INTRODUCTION

Robotic assisted surgery has revolutionized major specialities in surgery, including head and neck surgery.1–3 The advantages of transoral robotic surgery (TORS) are increasingly recognized, and more tertiary centers are embarking on training programs in TORS, especially in managing oropharyngeal cancer (OPC).4

The enhanced magnification, coupled with the three-dimensional visualization when using the robot, is useful for the surgeon to better appreciate the tissue planes.1–3,5–7 Furthermore, the 360-degree wristed movement of the robotic arm allows an unprecedented ability for the surgeon to “operate around corners,” which is invaluable in surgery in small cavities, such as the oropharynx.

However, despite the increasing utilization of TORS in resecting oropharyngeal tumors, the medial to lateral anatomic area of the oropharynx is not well described. In addition, the utility of contrast-enhanced cross-sectional imaging in assisting surgeons operating in the complex oropharyngeal anatomy is unknown. Therefore, the primary aim of this study was to describe the transoral robotic anatomy of the tonsillar fossa and lateral pharyngeal wall (LPW) and to perform clinical and radiologic correlations so that a systematic training program can be developed. We can use the information acquired to identify key anatomic landmarks during TORS, which may have clinical application in patients with early tonsillar cancer. The clinical relevance of this preclinical study is to ascertain the feasibility of preserving the glossopharyngeal nerve during TORS so that potential improvement in swallowing can be achieved.

MATERIAL AND METHODS

This study was approved by the institutional review board from the University of Pittsburgh Medical Center. Three fresh cadaveric heads were procured for the purpose of this study, and six complete dissections of the tonsillar fossa and LPW...
were performed using the Da Vinci Si system (Intuitive Surgical, Sunnyvale, CA). Anatomic landmarks in the oropharynx were evaluated including the superior constrictor muscle, glossopharyngeal nerve, styloglossus muscle, and carotid artery. Photo documentations were performed for each phase of the dissection and were used for correlation purposes.

Using the information acquired from these cadaveric dissections, two consecutive patients with T1 human papillomavirus (HPV)–positive squamous cell carcinoma (SCC) of the tonsil were managed using TORS, and feasibility of preserving the glossopharyngeal nerve was ascertained.

**Patient Information**

Using the anatomic information acquired from these cadaveric dissections, two consecutive patients with T1 HPV-positive SCC of the tonsil were managed using TORS of the tonsillar tumor, and correlations of these anatomic features were achieved.

Both patients presented with cervical lymphadenopathy, which was proven to be SCC on fine-needle biopsy. Further physical exam and biopsy confirmed HPV-positive T1 primary tonsillar SCC. Both patients underwent TORS radical tonsillectomy with concurrent neck dissection with no complications.

**TORS Setup**

The setup of the TORS dissection has been previously described.\(^3\) Briefly, the oral cavity was suspended using the Dingman mouth gag. The tongue was retracted with a suspensory stitch tagged in the midline. Once complete visualization of the tonsillar fossa, LPW, and tongue base was achieved, the Da Vinci robot was brought into the surgical field. The upturned 30-degree angled endoscope was placed in the midline, and the two working robotic arms were placed approximately 30 to 45 degrees from the endoscope. These dissections were performed in the exact clinical setting for both the cadaveric and clinical dissections.

