The evolution of oncologic surgical technology has moved toward reducing patient morbidity and mortality without compromising oncologic resection or oncologic outcomes. The goals in treating head and neck cancer are to cure patients, as well as to provide quality of life by improving functional and social outcomes through organ-preservation therapies, which may include surgery, chemotherapy, and/or radiation therapy. Transoral robotic surgery (TORS) is an emerging technique that provides several benefits over existing treatment regimens and over open surgery for head and neck cancer, including reductions in operative times, blood loss, intensive care unit stays, and overall duration of patient hospitalization. Transoral robotic techniques allow wide-view, high-resolution, magnified three-dimensional optics for visualization of the mucosal surfaces of the head and neck through an endoscope, while avoiding the extensive external cervical incisions often required for open surgeries. Radiologists play an important role in the successful outcome of these procedures, both before and after TORS. Determining a cancer patient's surgical candidacy for TORS requires a thorough preoperative radiologic evaluation, coupled with clinical and intraoperative assessment. Radiologists must pay particular attention to important anatomic landmarks that are clinical blind spots for surgeons. Knowledge of the expected postoperative imaging appearances, so that they can be distinguished from recurrent disease and second primary tumors, is essential for all radiologists involved in the care of these patients.

Introduction

Innovative technologic advances over the past 2 decades have led to the transition toward the next generation of minimally invasive surgery protocols, that is, those that use robotic assistance (1). Although robots have been employed in many industries for almost half a century, the use of medical robots designed to support surgeons is in its infancy. In 1993, the U.S. Food and Drug Administration (FDA) approved
the first robot for use in surgery; this robot was a voice-activated robotic system, designed for endoscopic procedures (2). Robotic-assisted surgery using the da Vinci surgical system is a minimally invasive surgical technique that was introduced in the early 1990s by Integrated Surgical Systems (now Intuitive Surgery, Sunnyvale, Calif) and was first approved by the FDA in 2000 for clinical use in laparoscopic cholecystectomy and other abdominal surgeries. Robotic-assisted surgery has increasingly been used in the treatment of many oncologic diseases, especially those affecting the prostate gland (3) and genitourinary tract (4,5), as well as in minimally invasive procedures to treat a spectrum of cardiac disorders, including valve replacement, ablation for arrhythmias, and coronary artery bypass surgery (6).

The goal in the treatment of head and neck cancer is to cure patients and to provide quality of life through improved functional and social outcomes by using organ-preservation therapies that may include surgery, chemotherapy, and/or radiation therapy. The major concerns with conventional open surgical approaches and nonsurgical chemotherapy and radiation therapy have been high mortality rates and the significant associated morbidities, including speech and swallowing dysfunction and cosmetic deformities (7,8). Organ- and function-preserving open surgeries include selective neck dissections (rather than radical neck resections) and partial laryngectomies (including the supracricoid laryngectomy). Recent technologic advances in minimally invasive surgical procedures, such as transoral laser microsurgery (TLM) and the newcomer transoral robotic surgery (TORS), alone or coupled with intensified irradiation and sometimes chemotherapy, are changing the face of management of head and neck cancer. TORS for the treatment of upper aerodigestive tract cancer was introduced and pioneered 1 decade ago by Weinstein, O’Malley, and colleagues (9–11) and was approved by the FDA for clinical use in late 2009 (12). It is a novel procedure with several advantages over existing treatment regimens and open surgeries. The da Vinci system allows endoscopic procedures to be performed through the mouth in appropriate candidates, rather than by means of traditional open approaches. Robotic technology affords three-dimensional high-resolution visualization of the pharynx and larynx and a more accurate perception of depth compared with minimally invasive transoral surgical techniques such as laser microsurgery or loupes magnification surgery; in addition, the technique takes advantage of the dexterity and precision afforded by the robotic instruments (13,14).

