Anatomic Considerations in Transoral Robotic Surgery

Bharat B. Yarlagadda and Gregory A. Grillone

Introduction

Classic approaches to the head and neck are well described in the surgical literature. These "external" or "open" approaches correspond to traditional anatomic dissections and are thus very familiar to head and neck surgeons. In contrast, the anatomy of the larynx and pharynx from a transoral robotic (TORS) standpoint must be approached from an "inside-out" perspective. Thorough knowledge of this anatomic perspective is necessary for achieving appropriate oncologic resection as well as avoiding potentially catastrophic complications.

The transoral approach to the pharynx and larynx has been described in the past, especially in the setting of transoral laser microsurgery (TLM). Wolfgang Steiner and colleagues have described several such approaches and procedures [1]. Although laryngoscopic exposure is considerably different than that achieved with the TORS approach, many of the anatomic details and considerations overlap.

Anatomic considerations of the TORS approach can be viewed from a perspective of (1) myofascial layers of the surgical field and (2) neurovascular structures that traverse the field. Given the confined space of dissection, three-dimensional understanding is critical. In addition, familiarity with this anatomic region of the head and neck from a trans-cervical standpoint is important for understanding the TORS perspective.

Tonsil and Lateral Pharyngeal Wall

The oropharynx is that portion of the pharynx extending from the level of the soft palate to the level of the epiglottis. Subsites of the oropharynx include the soft palate, base of tongue, posterior pharyngeal wall, and the lateral pharyngeal wall including the palatine tonsils. Stratified squamous epithelium comprises the surface of this portion of the pharynx, including the lining of the crypts within the lymphoid tissue of the base of tongue and palatine tonsils. This architecture is postulated to allow access to human papillomavirus, which is known to mediate the development of squamous cell carcinoma [2]. Given the interest and ability to treat such neoplasm with surgery, this anatomic area is of particular interest to the TORS surgeon.

The anatomy of the tonsil is well known to head and neck surgeons (Fig. 1). The squamous

B.B. Yarlagadda
Department of Otolaryngology—Head and Neck Surgery, Boston University School of Medicine, Boston, MA, USA
e-mail: yarlagb@gmail.com

G.A. Grillone (✉)
Department of Otolaryngology—Head and Neck Surgery, Boston University School of Medicine, Boston Medical Center, 820, Harrison Ave, FGH Building, 4th Floor, Boston, MA 02118, USA
e-mail: Gregory.Grillone@bmc.org

G.A. Grillone and S. Jalisi (eds.), *Robotic Surgery of the Head and Neck: A Comprehensive Guide*,
DOI 10.1007/978-1-4939-1547-7_2, © Springer Science+Business Media New York 2015

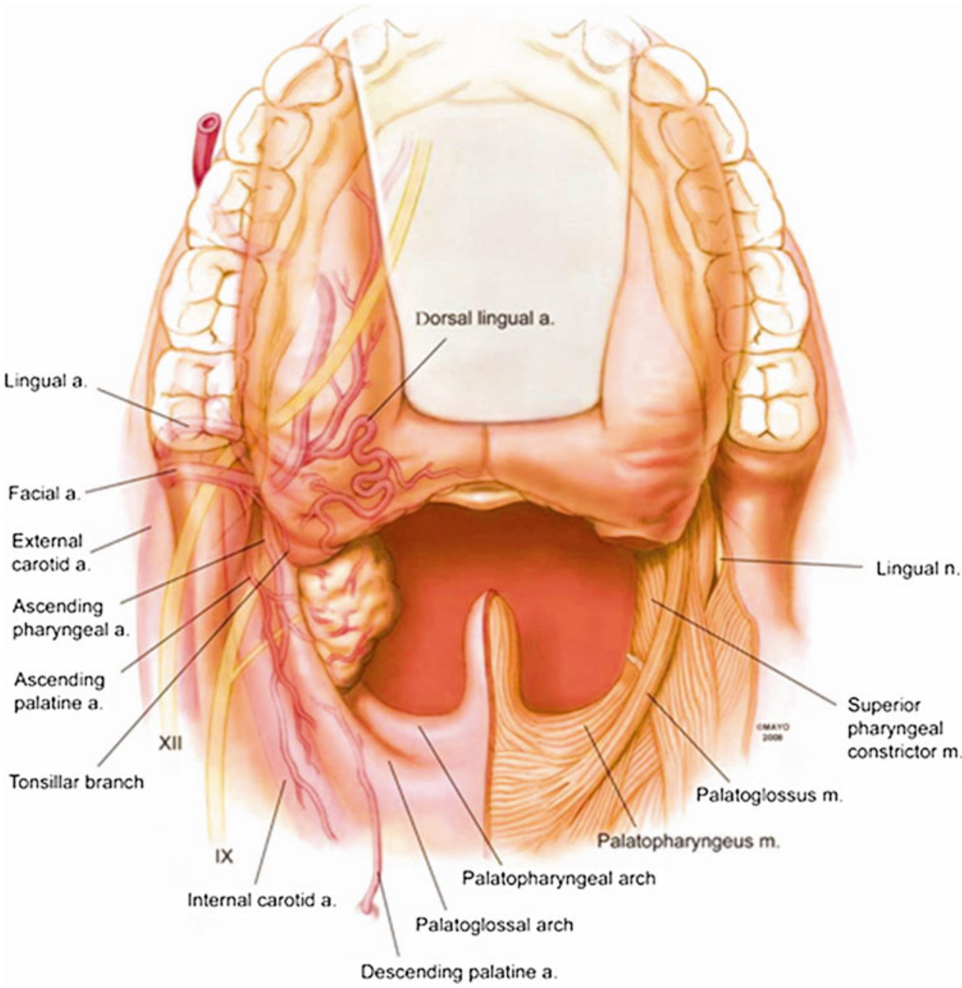

Fig. 1 A transoral view of the oropharynx demonstrating the arrangement of the superficial muscles of the lateral oropharyngeal wall and tonsillar fossa as it would appear with a surgical retractor in place. The vascular and neural supply to this region is outlined. From Moore, EJ, et al. Transoral robotic surgery of the oropharynx: Clinical and anatomic considerations. Clinical Anatomy, 2012. Reprinted with permission [11]

epithelium lined lymphoid tissue sits in the tonsil fossa, which is bordered anteriorly by the palatoglossus and posteriorly by the palatopharyngeus. The lateral border of the tonsil is bounded by fascial layers comprising the tonsillar capsule and the medial border of the peri-tonsillar space. Just deep to this lies the pharyngobasilar fascia. This layer of fascia, attached superiorly to the occipital and temporal bones, which is thickened at the level of the tonsil fossa, thins and disappears as it traverses inferiorly and is attached anteriorly to the pterygomandibular raphe [3]. Lateral to this is the superior pharyngeal constrictor muscle, which, along with the overlying pharyngobasilar fascia, forms the bed of the tonsillar fossa. Inferiorly, the muscular bed may be formed by the middle constrictor muscle overlapping the superior constrictor. In instances where a large gap exists between these constrictors, portions of the stylopharyngeus will then form the bed [4]. These muscles, as will be discussed, are critical landmarks for TORS pharyngeal surgery. On the deep, or lateral, surface of the superior constrictor muscle is the buccopharyngeal fascia.

Finally, access to the parapharyngeal space is achieved through dissection lateral to the bucco-pharyngeal fascia.

The parapharyngeal space is a well-known potential space in the shape of an inverted pyramid extending from the skull base to the greater cornu of the hyoid bone [3, 5]. This space is bounded anteriorly by the pterygomandibular raphe on the lingual surface of the mandibular ramus; laterally by the deep lobe of the parotid, pterygoid muscles, and stylomandibular ligament; medially by the buccopharyngeal fascia; and posteriorly by the retropharyngeal space. The pre- and post-styloid compartments are divided by fascial condensations arising from the stylohyoid ligament, although this boundary varies by author. Pre-styloid contents include the deep lobe of the parotid and fat tissue whereas the post-styloid contents consist of neurovascular structures including the carotid sheath and sympathetic chain. Performance of TORS tonsillectomy does not routinely involve deep dissection of the parapharyngeal space. However, intimate knowledge of this space is a requisite for safe and effective TORS surgery as the internal carotid artery (ICA) and external carotid artery (ECA) branches are encountered, and in addition, displacement or effacement of the parapharyngeal fat is indicative of the extent and resectability of tonsillar tumors.