**Radiologic Landmark Analysis**

For radiographic landmark analysis, we selected 25 consecutive patients who underwent preoperative stereotactic computed tomography (CT) of the head and neck for a variety of endoscopic skull base procedures. No prior surgical intervention had been performed on these patients, and no pathologic abnormalities were present in the oropharynx or adjacent soft tissues in the vicinity of our analysis. All CT imaging was performed on a 64-slice helical scanner (LightSpeed VCT; GE Healthcare, Milwaukee, WI). Images were obtained helically from the vertex through the upper cervical spine; the lower limit of the imaged field of view was variable according to the planned surgery. Intravenous contrast (Omnipaque 370, GE Healthcare, Piscataway, NJ) was administered using a split bolus technique via an 18- or 20-gauge tube as follows: 60 mL of contrast was administered at a rate of 3 mL/s. After 6 minutes, another 60 mL of contrast was administered at a rate of 3 mL/s. Contrast-enhanced images were then acquired 6 minutes and 25 seconds after the first contrast bolus and 25 seconds after the second contrast bolus using the following parameters: 1.25-mm thickness, 120 kV, 225 to 280 mA, 0.8 seconds per rotation, and pitch 0.53.

Axial images were displayed in 1.25-mm thickness in soft-tissue and bone algorithms. CT source images were reformatted in the sagittal and coronal planes in soft-tissue and bone algorithm using a 2-mm slice thickness.

Digital images were reviewed using the Stentor picture archiving and communications systems (Clinical IT - iSite PACS; Philips Healthcare, Royal Philips Electronics, Amsterdam, The Netherlands).

The shortest distance between the following structures was measured: 1) lateral oropharyngeal wall (corresponding to the gas-soft tissue interface along the medial margin of the faucial tonsil) to the external carotid artery (ECA) and the internal carotid artery (ICA) at the level of the C2-3 interspace (Fig. 1.); 2) the tip of the greater cornu of the hyoid bone to the ICA and to the ECA (Fig. 2.). These measurements were performed by (R.C.) and verified by our radiologist (T.R.), a CAQ-certified neuroradiologist with more than 5 years of dedicated neuroradiology experience.

**RESULTS**

All the oropharyngeal anatomic landmarks (superior constrictor muscle, IX nerve, styloglossus muscle, and...
ECA) were identified in our six cadaveric dissections. The relationship of these structures is summarized below.

**Superior Constrictor and IX Nerve**

**Cadaveric dissection.** A routine tonsillectomy was first performed by carefully dissecting the tonsil from the superior constrictor musculature. The constrictor muscle was then incised (as performed for a radical tonsillectomy) and reflected medially (Fig. 3.). The glossopharyngeal nerve was consistently identified deep to the superior constrictor and traced inferomedially toward the base of tongue. A consistent landmark for the main trunk of IX nerve was identified at the intersection of the posterior tonsillar pillar with the base of tongue (Fig. 3). At this junction, the main trunk of IX was seen before dividing into several smaller branches, which will innervate the LPW and the lateral portion of the tongue base (Fig. 4).

**TORS radical tonsillectomy.** In the TORS radical tonsillectomy, superior constrictor serves as an oncologic envelope for the tumor dissection. These features are better appreciated with the robotic system as it gives enhanced magnification with three-dimensional perception. Using the relationship of IX nerve and the superior constrictor derived from our transoral robotic dissection, a deliberate attempt was made to identify the IX nerve during TORS radical tonsillectomy for both our T1 tonsil cancer patients. In both patients, the main trunk of IX was identified and preserved. However, the terminal branches of IX nerve were oncologically sacrificed as they traverse near the inferior tonsillar pole to supply the medial and posterior pharyngeal wall. The enhanced vision afforded by the robotic system allowed the surgeon to trace the IX nerve and preserve the branches supplying the LPW, which may potentially improve postoperative swallowing function.

**Styloglossus Muscle as the Deep Plane of Dissection**

**Cadaveric dissection.** The styloglossus muscle formed the plane lateral to the ECA. It blended with the tongue musculature from its origin from the styloid process in an inferomedial plane. In a radical tonsillectomy, the styloglossus was identified inferomedially once the superior constrictor was removed en bloc with the tonsil. The plane of the styloglossus marked the deep plane of the dissection in this instance.

