]. Additional cadaver and canine studies [7,8] showed feasibility for multiple pharyngolaryngeal sites. This work laid the foundation for the first application of TORS in human patients in which three base of tongue neoplasms and supraglottis were successfully extirpated in an institutional review board (IRB)-approved human clinical trial [9,10]. The present number of TORS cases that have been performed at the University of Pennsylvania exceeds 225 cases.

Although the group at the University of Pennsylvania had the first IRB-approved study of TORS in the world, which started accruing patients in May 2005, it was the...
contention of O’Malley and Weinstein that ‘teachability’ was a critical factor in success of the program. Working together with Intuitive Surgical Inc, in October 2006, a research training seminar was held for 12 surgeons from around the United States to share concepts, research approaches and proctor a day-long cadaver training session. This model for training proved to be a great success, indicating the ‘teachability’ of these techniques, and since then surgical teams trained by Weinstein and O’Malley have developed TORS programs with much success, demonstrating its potential niche for TORS in head and neck surgery [11–13].

Feasibility

Some critics of robotic surgery have cited access and bulky robotic instruments as main limitations to TORS [14]. However, from our experience at the University of Pennsylvania, access to almost any oropharynx lesion and many supraglottic and hypopharyngeal lesions is not an issue if appropriate triage is utilized in the form of a separate preoperative endoscopy performed at a time prior to the day of TORS. In a series of 27 patients with T1–T3 tonsil cancer, surgical access was achieved in all patients using either the Crow–Davis or FK retractors (Gyrus ENT, LLC, Bartlett, Tennessee, USA). All robotic arms functioned optimally using 5 mm, and less commonly, 8 mm instruments, with no interference noted between the robotic arms [15]. Other groups have had similar experience using the Crow–Davis, FK, and Dingman retractors (Gyrus ENT, LLC) [16]. In another pilot study of 31 patients aimed at assessing the indications and limitations associated with TORS [17], five (16%) were ultimately terminated and deemed inaccessible via this approach. Reasons for restricted access in this series of patients with benign and malignant lesions of the upper aerodigestive tract included retrusive mandible (two), the inability to effectively retract peripheral soft tissue (one), and the inability to access the lesion because of the bulky nature of the robotic arms [17]. In a similar study aimed at assessing surgical exposure during TORS [13], 17 of 23 (73.9%) patients had successful tumor removal via a robotic approach. Of six patients who were ultimately terminated via a TORS approach, four were found to have inadequate exposure and two were found to have tumors too large for robotic-assisted resection [13]. However, it is unclear whether these other feasibility studies evaluated patients preoperatively under general anesthesia to assess for transoral exposure, which could have potentially reduced the number of cases that were intraoperatively terminated. It is clear, however, that, in the University of Pennsylvania series, the judicious utilization of preoperative panendoscopy was a very accurate way to triage patients to TORS or to other treatment options when access was considered a problem as, in the first 150 cases, only three were terminated because of inability to gain adequate access to perform TORS [18].

Total operative time and operating room setup time have also been cited as potentially limiting routine use of the da Vinci robot [14]. In our experience, as well as that of others, total operative time (including set-up) seems to fall with increased experience [9,10,15]. This trend seems to parallel those from other robotic surgical sub-specialties [4]. In a series of 150 patients with lesions in...
the oral cavity or laryngopharynx, an average additional setup time needed to achieve exposure and robotic positioning for TORS was just an additional 4 min when compared with exposure time for standard transoral resection [18].

Safety and efficacy

In general, there has been limited controversy in the literature over the encouraging operative outcomes for TORS with respect to estimated blood loss (EBL), hospital length of stay, and postoperative complication rates. EBL has been found to be very low (<200) in the majority of TORS patients with no series to date reporting requirement of blood transfusion [13,15**,16]. In comparison, open approaches have a much higher risk of requiring blood transfusions as well as an overall higher average EBL.

Although hospital length of stay has largely been institution-dependent, it appears that the overall stay, regardless of surgeon preference, has been shorter for TORS patients than for those who would have otherwise undergone an open approach. In one series by Moore et al. [12], all 35 patients with oropharyngeal squamous cell carcinoma were discharged from the hospital within 6 days. In another study by Boudreaux et al. [13], mean hospital stay was just 2.7 days. Our experience has been similar, with most patients staying between 5 and 7 days [9].

Another issue is the potential for postoperative complications. In a series of 27 tonsil cancer patients with surgery done by TORS, five of 27 (19%) developed minor complications that mostly resolved without significant sequelae [15**]. These included delirium tremens from alcohol withdrawal, transoral bleeding that was fixed by cautery for minor mucosal bleeding, exacerbation of sleep apnea from postoperative swelling, development of moderate trismus, and occurrence of temporary hypernasality of voice in one patient. Similar studies of 23, 35, and 31 patients, respectively, revealed no immediate complications [12,13,17]. None of the studies reported acute sequelae, which have been reported in the alternative treatments, such as death, pneumonia, or fistula or all of them [19,20]. Furthermore, the complication rate for primary chemoradiation has been cited as high as 80% and often times with synergistic toxicity [20].

Teachability

Surgeon and ancillary staff trainability is an important concern in creating or sustaining a TORS program at any institution. Although no proper set of guidelines has been set forth, it is encouraging to see that the majority of the surgeons of the original group (12 surgeons) who originally attended a training session by Drs Weinstein and O’Malley at the Intuitive Surgical Six Robot Training Center in Sunnyvale, California, went on to start successful TORS programs at their respective institutions. Furthermore, robotic surgical fellowships and training sessions have been developed in other surgical fields and show a feasible learning curve for resident training, which hints at its potential in head and neck surgery [21].