The stepwise surgical procedure of TORS radical tonsillectomy and the nuances thereof are have been previously described and are discussed elsewhere [6, 7]. However, further consideration of muscular and vascular anatomy can be appreciated in the context of the operation itself. Radical TORS tonsillectomy begins with a vertical incision through the pterygomandibular raphe. Dissection proceeds along the fascia of the medial pterygoid muscle and the surgeon enters the plane between the superior constrictor muscle and the buccopharyngeal fascia. The styloglossus and stylopharyngeus muscles are encountered and represent important anatomic landmarks in the procedure.

The styloglossus muscle arises from the inferior aspect of the styloid process and broadens as it descends, running deep to the medial pterygoid muscle before blending with the fibers of the intrinsic tongue muscles [3]. This muscle is located anterior and lateral to the stylopharyngeus and is encountered first. The stylopharyngeus originates from the medial aspect of the styloid process and courses medial and posterior to the styloglossus [3]. After running between the external and internal carotid arteries, the stylopharyngeus fans out and inserts into the pharynx between the superior and middle pharyngeal constrictors, spreading out between the middle constrictor and the pharyngobasilar fascia (Fig. 2). As noted previously, in instances where there is an anatomic dehiscence between the superior and middle pharyngeal constrictors, the stylopharyngeus will fill the space and form that portion of the tonsil bed. The styloglossus and stylopharyngeus muscles provide a key landmark as a sheath that separates the neurovascular structures of the parapharynx from the surgical bed and lumen of the oropharynx (Fig. 3). The neurovascular structures are lateral and inferior to the plane of the styloglossus, and thus the styloglossus often represents the deep boundary of dissection. Although they are carefully transected during performance of radical tonsillectomy, and in some cases are resected for

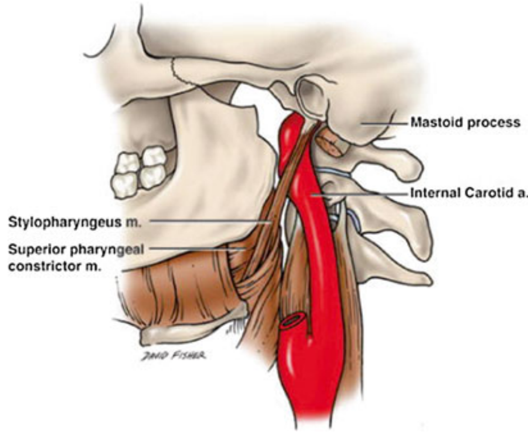

Fig. 2 External view of the musculature of the lateral oropharyngeal area and styloid apparatus. Note the course of the stylopharyngeus muscles as it starts lateral to the internal carotid artery at the level of the styloid, but at its insertion at the level of the oropharynx, lies medial to both the internal and external carotid arteries. From Tubbs RS, et al. Compression of the cervical internal carotid artery by the stylopharyngeus mucle. J Neurosurg. 2010. Reprinted with permission [8]

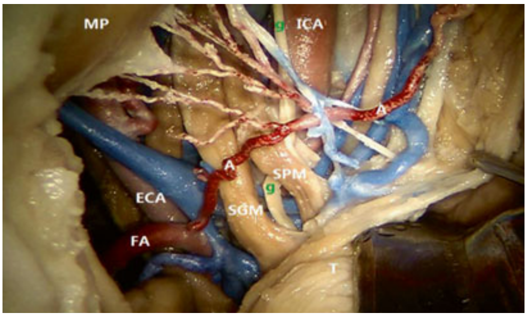

Fig. 3 Transoral view of the parapharyngeal space contents after removal of the superior constrictor muscle in a cadaveric dissection. Note the styloglossus and stylopharyngeus slings protecting the lateral contents including the major cervical vessels. In this anatomic variant, the ascending pharyngeal is seen arising from the facial artery rather than directly from the external carotid artery. *A* ascending pharyngeal artery, *MP* medial pterygoid muscle, *ICA* internal carotid artery, *ECA* external carotid artery, *FA* facial artery, *SGM* styloglossus muscle, *SPM* stylopharyngeus muscle, *g* glossopharyngeal nerve, *T* tongue. From Wang, C, et al. A description of arterial variants in the transoral approach to the parapharyngeal space. Clinical Anatomy. 2014. Reprinted with permission [9]

oncologic purposes, structures medial to these muscles must be respected.

The lingual nerve may be encountered if dissection is continued inferiorly and anteriorly at this location (Fig. 4). This main branch of V3 is joined by the chorda tympani at the level of the posterior border of the medial pterygoid muscle and provides general sensation and taste to the anterior two-thirds of the tongue as well as parasympathetic innervation to the submandibular and sublingual salivary glands. The nerve courses anteriorly and inferiorly between the lingual surface of the mandible and the lateral surface of the medial pterygoid. At the anterior aspect of the medial pterygoid, the lingual nerve runs lateral to the superior constrictor muscle and thus may be near the field of dissection. Dissection of the nerve itself is usually not necessary in routine radical tonsillectomy, buts its location in this region should be noted to avoid injury.

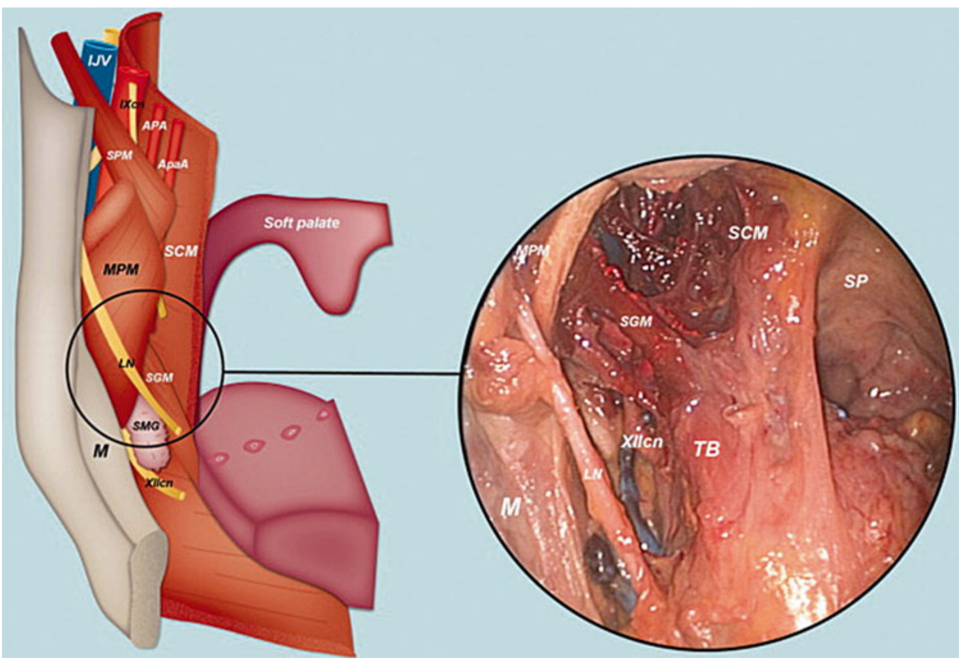

Fig. 4 A schematic drawing and correlating cadaver dissection depicting an anterior–posterior view of the dissected lateral pharyngeal wall. *APA* ascending pharyngeal artery, *ApaA* ascending palatine artery, *IJV* internal jugular vein, *LN* lingual nerve, *M* mandible, *MPM* medial pterygoid muscle, *SCM* superior constrictor muscle, *SGM* styloglossus muscle, *SMG* submandibular gland, *SP* soft palate, *SPM* stylopharyngeus muscle, *TB* tongue base, *IXcn* glossopharyngeus nerve, *XIIcn* hypoglossal nerve. From Dallan, I, et al. Transoral endoscopic anatomy of the parapharyngeal space: A step-by-step logical approach with surgical considerations. Head and Neck. 2010. Reprinted with permission [5]

The second important nervous structure to consider in TORS tonsillectomy is the glossopharyngeal nerve (CN IX). This nerve is responsible for providing sensation in the oropharynx, motor innervation to the stylopharyngeus, and autonomic innervation to the parotid gland and carotid body. After exiting the skull base via the jugular foramen, CN IX runs inferiorly, coursing medial to the styloid process between the stylopharyngeus and styloglossus muscles, laying on the lateral aspect of the stylopharyngues. As it courses toward the middle constrictor muscle, it sends terminal branches to the tonsil and posterior one-third of the tongue. The main trunk of the nerve may be very close to the tonsil fossa especially if there is dehiscence between the middle and superior pharyngeal constrictors. Transection of the lingual and tonsillar branches of CN IX occurs during the course of a TORS extirpation. This, as well as potential damage to the main nerve itself, is likely responsible for postoperative dysgeusia noted in patients undergoing routine tonsillectomy as well as TORS operations [10].