When the muscle is transected at its origin and reflected, the lingual, facial, and ascending pharyngeal branches of the ECA are identified. The distance from these ECA branches is approximately 5- to 8-mm deep to the styloglossus muscle. Medial to these branches are the branches from the pharyngeal venous plexus. Therefore, when performing a radical tonsillectomy, the surgeon should be acutely aware that branches of ECA are in close proximity at the level of the styloglossus during the dissection in the inferomedial plane. Furthermore, if dissection needs to be performed more medially, branches of the pharyngeal venous plexus will need to be preemptively addressed to prevent troublesome intraoperative bleeding.

**TORS dissection.** In both patients, the styloglossus muscle was preserved without compromising oncologic safety. The carotid pulsation was visualized prominently with the magnification afforded by the robotic system. However, when the tumor extends inferomedially toward the styloglossus, care must be taken to avoid injuring the ECA and its branches, especially when the styloglossus is sacrificed for oncologic margin. In this instance, a local or free tissue flap closure will be required to protect the major vascular structures.8,9 Ligation of these terminal branches of the lingual, ascending pharyngeal, and facial arteries can be performed transorally using surgical clips (Covidien, Mansfield, MA). However, we recommend additional ligatures on these terminal branches of the ECA in the neck during the neck dissection procedure for added vascular control if concurrent neck dissection is performed. The venous plexus bleeding can be safely controlled with monopolar or bipolar cautery.

**Clinical Outcome**

Both patients underwent TORS radical tonsillectomy successfully, and negative margins were obtained. The estimated blood loss was minimal. They were discharged uneventfully 2 days following surgery and were disease free and doing well on their last follow-up (4 and 6 months).
Radiologic Analysis

 Measurements were obtained from the LPW to the ECA in 23 patients and from the LPW to the ICA in 25 patients, each at the level of the C2-3 interspace. The mean measurements for left LPW to ECA and right LPW to ECA were 17.6 $\pm$ 0.8 mm and 18.4 $\pm$ 0.8 mm, respectively. Mean measurements for left LPW to ICA and right LPW to ICA were 22.0 $\pm$ 1.1 mm and 20.5 $\pm$ 1.3 mm, respectively.

 Similarly, measurements were obtained from the hyoid to ECA in 15 patients and hyoid to ICA in 21 patients. Accrual of these measurements was not possible in all patients, as CT of the neck did not include the hyoid bone in some of these patients.

 The mean measurements for left hyoid-ECA and right hyoid-ECA were 3.4 mm $\pm$ 0.8 mm and 4.3 $\pm$ 0.6 mm, respectively. Mean measurements for left hyoid-ICA and right hyoid-ICA were 7.3 mm $\pm$ 1.2 mm and 5.7 $\pm$ 0.7 mm, respectively.

 These findings showed a fair consistency in the relationship of the ECA/ICA with the two bony landmarks in the neck in this cohort of patients. For the purpose of TORS of the oropharynx, the C2-3 interspace represents a reliable bony landmark to evaluate the relationship of the ECA/ICA with the LPW. Similarly, when resecting a tongue-base tumor toward the vallecula/hyoid, one should be aware of the close proximity of the ECA/ICA in the inferolateral aspect when the greater horn of the hyoid is visualized.

 DISCUSSION

 The use of TORS in head and neck surgery is approved by the U.S. Food and Drug Administration in the management of early OPC. The benefits of using TORS include enhanced magnification, three-dimensional visual perception, and increased freedom of wristed movements. These features greatly enhance the surgeon’s ability to resect tumor in small-cavity areas such as the oropharynx.

 Although TORS has been used increasingly in early OPC, the detailed transoral anatomic areas of the tonsillar fossa and LPW have not been well described. Therefore, this preclinical cadaveric dissection serves to address this gap of knowledge and highlight key anatomic landmarks that will help shorten the learning curve as well as allow safe dissection in patients with minimal morbidity. Furthermore, the feasibility of preserving the glossopharyngeal nerve during TORS is addressed in this preclinical study.