It provides improved definition of safe surgical margins for complete en bloc resection of tumors, compared with other minimally invasive transoral techniques, and it allows the surgical procedures to be adapted to intraoperative findings (13,14). TORS has been shown to be an effective, minimally invasive surgical procedure for head and neck cancer, with excellent functional and oncologic outcomes (7–23). Investigations have shown reductions in operative times, blood loss, intensive care unit stays, and overall duration of patient hospitalization, compared with open procedures (20–23) (Table 1). With over 50 institutions in more than 20 countries reporting on the use of this new technology, there has been a paradigm shift in the treatment of head and neck tumors, reverting back to primary surgical management with minimally invasive techniques and using robotic resection as part of a multimodality approach for other neoplasms, especially oropharyngeal cancer (13,14,18,24). At this time, the use of TORS has been focused on treating squamous cell carcinoma (SCCA), especially of the oropharynx; however, the application of TORS to treat other malignant and benign pathologic conditions of the neck is rapidly evolving, for example, in robotic-assisted lingual tonsillectomy and uvulopalatopharyngoplasty for obstructive sleep apnea (25,26).

This article introduces robotic technology and robotic-assisted transoral head and neck surgery, especially as it is applied to the treatment of SCCA of the upper aerodigestive tract. The most frequent applications of this minimally invasive surgical option are described, with emphasis on its advantages. Determining a cancer patient’s surgical candidacy for TORS requires a thorough preoperative radiologic assessment, coupled with clinical and intraoperative assessment. Important anatomic landmarks that must be evaluated at imaging because they are clinical blind spots for sur-
Figure 1. The da Vinci robotic system. (a) Intraoperative photograph of the manipulator unit shows a centrally located endoscope (straight white arrow) that is integrated to cameras and two laterally placed instrument arms (black arrows). The patient’s mouth is held open with an FK-WO retractor. Curved arrow = orotracheal intubation tube. (b) View from the surgeon’s console. The working ends of the two instrument arms, with very small endowrist instruments (top), are controlled with the handles (bottom) at the surgeon’s console. (c) Diagram illustrates the operating room setup for transoral robotic surgery. The anesthesiologist is positioned at the foot of the patient bed, and a surgeon assistant and scrub nurse sit near the head of the patient with the robotic manipulator unit. Instrument tables and the surgeon at the console are shown. (d) Intraoperative photograph shows the operating room setup for a robotic-assisted lateral oropharyngectomy.

Surgical robots are addressed. The expected normal postoperative appearances of patients after TORS are also illustrated, so that they can be distinguished from recurrent disease and second primary tumors.

Transoral Robotic Technique and Instrumentation

Transoral robotic techniques allow wide-view, high-resolution, magnified three-dimensional optics for visualization of the mucosal surfaces of the head and neck through an endoscope with direct line of site. Robotic-assisted surgery performed with the da Vinci system brings the surgeon’s hands through a tight opening (the mouth) to the tumor, to resect it as if in an open procedure. It allows minimally invasive, transoral procedures and avoids the extensive external cervical incisions often required for open surgeries. The system consists of a surgeon’s console, a manipulator unit equipped with at least three robotic arms, a centrally located endoscope with integrated cameras, and two laterally placed instrument arms (Fig 1a, 1b). Through the endoscope, the surgeon views magnified three-dimensional images of the tumor.
and surgical field. The working ends of the two instrument arms are equipped with extremely small (5-mm and 8-mm) robotic “endowrists,” which have a 360° range of motion and which are controlled with handles at the surgeon’s console. The system includes hand tremor filtration and motion scaling that translates the large movements of the surgeon’s hands to the small movements of the robotic instruments. The dexterity and precision afforded by the more agile movements of the small robotic instruments allows more precise handling of tissues, improved definition of safe surgical margins, and the ability to adapt surgical procedures to intraoperative findings (13,14). Verification of an adequate mouth opening, allowing excellent exposure of the tumor by using FK-WO laryngopharyngeal retractors (Feyh-Kastenbauer–Weinstein O’Malley retractors; Olympus, Tokyo, Japan) and a 30° endoscope during initial panendoscopy, is required in TORS candidates. Micrognathia, limited neck extension, or other anatomic factors that result in inadequate exposure of the tumor are contraindications to the use of TORS.