Functional outcomes

Functional outcomes have largely remained one of the most important factors in determining therapy as this has such a major impact on quality of life. Although long-term studies are not yet available for TORS, preliminary outcomes have been extremely encouraging.

It is the authors’ opinion that a reasonable surrogate for swallowing function, which allows comparison between studies of various modalities that report this outcome, is gastrostomy-tube dependence. In our series, 26 of 27 patients (96%) were swallowing without the use of a gastrostomy tube at last follow-up [15**]. In another series by Boudreaux et al. [13], of 23 patients, three were gastrostomy-tube-dependent (however, one patient was already dependent preoperatively). Genden et al. [16] did not use preoperative gastrostomy tubes in one series and began feeding pureed diet on postoperative day 1, provided that the patient was evaluated by a speech therapy team preoperatively and postoperatively and the patient showed no evidence of aspiration. Other groups have found similar results, with all 35 patients in one series tolerating an oral diet within 2 weeks of the procedure [12]. The use of a gastrostomy tube to ensure proper nutrition has largely remained surgeon and institution preference and long-term comparison studies are warranted. Regardless, the encouraging swallowing function afforded by TORS may ultimately show an advantage when compared with the alternative of primary chemoradiation for head and neck cancer, which has shown a gastrostomy-tube dependence, in one literature review, in 17–30% of patients followed up for 1 year [22].

Nguyen et al. [22] had then focused on an often
overlooked problem in the literature – the significant risk of long-term swallowing dysfunction after chemoradiation for head and neck cancer. It is reports such as this that provide an important rationale for utilizing TORS, in particular for oropharyngeal carcinomas.

**Oncologic outcomes**

During a lack of conclusive evidence for the benefits of chemoradiation over open or endoscopic primary surgery followed by radiation or chemoradiation, there appears to be a national trend toward increasing use of chemoradiation as a primary modality for oropharyngeal carcinoma [23]. Although, at this time, it is not possible to assess long-term oncologic outcome in patients who underwent TORS, predictions and observations can be made on the basis of current trends and data.

In an important paper by Machtay et al. [20] at the University of Pennsylvania, it was found that negative surgical margins always resulted in local control. Although this group could achieve negative margins in all cases of tongue base carcinomas via an open surgical approach, it was at the cost of significant functional deficits. However, in our TORS radical tonsil series, we could achieve negative margins in all 27 patients with acceptable morbidity. In that series, there was no early local or regional recurrence and only one distant oncologic failure [15**]. Other groups including Moore et al. [12], Boudreaux et al. [13], and Genden et al. [16] all achieved negative surgical margins in their respective experiences as well.

Of interest, the results from a study at the University of Pennsylvania comparing outcomes following TORS on patients with and without human papilloma virus positivity are presently pending. The oncologic and functional results of each group will then be compared with equivalent lesions that have undergone chemoradiation, previously reported in the literature. Indeed, if it is found that the oncologic outcomes are equivalent or superior to those of similar group of chemoradiated patients, then the most important factor for triaging patients to TORS or chemoradiation will be the swallowing outcomes. As this review shows, the early data favor TORS over chemoradiation in terms of swallowing outcomes.

**Cost considerations**

Several skeptics cite cost as a primary limitation to widespread use of the da Vinci surgical robot. The initial cost of approximately 1.5 million dollars, coupled with an approximately $100,000 yearly maintenance fee and $200 per case for disposable instrument, is a significant financial investment [10*]. However, as seen in the robotic surgical literature, the main factor responsible for the higher cost per case occurs when the initial cost of purchasing the robot is factored in [24]. According to their 17 October 2008 filings with the Securities and Exchange Commission (http://investor.intuitivesurgical. com/phoenix.zhtml?c=122359&p=irol-sec), Intuitive Surgical Inc. has installed units in over 1032 academic and community hospital sites worldwide (766 in North America). Furthermore, according to one robotic cost analysis, profitability increases with increased caseload. Therefore, it is in the best interest of hospitals to utilize their purchase to its maximum by encouraging use of the robot by various surgical specialties [25]. It is our opinion that the actual purchase price of the robotic system is somewhat superfluous to the TORS discussion, as the only surgeons who will be formally trained and potentially create programs in TORS will be those at institutions that already have a robot, which was likely purchased for other more high volume uses (i.e. cardiac or prostatectomy), and the addition of TORS cases, as noted above, will only add to the value of the original purchase by a given institution.

**Conclusion**

It does appear that TORS affords potential advantages and benefits over current treatment modalities. Such advantages include better visualization and access to tumors via a minimally invasive, less morbid approach, resulting in better overall functional outcome. The expensive cost of the robot may clearly hinder widespread use; however, the benefits of decreased operative time and decreased length of hospital stay could counteract this cost. A direct cost analysis study comparing different treatment modalities is necessary to draw further conclusions. Although long-term oncologic outcomes are not yet available, current evidence of local regional control is extremely promising. Further studies, including long-term studies, are warranted. However, based on the current literature from numerous institutions, it does appear likely that ultimately the ends will justify the means for TORS.

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G.S.W., B.W.O’M. Jr, and S.C.D. should be regarded as joint first authors.

**References and recommended reading**

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 135–136).


This paper presents the first patients to undergo TORS supraglottic laryngectomy and compares and contrasts the technique with transoral laser supraglottic partial laryngectomy.