As dissection continues medial to the parapharyngeal fat, the surgeon will encounter and must control the arterial supply to the surgical field. Vascular supply to the tonsil and lateral pharyngeal wall is based on the branches of the ECA [11]. The blood supply to the tonsil includes the ascending palatine and tonsillar branches of the facial artery, the ascending pharyngeal artery, and branches from the lingual artery, ascending palatine artery, and internal maxillary artery. During routine tonsillectomy, these branches are easily controlled with cautery. However, dissection deep to the superior constrictor muscles during radical tonsillectomy encounters blood vessels of a higher caliber that may require ligation with surgical clips to avoid hemorrhage. In addition, several variations and aberrant courses of these vessels will be discussed.

The dominant arterial supply to the tonsil is the tonsillar branch of the facial artery. The facial artery, along with the lingual and ascending pharyngeal arteries, lies approximately 5- to 8-mm deep to the styloglossus muscle [12]. The tonsillar branch has a variable course and can run between, anterior, or posterior to the styloglossus and stylopharyngeus muscles. Application of surgical clips facilitates control of this dominant branch. Another consideration related to the facial artery relates to the main trunk of the vessel. After originating from the ECA in the neck, the artery courses superiorly before turning anteriorly to supply the submandibular gland and face. Tumors with anterior and inferior extension can approximate the artery at either the horizontal portion or the anterior turn, and troublesome bleeding may be encountered [13].

The pharyngeal venous plexus is encountered inferomedially when dissecting lateral to the superior constrictor muscle. These venous branches are encountered medial to the branches of the external carotid artery (ECA) within the space between the stylopharyngeus and the superior constrictor muscle [5, 12]. Terminal drainage of this plexus is to the internal jugular vein. The vessels of this plexus are highly variable in their course and redundancy and can often be controlled readily with monopolar or bipolar electrocautery.

Thus, hemostasis is readily achieved in TORS radical tonsillectomy with knowledge and anticipation and control of the known arterial supply. Further, several maneuvers have been described in order to protect the patient from vascular injury and hemorrhage encountered during TORS radical tonsillectomy. This includes, for example, ligation of the lingual artery or placement of cotton patties medial to the carotid sheath to protect the sheath contents via a cervical approach, prior to the TORS procedure [7, 11]. Whether or not such methods are used, intimate knowledge of the vasculature and anatomic variations is needed to avoid complications. In addition, advanced TORS approaches are currently under investigation including dissection of the parapharyngeal space and infratemporal fossa which require knowledge of vascular aberrations.

The ascending palatine artery contributes to the blood supply of the tonsil and lateral pharyngeal wall. This artery branches from the facial artery and crosses the styloglossus muscle prior to entering the prestyloid parapharyngeal space. In one described variant, the ascending palatine

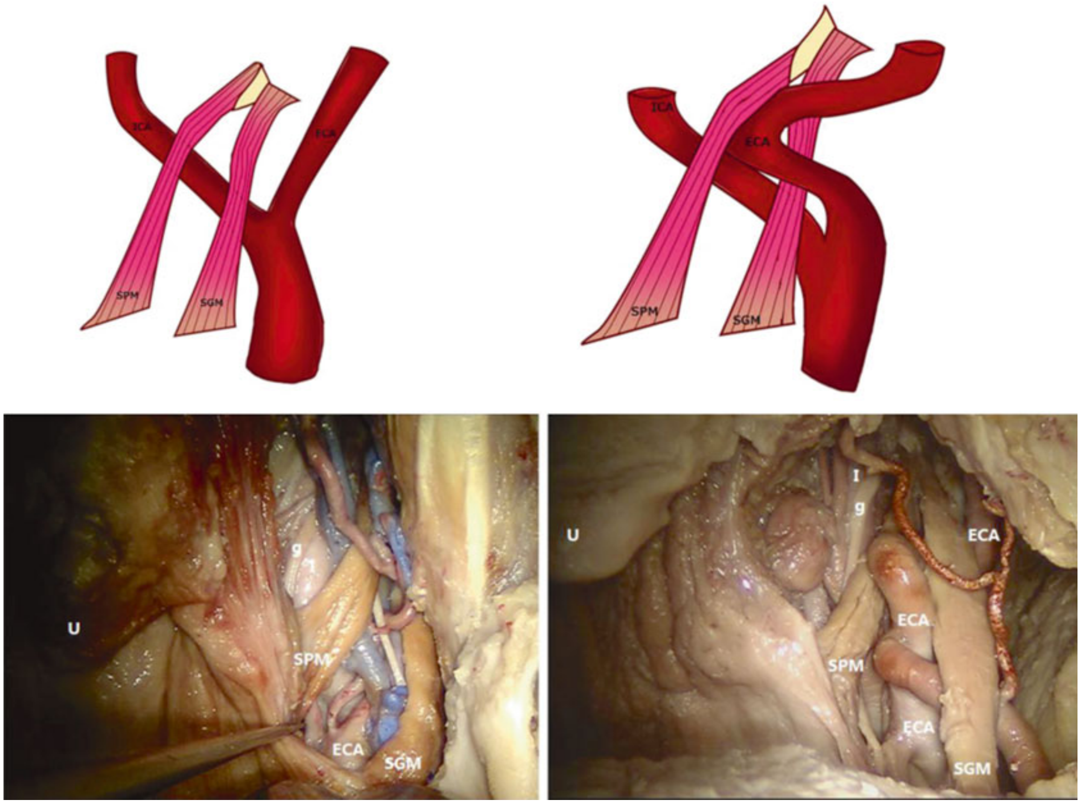

Fig. 5 Depicted in the left column is the normal arrangement of the external carotid artery in relation to the stylopharyngeus and styloglossus muscles. In the right column, the external carotid is coursing medially through a dehiscence between the two muscle bellies. *S* styloid process, *g* glossopharyngeal nerve, *I* internal carotid artery, *ECA* external carotid artery, *SGM* styloglossus muscle, *SPM* stylopharyngeus muscle, *P* medial pterygoid muscle, *U* uvula, *IJV* internal jugular vein, *D* digastric muscle. From Wang, C, et al. A description of arterial variants in the transoral approach to the parapharyngeal space. Clinical Anatomy. 2014. Reprinted with permission [9]

courses between the styloglossus and stylopharyngeus [9]. If encountered, this artery can be controlled with clips or cautery. The ascending pharyngeal artery is a more robust artery providing blood supply to the same region. This originates from the medial surface of the ECA near the carotid bifurcation, but has been known to originate from the ICA or the occipital artery [9]. The artery ascends vertically lateral to the pharyngeal wall towards the skull base. A mean distance of between 5- and 8-mm was noted between the ascending pharyngeal artery, as well as other ECA branches, and the styloglossus muscle [12]. Control of this artery with appropriate clipping from a transoral approach or ligation from a cervical approach is critical.