The utilization of robotic-assisted surgery requires an operating room designed for this technology (Fig 1c). Unlike many other surgeries in which the anesthesiologist is positioned at the head of the bed, in robotic-assisted head and neck surgery the anesthesiologist is stationed at the foot of the bed because a surgeon assistant and scrub nurse must be near the patient’s head, next to the robotic manipulator unit (Fig 1d). The surgeon assistant monitors the surgical site, provides suction, assists in cauterization, retracts tissues to facilitate surgery, and places hemostat clips.

After the operating room is set up, the patient is put to sleep with general anesthetics and the airway is maintained with orotracheal intubation. The patient’s head is extended, and an FK-WO retractor is placed to hold the patient’s mouth open and to expose the primary tumor. The dual-camera endoscope is placed centrally through the oral cavity, the endowrist robotic arms are inserted into the mouth laterally, and then the surgeon at the console resects the tumor.

**Rise of TORS: Evolution of Treatment Paradigms in Oropharyngeal Carcinoma**

Over the past 2 decades, there had been a trend to use primary irradiation and chemotherapy (hereafter, chemoradiation therapy) to treat oropharyngeal cancers and, increasingly, laryngeal carcinomas (27,28). The rationale for exploring these nonsurgical approaches was organ preservation, decreasing the morbidity associated with radical open surgical approaches, and possibly decreasing the rate of distant metastasis (29). Local control, overall survival, and functional outcomes for any treatment approach remain significant issues. Patients whose cancer is treated with primary chemoradiation, or open surgery followed by postoperative radiation or chemoradiation therapy, have up to a 30% risk of requiring long-term gastrostomy tubes for feeding, in addition to tracheostomy tubes for airway management, and developing long-term mucositis (8,30–34). Furthermore, with primary chemoradiation, killing “all” of the tumors cells is never a certainty, whereas negative surgical margins usually results in local control (8,18,22,23). Open radical surgical approaches to treat oropharyngeal cancers often require large cervical incisions and dissection, split-lip mandibulotomy, extensive pharyngectomy, and complex flap reconstructions (Fig 2), procedures that leave the patient with various levels of speech and swallowing dysfunction, and often significant cosmetic deformities, depending on the location, size, and extent of the primary tumor being resected (7,8). In addition, pharyngectomy and pharyngolaryngectomy, especially with a concurrent neck dissection, can create a communication between the pharynx and the neck that leads to development of pharyngocutaneous fistulas and superimposed infection. The risk of fistula formation is further increased in the setting of radiation therapy (35,36).

The morbidity caused by these treatment approaches has been problematic, particularly in the area of oropharyngeal SCCA, since the past decade has seen a dramatic rise in the number of SCCAs related to the human papilloma virus (HPV) and this cancer occurs in individuals
Figure 2. Intraoperative photograph of open surgery for oropharyngeal cancer. A large cervical incision and split-lip mandibulotomy are required to perform oropharyngectomy. Arrow = tracheotomy tube.

younger and healthier than those who develop oropharyngeal SCCA associated with smoking (37,38). The long life expectancy of patients with HPV-related oropharyngeal SCCA has made the morbidity and mortality associated with standard chemoradiation therapy less acceptable and has heightened the need for effective, minimally invasive surgical alternatives. Recent technical advances in minimally invasive transoral surgery include TORS and endoscopic TLM, which do not create through-and-through defects because there is no skin incision. TLM for tongue base cancer was introduced a decade ago (39), but the limited operative field of view, technical difficulty, and steep learning curve has prevented widespread learning and use of this approach for treating oropharyngeal SCCA (13).

TORS has been shown to be an effective procedure with excellent functional outcomes that has led to a paradigm shift, reverting back to primary surgical management of oropharyngeal SCCA (13–16,18,22–24,40). Most patients can eat within days of the procedure and do not require gastrostomy tubes or tracheotomies (13–15,18,21,24,40). Evidence suggests that use of robotic-assisted transoral resection of mucosal carcinomas—either as a sole treatment, combined with deintensified postoperative irradiation alone, or in combination with chemotherapy as determined by pathologic risk factors—results in improved posttreatment quality of life without compromising oncologic outcomes (18). Timing of neck dissections in patients with clinically or radiologically detected cervical lymph node metastases, or with primary tumors at risk for regional metastases, varies among institutions. Neck dissection may be performed at the same time as the TORS procedure, but it is often performed 1 week before or after TORS for treatment of a primary tumor. This timing eliminates the risk of a pharyngocutaneous communication that may rarely be seen when TORS and ipsilateral neck dissection are performed at the same time (15).