 To that end, we have identified several key features to allow for safe dissection without unnecessary morbidity. First, the superior constrictor musculature serves as the lateral most plane of radical tonsillectomy as well as a landmark to identify the main trunk of IX nerve at the intersection of the superior constrictor with the tongue base. In early T1 tonsil cancer, this plane is usually not breached by cancer. Furthermore, the main trunk of IX can be identified deep to this plane and can be traced inferiorly. Preservation of the terminal branches of IX to the LPW can be accomplished without compromising oncologic principle. This is made possible using the robotic system because it gives a magnified three-dimensional view of the local anatomy that is not possible using a standard transoral approach. With preservation of these terminal branches of IX nerve to the LPW, sensory function may be better preserved, which may potentially improve postoperative swallowing function. Further studies are necessary to evaluate and validate this hypothesis.

 Second, we have identified the styloglossus muscle as the plane medial to the ECA and its branches. This plane is rarely breached in early tonsil cancer, and dissection superficial to this plane should not result in arterial injury to the branches of ECA. However, if the styloglossus muscle is sacrificed for oncologic reasons, vascular control of the branches of the ECA can be controlled transorally using the robotic system by using surgical clips. In this situation, we also advocate ligation of the branches of the ECA in the neck during the neck dissection for additional vascular control. In addition, a local or free flap closure of the lateral pharyngeal defect becomes necessary to seal the pharyngeal defect from the neck. This can be accomplished, either via a rotational muscular flap transcervically or transorally with a free fasciomuscular flap using the robotic system.8,9

 The pharyngeal venous plexus will be encountered at the inferior tonsillar pole during the radical tonsillectomy as one carries the dissection medially. This venous plexus should be meticulously coagulated when dissecting the tumor off the inferior aspect during radical tonsillectomy so that troublesome postoperative bleeding may be prevented.

 Establishing consistent anatomic relationships of the LPW to the carotid artery system is essential for preoperative planning and avoidance of these critical structures intraoperatively. The use of the C2-3 interspace and the hyoid bone was chosen based on their reliable, easily identifiable locations in a CT scan of the neck. After measurements were averaged in 23 patients, we determined that the ECA runs approximately 1.8 cm from the LPW, and the ICA lies about 2.1 cm from the LPW at the level of the C2-3 interspace on both sides. At the level of the hyoid (C6), both the ECA and ICA lie within 5 mm of the greater horn, which is consistent because C6 demarcates the level where the common carotid artery divides into the ECA and ICA. It highlights the point at which inferolateral pharyngeal wall dissection at that level needs to be performed with care to avoid injuring the carotid artery. Overall, in both the anatomic dissections and radiologic measurements, the C2-3 interspace presents a practical level to evaluate the relations of the LPW to the carotid system, with the ECA most commonly encountered before the ICA. Any variability to the standard 1.8-cm distance of the ECA to the LPW because of tumor effect should be noted before surgery. Hence, we propose standardized preoperative arterial-phase imaging extending through the carotid bifurcation to demonstrate the distance of the ECA and ICA to the LPW and
to identify any anatomic variations in the relationship of LPW or hyoid bone with the carotid system in patients undergoing TORS radical tonsillectomy. Split bolus contrast administration (as was performed in this retrospective study) may be helpful to delineate the margins of the primary OPC to the arterial vasculature but requires further study in patients with known oropharyngeal malignancies.

CONCLUSION

From this TORS dissection in a cadaveric model, we have shown that a systematic approach to dissect the tonsillar fossa and LPW can be performed. In patients with early T1 tonsil cancer, the main trunk of IX nerve can be safely preserved without compromising oncologic principle. Furthermore, the ECA is not encountered because it lies deep to the plane of the styloglossus muscle. CT measurements taken at the C2-3 interspace and greater horn of hyoid bone (C6 level) to the ECA are consistently and reliably achieved. The clinical utility of contrast-enhanced CT needs to be prospectively addressed.

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BIBLIOGRAPHY