The ECA has a fairly consistent relationship with the lateral pharyngeal wall. When measured at the C2–C3 vertebral interspace, the ECA lies approximately 1.8 cm lateral to the lateral pharyngeal wall [12]. This distance may of course be altered by the mass effect of tumor and should be noted preoperatively. In cadaveric studies, Wang and colleagues noted the presence of an aberrant ECA in a minority of specimens [9]. In 92 % of cases, the ECA ran deep to and was protected by the styloglossus muscle. Thus, the main trunk of ECA was exposed to injury when dissection proceeded deep to the styloglossus and stylopharyngeus muscle slings. However, in the remaining 8 %, the ECA perforates a dehiscence in the fascial plane between the styloglossus and stylopharyngeus, and thus lies in close relationship to the constrictor musculature (Fig. 5). This creates a situation of potential injury during TORS radical tonsillectomy as well as parapharyngeal space dissection (Fig. 5). In addition, as seen in cadaveric dissection, completion of TORS radical tonsillectomy in a patient with this variation may leave the ECA exposed through the pharyngeal defect and require reconstruction for coverage.

A potentially catastrophic complication of TORS radical tonsillectomy may be ICA injury and this should be avoided at all costs. The cervical ICA normally runs vertically through the neck to the skull base without branching. As one reaches adulthood, the distance between the ICA and the tonsillar fossa approaches 25 mm [14]. Thus, dissection lateral to the constrictor muscle, especially in a blunt manner, can be performed safely under normal circumstances. The styloglossus and styloparyngeus muscles serve as landmarks for the location and therefore protection of the ICA. Although the styloglossus originates lateral to the ICA, it courses medially and, along with the stylopharyngeus, is medial to the ICA at the level of the oropharynx. Thus, transection of these muscles can be performed, if needed, in the presence of a known parapharyngeal fat pad that can be bluntly dissected away to protect the ICA.

However, between 10 and 40 % of the general population may have some aberration of the cervical ICA that alters this course and relation to the oropharynx [15]. Tortuosity, kinking, or coiling of the ICA must be assessed with preoperative imaging. These variants are associated with decreased distance between the ICA and tonsil fossa as well as loss of integrity in the tunica media and adventitia [16]. In addition, the presence of a submucosal or retropharyngeal carotid artery must be ruled out. This is a contraindication to TORS radical tonsillectomy due to a high risk of catastrophic vascular injury.

The remaining steps of TORS radical tonsil resection include a soft palate incision, and floor of mouth and base of tongue resection depending on the extent of the tumor, as well as an incision through the superior constrictor muscle and overlying mucosa posteriorly. At the completion of the procedure, the wound bed is comprised of the buccopharyngeal fascia and the styloglossus and stylopharyngeus muscles. Thus, care is taken to preserve the buccopharyngeal fascia if possible while the lateral surface of the constrictor muscle is dissected away during the surgery. The presence of these structures prevents communication into the neck via the parapharyngeal space and protects the carotid vasculature from exposure into the neck. If this barrier is excised for oncologic purposes, reconstruction can be performed for protection of the parapharyngeal contents, such as suturing of the fascial edges or use of a mucosal advancement flap for coverage of the defect [7].

Lymphatic drainage of the tonsillar region involves levels IIa, IIb, III, and IV of the neck as well as the retropharyngeal nodes. Classically defined by Rouviere and described in modern literature, the retropharyngeal nodes are divided into the poorly defined medial nodes that are often absent in adults, and the lateral nodes which are more pertinent to tumors of the oropharynx [13, 17]. Although there is generally one lateral retropharyngeal node on each side, up to three may be present. The location of the lateral nodes is fairly consistent and is anterior to the prevertebral fascia at the level of C1 and medial to the ICA and cervical sympathetic chain. The surgical resection of the lateral retropharyngeal nodes via the TORS approach has been described, and is performed after completion of robotic oropharyngectomy [18].

Although the data continue to evolve, it does not appear that lateral retropharyngeal nodal resection is universally required in tonsillar squamous cell carcinoma. Data have shown that when patients with early stage disease (T1 or T2 and N0-N2a) and no retropharyngeal involvement on preoperative imaging undergo routine retropharyngeal dissection, the rates of histologically confirmed metastasis are zero [17]. High quality multi-modality imaging is required for this purpose: either fine-cut computed tomography or magnetic resonance imaging combined with positron emission tomography. Thus surgery of the pharynx and tonsil alone may be sufficient in the appropriate patient.

Base of Tongue

The tongue is divided by the circumvallate papilla into two major units, the base of tongue and the oral tongue. The dorsal and posterior aspect of

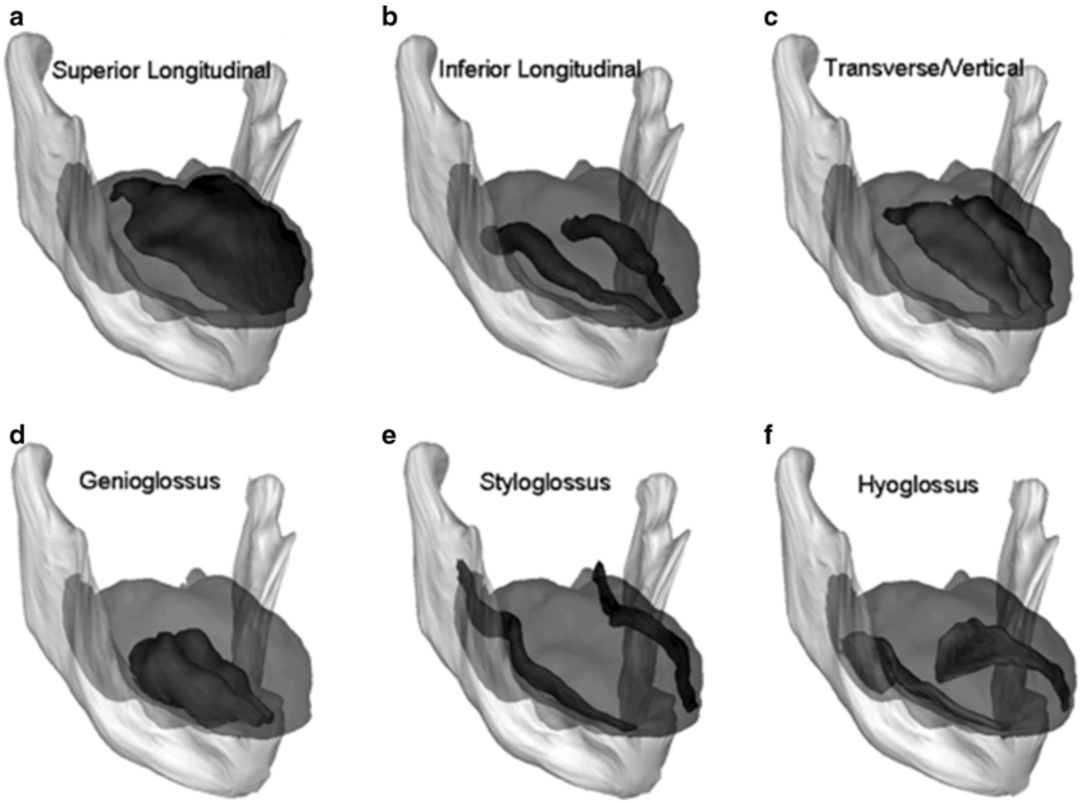

Fig. 6 Depiction of the intrinsic (**a**, **b**, **c**) and extrinsic (**d**, **e**, **f**) muscles of the tongue. Although depicted separately, these muscles have extensive overlap and interdigitation. From Sanders I, et al. A three-dimensional atlas of human tongue muscles. Anat Rec. 2013. Reprinted with permission. [20]

the tongue base comprises the anterior wall of the oropharynx. Like the lateral oropharyngeal wall, transoral robotic surgery greatly facilitates surgical access to the tongue base. Successful robotic surgery of the tongue base, as with other regions, is contingent on knowledge of the neurovascular anatomy. Preservation of at least one tongue base neurovascular bundle is necessary for survival and function of the remaining tongue.