Imaging and Clinical Evaluation for TORS in Head and Neck Neoplasms

The TNM classification established by the American Joint Committee on Cancer (AJCC) incorporates all information available, including findings from the clinical examination, endoscopy, cross-sectional imaging, and histologic analysis (Table 2). The guidelines rely on cross-sectional imaging for TNM staging and what this staging
means for treatment decisions. At this time, the common application of TORS includes resection of most small and medium-sized tumors (T1 and T2) in the oropharynx (tonsil and base of the tongue), larynx (supraglottis), and hypopharynx (piriform sinus). However, in clinics with sufficient experience with this surgery, TORS is being extended to address larger tumors (T3), glottic tumors (21,23), and submucosal soft-tissue tumors below the skull base that arise in the prestyloid parapharyngeal and retropharyngeal spaces (43–45). Evaluation for regional metastases in all patients with carcinoma of the upper aerodigestive tract is essential. Cervical lymph node metastases that are not resectable because of invasion of or fixation to adjacent soft tissues or encasement of the carotid artery are contraindications to TORS (Fig 3).

### Table 2

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Oropharyngeal Cancer</strong>&lt;sup&gt;*&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>Tumor ≤ 2 cm in greatest dimension</td>
</tr>
<tr>
<td>T2</td>
<td>Tumor &gt; 2 cm but ≤ 4 cm in greatest dimension</td>
</tr>
<tr>
<td>T3</td>
<td>Tumor &gt; 4 cm in greatest dimension or extension to lingual surface of the epiglottis</td>
</tr>
<tr>
<td>T4a</td>
<td>Tumor invades larynx, extrinsic tongue muscle, medial pterygoid, hard palate, or mandible</td>
</tr>
<tr>
<td>T4b</td>
<td>Tumor invades lateral pterygoid muscle, pterygoid plates, lateral nasopharynx, or skull base, or encases carotid artery</td>
</tr>
<tr>
<td><strong>Supraglottic Laryngeal Cancer</strong>&lt;sup&gt;†&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>Tumor limited to one subsite of the supraglottis with normal vocal cord mobility</td>
</tr>
<tr>
<td>T2</td>
<td>Tumor invades mucosa of more than one subsite of the supraglottis or glottis or region outside the supraglottis (mucosa of the base of the tongue, valleculae, medial wall of the piriform sinus) without fixation of the larynx</td>
</tr>
<tr>
<td>T3</td>
<td>Tumor limited to larynx with vocal cord fixation and/or invades: postcricoid area, pre-epiglottic space, paraglottic space, and/or inner cortex of the thyroid cartilage</td>
</tr>
<tr>
<td>T4a</td>
<td>Tumor invades through the thyroid cartilage and/or invades tissues beyond the larynx (trachea, soft tissues of the neck including deep extrinsic muscles of the tongue, strap muscles, thyroid, or esophagus)</td>
</tr>
<tr>
<td>T4b</td>
<td>Tumor invades prevertebral space, encases carotid artery</td>
</tr>
<tr>
<td><strong>Piriform Sinus Cancer</strong>&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>Tumor limited to one subsite of the hypopharynx and/or ≤ 2 cm in greatest dimension</td>
</tr>
<tr>
<td>T2</td>
<td>Tumor involves more than one subsite of the hypopharynx or an adjacent site, or &gt; 2 cm but &lt; 4 cm in greatest dimension without fixation of the hemilarynx</td>
</tr>
<tr>
<td>T3</td>
<td>Tumor &gt; 4 cm in greatest dimension, fixed to the hemilarynx, or extension to the esophagus</td>
</tr>
<tr>
<td>T4a</td>
<td>Tumor invades thyroid/cricoid cartilage, hyoid bone, thyroid gland, or central compartment</td>
</tr>
<tr>
<td>T4b</td>
<td>Tumor invades prevertebral fascia, encases carotid artery</td>
</tr>
</tbody>
</table>