Posterior to the tongue base lies the epiglottis. A median and two lateral glossoepiglottic folds connect these two structures. The valleculae represent the depression between the median and lateral folds. Even further laterally are the glossotonsillar folds, created by the palatoglossus muscle, which are continuous with the palatoglossal arch that runs anterior to the palatine tonsils.

The tongue and tongue base are comprised of intrinsic and named extrinsic muscles. The intrinsic muscles are bundles of interlacing fibers separated by connective tissue septa, which is particularly well formed at the midline. The superior fibers lie submucosally and run along the entire dorsum of the tongue, splaying laterally. The inferior longitudinal fibers course between the genioglossus and hyoglossus muscles. Transverse and vertical fibers contribute to the remainder of tongue bulk and run, respectively, from the septum to the lateral surface and from the dorsal to lateral surface of the tongue [19].

The extrinsic muscles of the tongue include the genioglossus, the hyoglossus, and the styloglossus muscles (Fig. 6). Some consider the palatoglossus to be included in this group but other authors exclude this muscle due to its innervation by the pharyngeal plexus rather than the hypoglossal nerve [19]. The genioglossus arises from the upper part of the mental spine on the lingual surface of the mandibular symphysis. It extends in a fan-like manner to insert onto the tongue along its length towards the hyoid. The styloglossus muscle has been previously described. The hyoglossus muscle originates from the lateral body and greater cornua of the hyoid bone. The fibers extend superiorly and anteriorly to interdigitate with the syloglossus and instrinsic tongue muscles. The importance of the hyoglossus muscle is due to its relationship with the neurovasculature of the region. The hypoglossal nerve and lingual vein run along the lateral aspect of this muscle as they enter the tongue. Also lateral to the hyoglossus muscle is the lingual nerve and submandibular duct. The lingual artery runs on the deep surface of the hyoglossus muscle, sandwiched between this and the genioglossus muscle. It is in this location that the TORS surgeon will encounter the lingual artery and must obtain control to prevent troublesome hemorrhage.

The lingual nerve provides general sensation and taste to the anterior two-thirds of the tongue. Fibers of general sensation include those transmitting touch, pain, and temperature. These fibers derive from the trigeminal ganglion and are a component of the V3 distribution. Taste fibers are derived from the geniculate ganglion of the facial nerve and travel with the lingual nerve by way of chorda tympani. The chorda tympani nerve joins the lingual nerve at the level of the posterior border of the medial pterygoid muscle. The lingual nerve then runs anteriorly between the mandible and the lateral surface of the medial pterygoid muscle continuing forward, lateral to the styloglossus and then the hyoglossus muscles. It courses around the submandibular duct and runs upward into the tongue between the sublingual gland and genioglossus muscle. It is at the anterior border of the medial pterygoid that the nerve is exposed to risk during TORS tongue base procedures, as described previously.

Motor innervation is provided by the hypoglossal nerve. After exiting the skull base, the hypoglossal nerve descends between the ICA and internal jugular vein. It courses forward and crosses over superficial to both carotid vessels. It is tethered at the forward turn by branches of the occipital artery which feed the sternocleidomastoid muscle. The nerve then passes lateral to the hyoglossus muscle and over the greater cornu of the hyoid bone. It continues deep to the mylohyoid muscle and divides into terminal branches which course upwards on the lateral surface of the genioglossus to enter the tongue musculature. It is in this area, as the nerve runs lateral to the hyoglossus and above the hyoid bone, that it is at greatest risk of injury during TORS tongue base resection. Resections of the tongue base extending deep towards the greater cornu of the hyoid, as well as resection of the hyoglossus, expose the nerve to direct or thermal injury during resection and cautery.

The lingual artery is the second branch arising anteriorly from the ECA. Within the curvature early after its origin from the ECA, the tonsillar branch is given off, and the artery runs anteriorly, above the hyoid and medial to the hypoglossal nerve (Fig. 7). It courses deep to the superior border of the digastric tendon and then medial to the hyoglossus muscle. There are variable collateral patterns between the lingual and facial artery after the takeoff of lingual artery from the ECA. Thus, ligation above the level of the hyoid is suggested if interruption of the vessel is desired [19]. For this purpose, the artery can be found just deep to the plane of Lesser's Triangle—the space bounded by the hypoglossal nerve and the two bellies of the digastric muscle and tendon. At the posterior border of the hyoglossus, the lingual artery gives off the dorsal lingual branches. At the anterior border of the muscle, the lingual artery divides into its terminal branches, the deep lingual and sublingual arteries. These arteries have more robust anastomoses distally towards the tongue tip as compared to more posterior areas. Thus, from the perspective of TORS, the hyoglossus muscle and hyoid bone provide useful landmarks for the location of the lingual artery. Resection deep to the superior constrictor muscle at the level of the greater cornu of the hyoid bone will expose lingual artery as it sits medial to the hyoglossus muscle (Fig. 8).

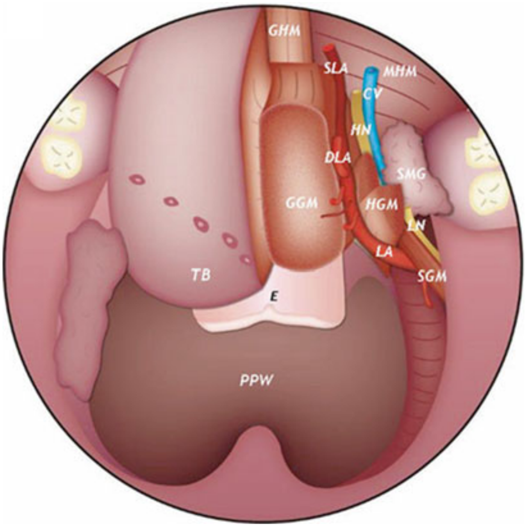

Fig. 7 A schematic reconstruction demonstrating the anatomy of the tongue base and surrounding structure from the perspective of a TORS approach. The lingual artery courses between the hyoglossus and genioglossus muscles. *TB* tongue base, *GGM* genioglossus muscle, *HGM* hyoglossus muscle, *MHM* mylohyoid muscle, *GHM* geniohyoid muscle, *SGM* styloglossus muscle, *SMG* submandibular gland, *LN* lingual nerve, *IXcn* glossopharyngeal nerve, *HN* hypoglossal nerve, *CV* comitant vein, *LA* lingual artery, *DLA* dorsal lingual artery, *SLA* sublingual artery, *E* epiglottis, *PPW* posterior pharyngeal wall. From Dallan, I, et al. Anatomical landmarks for transoral robotic tongue base surgery: comparison between endoscopic, external, and radiological perspectives. Surgical and Radiologic Anatomy. 2013. Reprinted with permission [21]

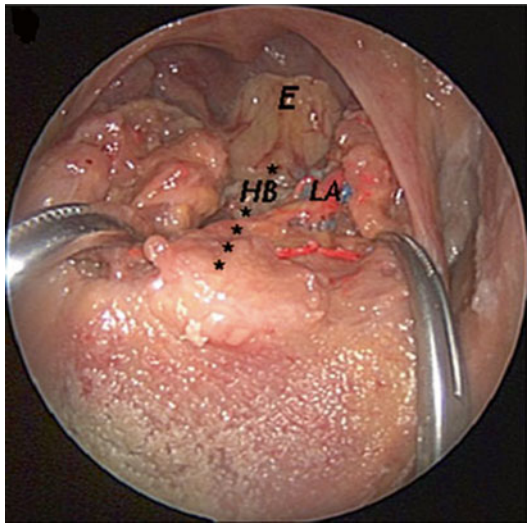

Fig. 8 An endoscopic transoral tongue base dissection demonstrates the exposure of the lingual artery at the level of the hyoid bone. *E* epiglottis, *HB* hyoid bone, *LA* lingual artery, *Black asterisks*—midline. From Dallan, I, et al. Anatomical landmarks for transoral robotic tongue base surgery: comparison between endoscopic, external, and radiological perspectives. Surgical and Radiologic Anatomy. 2013. Reprinted with permission [21]

Analysis of the relevant anatomy from a cervical perspective appears to indicate that TORS tongue base resection is safely and readily performed towards the midline, but one will encounter critical structures as one approaches the lateral aspect of the dissection towards the glossotonsillar folds. This, of course, is true from a transoral perspective as well. The submucosal vessels of the dorsal lingual anastomoses are first encountered with the anterior and horizontal tumor cuts. As the surgeon dissects through the intrinsic muscles and the genioglossus, the dorsal lingual artery itself is visualized laterally, especially as one approaches the hyoid bone at the level of the glossoepiglottic space [21]. This can be traced laterally to identify the main lingual artery trunk running medial to the hyoglossus. Standard cervical landmarks used to identify this "lateral" neurovascular bundle do not apply to the TORS approach. Variations in the volume of lingual lymphoid tissue and the bulk of the tongue itself confound the distance to the arteries and nerves of interest. Lauretano and colleagues noted that on average in cadavers, the neurovascular bundle lie 2.7 cm inferior and 1.6 cm lateral to the foramen cecum [22]. Kokot and colleagues noted the bundle to be on average 2.2 cm inferior and 1.3 cm lateral to the foramen cecum [13]. The hypoglossal nerve was approximately 1.6 cm lateral to the foramen cecum, and its distance from the lingual artery was variable. However, these measurements may not apply in the live patient, especially in light of distortion due to retraction and tumor effect. Regardless, the surgeon should be aware and obtain control of the lingual artery at the lateral aspect of the dissection as the vessel enters the tongue musculature.

Supraglottic Larynx

The transoral view of the larynx is very familiar to most head and neck surgeons. Techniques to maximize the endoscopic exposure of this anatomy

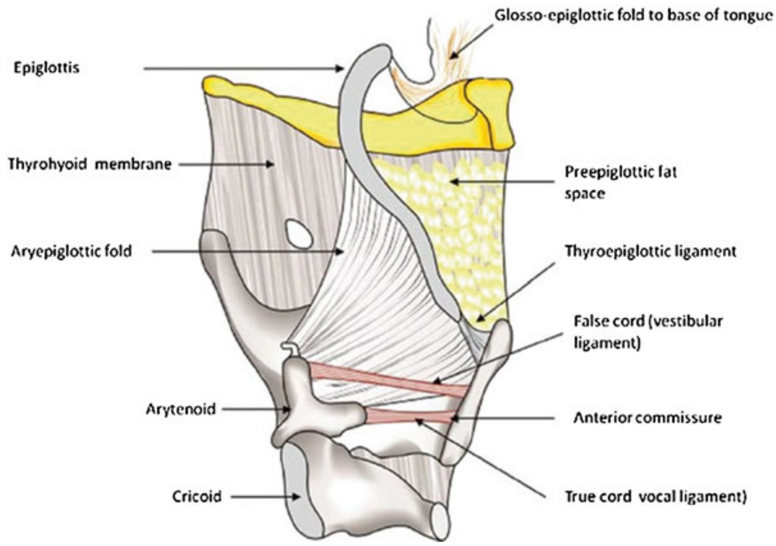

Fig. 9 A midline sagittal view which demonstrates the laryngeal framework, ligaments, and the pre-epiglottic space. From Joshi VM, et al. Imaging in laryngeal cancer. Indian J Radiol Imaging. 2012. Reprinted under Creative Commons license [24]

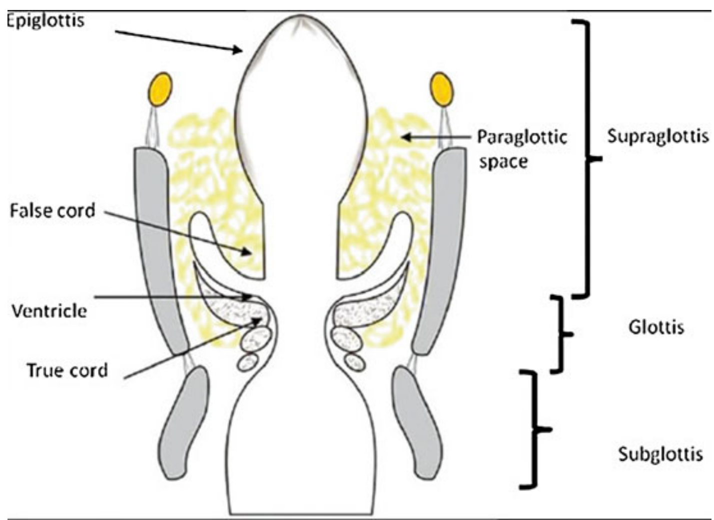

Fig. 10 Coronal section demonstrating the subdivisions, compartments, and barriers of the larynx. These are routes and barriers to tumor spread through the organ. From Joshi VM, et al. Imaging in laryngeal cancer. Indian J Radiol Imaging. 2012. Reprinted under Creative Commons license [24]

have been well described in the literature [23]. Cervical positioning and the choice of laryngoscope are critical elements of obtaining an appropriate view for surgery of the larynx. Knowledge of the structural and neurovascular anatomy of the larynx obtained from traditional endoscopic interventions form the basis of successful robotic surgeries of this region.

The larynx is divided into three main regions (Figs. 9 and 10). The supraglottic larynx extends from the level of the hyoid bone to the level of the laryngeal ventricle. Components of this region include the hyoid bone, epiglottis, arytenoid cartilages, aryepiglottic folds, false vocal folds, pre-epiglottic space, and the mucosa covering these structures. The glottic larynx extends from the laryngeal ventricles to 1 cm inferior to the level of the true vocal folds. The subglottic larynx extends from the inferior aspect of the glottic region to the inferior border of the cricoid cartilage and is mainly comprised of the cricoid cartilage and associated mucosa.

The laryngeal framework is comprised of the thyroid and cricoid cartilages and the hyoid bone.

The hyoid bone is the superior most structure and consists of a body and pairs of greater and lesser horns. It serves as an attachment point for the supra- and infra-hyoid strap muscles and the stylohyoid ligament. The thyroid cartilage forms most of the anterior and lateral walls of the larynx and is attached superiorly to the hyoid bone by the thyrohyoid membrane. The inferior horns articulate with the cricoid cartilage below. The cricoid is a signet shaped structure and is the only complete ring of the normal human airway. Anteriorly and laterally, the arch of the cartilage is relatively thin while the posterior lamina is 2–3 cm in height. The cricoid is attached to the first tracheal ring below by the cricotracheal ligament.

The endolaryngeal structures include the epiglottis, arytenoid cartilages, and the corniculate and cuneiform cartilages. The epiglottis is divided into three parts: the suprahyoid portion, the infrahyoid portion, and the petiole. The curved epiglottic cartilage contains numerous fenestrations which may act as a route of entry for carcinoma into the pre-epiglottic space. The arytenoid cartilages rest above and articulate with the cricoid cartilage. The paired cricoarytenoid units are the functional elements of the larynx involved in speech and swallowing. These units consist of the cricoid-arytenoid articulation, the corniculate and cuneiform cartilages, and the muscular attachments of the posterior cricoarytenoid, lateral cricoarytenoid, and interarytenoid muscles, and are innervated by branches of the superior laryngeal and recurrent laryngeal nerves. Generally, at least one of these units must be preserved when performing oncologic partial laryngeal resection in order to preserve meaningful function of the larynx.

The quadrangular membrane and conus elasticus are the paired fibroelastic sheets that also provide structure to the larynx and contain the laryngeal potential spaces. The quadrangular membrane extends from the sides of the epiglottis to the arytenoids, and is covered by mucosal folds on either side creating the aryepiglottic folds. The membrane extends inferiorly to form the vestibular folds, or false vocal folds. The conus elasticus is a more strongly developed layer. It originates from the superior aspect of the cricoid and sweeps upward and medially. Anteriorly the paired sheets of the conus elasticus attach to the inner surface of the thyroid cartilage near the midline. The superior edge of this sheet contributes to the vocal ligament and attaches to the vocal process of the arytenoid.

The portion of the pharynx most intimately involved with the larynx is the hypopharynx. The pyriform sinus is a subsite of the hypopharynx and sits just lateral to the endolarynx. The pyriforms are bounded laterally by the inner surface of the thyroid cartilage and medially by the pharyngoepiglottic folds. The pyriform sinuses funnel inferiorly into the esophageal inlet. The post-cricoid region and the posterior hypopharyngeal wall comprise the remainder of the hypopharynx. The mucosa of the hypopharynx is bounded by the muscle of the inferior constrictor muscle as it travels from one posterior border of the thyroid lamina to the other.

The larynx contains several adipose filled spaces that are formed by the above described structures (Figs. 9 and 10). These spaces must be considered when performing oncologic resections as they are routes of tumor spread. The pre-epiglottic space is anterior to the epiglottis and is bounded anteriorly by the thyrohyoid membrane, superiorly by the hyoid bone and hyoepiglottic ligament, inferiorly by the thyroepiglottic ligament, and laterally by the paraglottic spaces. The paired paraglottic spaces are bounded laterally by thyroid lamina, medially by the quadrangular membrane and conus elasticus, dorsally by the mucosa of the pyriform sinus, and are confluent anteriorly with the pre-epiglottic space [25].

TORS supraglottic laryngectomy has been described by Weinstein [26] and is an evolution of techniques using laryngoscopic exposures and laser-assisted supraglottic resections [27]. Though the steps of the procedure are explained elsewhere is this text, the operation includes the vertical transection of the epiglottis through the level of the vallecula. The dissection is carried anteriorly to the level of the hyoid bone and the contents of the pre-epiglottic space are dropped down and included in the resection. The surgeon dissects laterally and in a cranial-caudal direction.

In this manner, the pharyngoepiglottic fold is encountered which contains the neurovascular structures critical to the operation.

The neurovascular bundle pertinent to TORS supraglottic laryngectomy includes the superior laryngeal artery, superior laryngeal vein, and the internal branch of the superior laryngeal nerve. The superior laryngeal artery (SLA) provides the dominant blood supply to the supraglottic larynx. The SLA is most commonly a branch of the superior thyroid artery, but may arise directly from the external carotid artery as well. From its origin, it travels anteromedially, and along with the internal branch of the superior laryngeal nerve, pierces the thyrohyoid ligament at a point anterior to the superior horn of the thyroid cartilage to enter the larynx. Here it travels within the pharyngoepiglottic fold and divides into five branches to supply the supraglottic larynx [28]. The ascending branch is the most superficial when dissecting in a cranial-caudal direction, and courses across the upper aspect of the pyriform sinus to supply the epiglottis. The remainder of the branches includes the ventral branch supplying the laryngeal ventricle, the dorsal branch supplying the post-cricoid region, the medial branch supplying the false vocal folds, the dorsal branch supplying the post-cricoid region, and the descending branch supplying the thyroarytenoid muscle. For the purposes of TORS supraglottic laryngectomy, the ascending and ventral branches are most relevant.

Vascular control is obtained at the main trunk of the SLA. Goyal and colleagues describe identification of the main trunk at the level of the pharyngoepiglottic fold from a cranio-caudal approach (Figs. 11 and 12) [29]. Here, the main arterial trunk can be seen with blunt dissection of the pharyngoepiglottic fold immediately after it pierces the thyrohyoid membrane. Souvirón and colleagues describe a landmark-based approach to the main trunk of the SLA in which the neurovascular pedicle can be found in the superior (anterior) third of a triangle formed by the anterior commissure, the vocal process, and the attachment of the aryepiglottic fold to the epiglottis [30]. The spatial orientation of the pedicle

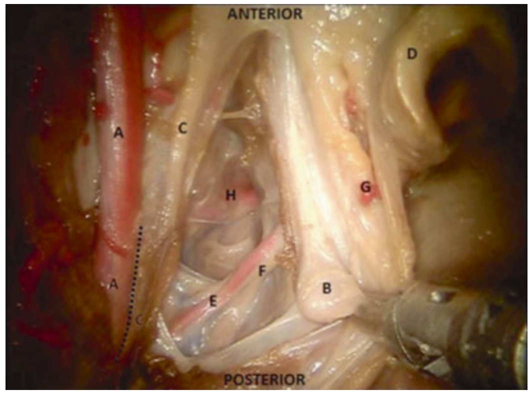

Fig. 11 Robotic dissection of the pharyngoepiglottic fold demonstrates the superior laryngeal neurovascular bundle. In this dissection the suprahyoid attachments were cut and the hyoid retracted medially. A—lingual artery, B—greater cornu of hyoid bone, C—digastric muscle and tendon, D—epiglottis, E—superior laryngeal artery (SLA), F—internal branch of superior laryngeal nerve, G—superior branch of the SLA, H—superior thyroid artery, *Dotted line*—lateral border of the digastric muscle as it comes over the lingual artery. From Goyal, N, et al. Surgical anatomy of the supraglottic larynx using the da Vinci robot. Head and Neck. 2013. Reprinted with permission [29]

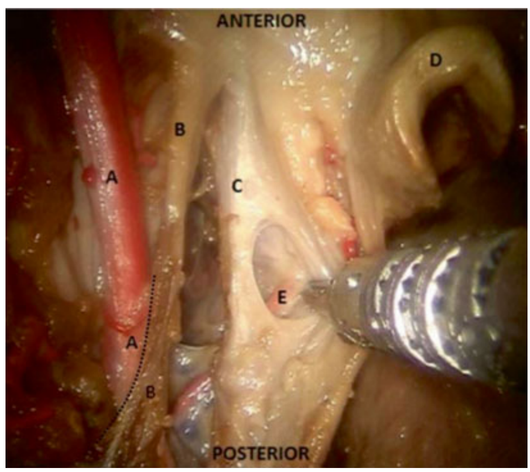

Fig. 12 The superior laryngeal bundle is seen on the medial aspect of the hyoid bone. A—lingual artery, B—digastric muscle and tendon, C—hyoid bone, D—epiglottis, E—superior laryngeal artery and internal branch of superior laryngeal nerve, *Dotted line*—lateral border of the digastric muscle. From Goyal, N, et al. Surgical anatomy of the supraglottic larynx using the da Vinci robot. Head and Neck. 2013. Reprinted with permission [29]

is such that either the superior laryngeal artery or superior laryngeal vein is found superficial to the internal branch of the superior laryngeal nerve in the majority (91 %) of specimens. In the minority, the nerve is the most superficial of the three. Regardless of the method used, control of the main SLA trunk with application of hemostatic clips is critical to avoid troublesome postoperative hemorrhage.

Multiple patterns of the intra-laryngeal branches of the SLA exist. In addition, there is a described aberrant SLA course in which the larynx is entered through a thyroid foramen posterior to the posterior border of the thyroid lamina [31]. In this variant, the main trunk is then found directly in the paraglottic space and can be controlled in this location, rather than within the pharyngoepiglottic fold. An additional consideration is the anastomoses between the ascending branch of the SLA and the suprahyoid branch of the lingual artery. This may lead to bleeding when the dissection includes tissues above the level of the hyoid bone.

The internal branch of the superior laryngeal nerve travels with the SLA through the thyrohyoid membrane and most commonly separates into two or three intra-laryngeal branches [32]. The upper one or two branches provide sensation to the mucosa of the epiglottis, vallecula, vestibule, and false vocal folds. The lower branch provides sensation to mucosa below the vestibule and the mucosa of the pyriform sinus, and motor innervation of the interarytenoid muscles. Much of the mucosal surface innervated by the upper branches is requisitely excised as a component of the oncologic resection, and preservation of these branches is thus superfluous. However, preserving the inferior branch may result in retained sensory innervation of mucosa of the hypopharynx and larynx below the vestibule, motor innervation of the inter-arytenoid musculature, and a preserved cough reflex, potentially improving outcomes postoperatively. With the knowledge of the spatial orientation of the neurovascular bundle within the pharyngoepiglottic fold, the magnification and visualization offered by the TORS approach may be exploited to prevent undue sacrifice of the innervation when placing clips on the vasculature.

Summary

As with traditional surgical approaches, successful and safe TORS procedures are predicated on a thorough understanding of the anatomy. Particular attention must be paid to the presence and course of the relevant neurovascular structures. Previous experience and knowledge of pharyngeal and laryngeal anatomy from a cervical perspective, as well as through traditional laryngoscopic exposures, must be integrated into considerations of the anatomic structures from the "inside-out" approach of experienced with TORS.

Each TORS procedure has its own pertinent vascular supply to consider. These neurovascular pedicles should be anticipated and handled accordingly. In addition, aberrations of the vascular anatomy due to congenital variations or mass effect of tumor must be considered. Preoperative evaluation with appropriate imaging is needed to avoid troublesome complications with hemorrhage and inadvertent neural damage. Particularly, the course of the ICA must be delineated to ensure that disastrous vascular trauma is avoided. Anatomic studies dedicated to the TORS perspective continue to build upon the body of knowledge and allow increasingly nuanced approaches.

References

1. Steiner W, Ambrosch P. Endoscopic laser surgery of the upper aerodigestive tract: with special emphasis on cancer surgery. New York: Theime Stuttgart; 2000.
2. Begum S, Cao D, Gillison M, Zahurak M, Westra WH. Tissue distribution of human papillomavirus 16 DNA in patients with tonsillar carcinoma. Clin Cancer Res. 2005;11(16):5694–9.
3. Janfaza P, Nadol JB, Galla RJ, Fabian RL, Montgomery WW, editors. Surgical anatomy of the head and neck. Philadelphia, PA: Lippincott Williams & Wilkins; 2011.
4. Ohtsuka K, Tomita H, Murakami G. Anatomy of the tonsillar bed: topographical relationship between the palatine tonsil and the lingual branch of the glossopharyngeal nerve. Acta Otolaryngol Suppl. 2002;546: 99–109.
5. Dallan I, Seccia V, Muscatello L, Lenzi R, Castelnuovo P, Bignami M, Montevecchi F, Tschabitscher M, Vicini C. Transoral endoscopic anatomy of the parapharyngeal space: a step-by-step logical approach with surgical considerations. Head Neck. 2011;33(4):557–61.

6. Holsinger FC, McWhorter AJ, Ménard M, Garcia D, Laccourreye O. Transoral lateral oropharyngectomy for squamous cell carcinoma of the tonsillar region: I. Technique, complications, and functional results. Arch Otolaryngol Head Neck Surg. 2005;131: 583–91.
7. Weinstein GS, O'Malley BW, Snyder W, Sherman E, Quon H. Transoral robotic surgery: radical tonsillectomy. Arch Otolaryngol Head Neck Surg. 2007;133: 1220–6.
8. Tubbs RS, Loukas M, Dixon J, Cohen-Gadol AA. Compression of the cervical internal carotid artery by the stylopharyngeus muscle: an anatomical study with potential clinical significance. Laboratory investigation. J Neuosurg. 2010;113:881–4.
9. Wang C, Kundaria S, Fernandez-Miranda J, Duvvuri U. A description of arterial variants in the transoral approach to the parapharyngeal space. Clin Anat. 2014;27(7):1016–22.
10. Goins MR, Pitovski DZ. Posttonsillectomy taste disturbance: a significant complication. Laryngoscope. 2004;114(7):1206–13.
11. Moore EJ, Janus J, Kasperbauer J. Transoral robotic surgery of the oropharynx: clinical and anatomic considerations. Clin Anat. 2012;25:135–41.
12. Lim CM, Mehta V, Chai R, Pinheiro CN, Rath T, Snyderman C, Duvvuri U. Transoral anatomy of the tonsillar fossa and lateral pharyngeal wall: anatomic dissection with radiographic and clinical correlation. Laryngoscope. 2013;123(12):3021–5.
13. Weinstein GS, O'malley BW. Transoral robotic surgery (TORS). San Diego: Plural; 2012.
14. Deutsch MD, Kriss VM, Willging JP. Distance between the tonsillar fossa and internal carotid artery in children. Arch Otolaryngol Head Neck Surg. 1995;121(12):1410–2.
15. Pfeiffer J, Ridder GJ. A clinical classification system for aberrant internal carotid arteries. Laryngoscope. 2008;118(11):1931–6.
16. Ozgur Z, Celik S, Govsa F, Aktug H, Ozgur T. A study of the course of the internal carotid artery in the parapharyngeal space and its clinical importance. Eur Arch Otorhinolaryngol. 2007;264(12):1483–9. Epub 19 July 2007.
17. Moore EJ, Ebrahimi A, Price DL, Olsen KD. Retropharyngeal lymph node dissection in oropharyngeal cancer treated with transoral robotic surgery. Laryngoscope. 2013;123:1676–81.
18. Byeon HK, Duvvuri U, Kim WS, Park YM, Hong HJ, Koh YW, Choi EC. Transoral robotic retropharyngeal lymph node dissection with or without lateral oropharyngectomy. J Craniofac Surg. 2013;24(4): 1156–61.
19. Hollinshead WH. Anatomy for surgeons: the head and neck. 3rd ed. Philadelphia: Harper and Row Publishers; 1982.
20. Sanders I, Mu L. A three-dimensional atlas of human tongue muscles. Anat Rec. 2013;296(7):1102–14.
21. Dallan I, Seccia V, Faggioni L, Castelnuovo P, Montevecchi F, Casani AP, Tschabitscher M, Vicini C. Anatomical landmarks for transoral robotic tongue base surgery: comparison between endoscopic, external and radiological perspectives. Surg Radiol Anat. 2013;35(1):3–10.
22. Lauretano AM, Li KK, Caradonna DS, Khosta RK, Fried MP. Anatomic location of the tongue base neurovascular bundle. Laryngoscope. 1997;107(8): 1057–9.
23. Vaughan CW. Vocal fold exposure in phonosurgery. J Voice. 1993;7(2):189–94.
24. Joshi VM, Wadhwa V, Mukherji SK. Imaging in laryngeal cancer. Indian J Radiol Imaging. 2012;22(3): 209–26.
25. Reidenbach MM. The paraglottic space and transglottic cancer: anatomical considerations. Clin Anat. 1996;9(4):244–51.
26. Weinstein GS, O'Malley Jr BW, Snyder W, Hockstein NG. Transoral robotic surgery: supraglottic partial laryngectomy. Ann Otol Rhinol Laryngol. 2007; 116(1):19–23.
27. Rudert HH, Werner JA. Endoscopic resections of glottic and supraglottic carcinomas with the CO_2 laser. Eur Arch Otorhinolaryngol. 1995;252(3):146–8.
28. Rusu MC, Nimigean V, Banu MA, Cergan R, Niculescu V. The morphology and topography of the superior laryngeal artery. Surg Radiol Anat. 2007;29(8):653–60.
29. Goyal N, Yoo F, Setabutr D, Goldenberg D. Surgical anatomy of the supraglottic larynx using the da Vinci robot. Head Neck. 2013;36:1126–31.
30. Souvirón R, Maranillo E, Vázquez T, Patel N, McHanwell S, Cobeta I, Scola B, Sañudo J. Proposal of landmarks for clamping neurovascular elements during endoscopic surgery of the supraglottic region. Head Neck. 2013;35:57–60.
31. Liu JL, Liang CY, Xiang T, Wang F, Wang LH, Liu SX, Yang HJ. Aberrant branch of the superior laryngeal artery passing through the thyroid foramen. Clin Anat. 2007;20:256–9.
32. Raikos A, Paraskevas GK. The thyroid foramen: a systematic review and surgical considerations. Clin Anat. 2013;26(6):700–8.

http://www.springer.com/978-1-4939-1546-0

Robotic Surgery of the Head and Neck
A Comprehensive Guide
Grillone, G.; Jalisi, S. (Eds.)
2015, XVII, 160 p. 95 illus., 58 illus. in color., Hardcover
ISBN: 978-1-4939-1546-0