<sup>*</sup>Source: Reprinted, with permission, from reference 41.  
<sup>†</sup>Subsites of the supraglottic larynx include the epiglottis, paired aryepiglottic folds, paired false vocal cords, and paired arytenoid cartilages. Source: Reprinted, with permission, from reference 42.  
<sup>‡</sup>Subsites of the hypopharynx include the posterior wall, postcricoid/pharyngoesophageal junction, and piriform sinus. Source: Reprinted, with permission, from reference 41.
the hyoglossus muscles along the lateral surface of the genioglossus muscles where branches innervate the tongue base and oral cavity tongue (46). Resection of the tongue base can be associated with impaired speech, compromised deglutition, and chronic aspiration. Therefore, preservation of the contralateral neurovascular bundle is necessary when considering treatment of tongue base tumors.

A thorough understanding of anatomy by radiologists is paramount to assist the clinician with TNM staging. Important parameters for T staging that influence whether a patient with oropharyngeal cancer is a candidate for surgery include the presence of tumor in submucosal areas that are clinical blind spots and that should be assessed with CT or MR imaging. In patients with tonsillar fossa cancers who are being considered for robotic-assisted lateral oropharyngectomy, stage T1 and T2 tumors (confined tumors ≤4 cm) (Fig 4a, 4b), and some stage T3 tumors (>4 cm) (in experienced hands), are good candidates (Table 2) (22,23). The tonsil, anterior and posterior tonsillar pillars, and portions of the adjacent soft palate, tongue base, and posterior pharyngeal wall are resected. Assessment of the location of the ipsilateral internal carotid artery is also required by the radiologist. A retropharyngeal course of the internal carotid artery is a contraindication to robotic lateral oropharyngectomy because the surgeon and robot must cut through the constrictor muscles, which would put this artery at risk (Fig 5) (Table 3). Anatomic landmarks that must be assessed by the radiologist at CT or MR imaging include the pterygoid bone, pterygomandibular raphe, mandible, eustachian

Figure 3. Unresectable nodal metastases in two patients that excluded them from undergoing TORS. (a) Axial T1-weighted magnetic resonance (MR) image of a patient with primary oropharyngeal carcinoma shows a high right level II nodal mass that encases the right internal carotid artery (arrowhead) and invades the prevertebral muscles (arrow). (b, c) Axial enhanced computed tomographic (CT) scans at two different levels in a patient with primary tongue base carcinoma. (b) Higher-level image shows the primary tumor (T) on the left, with a large nodal metastasis (arrowheads) that encases the left internal carotid artery (arrow). (c) Lower-level image shows that the nodal metastasis (arrowheads) invades the sternocleidomastoid muscle (white arrow). The internal jugular vein is also invaded and is not visualized. Black arrow = internal carotid artery.
Figure 4. Stage T2 left tonsillar carcinoma treated with TORS lateral oropharyngectomy and N2a nodal disease treated with left neck dissection 1 week later in a 48-year-old man. (a, b) Pretreatment axial enhanced CT images show a 2.4-cm left tonsillar carcinoma (T), preservation of the fat (arrow in a) anterior to the prevertebral muscles, and a lateralized left internal carotid artery (arrowhead in a) with a plane of normal tissues between the tumor and the artery. The tumor bulges into the glossotonsillar sulcus (•) and does not involve the floor of the mouth or tongue muscles. G = genioglossus muscle, H in b = hyoglossus muscle, M in b = mylohyoid muscle, N = nodal metastasis. (c, d) Posttreatment axial enhanced CT images 8 weeks after surgery show vascular clips in the surgical bed. There is distortion of the fat planes around the left medial pterygoid muscle (M) and pterygomandibular raphe, as well as mild retraction of the left lateral oropharyngeal wall (arrow in c), soft palate (• in c), and uvula (U in c). (e, f) Axial T1-weighted MR images 6 months after surgery show resolution of the acute postsurgical changes and further left lateral retraction of the pharyngeal wall and soft palate (arrow in e). The soft palate “tilts” toward the side of oropharyngectomy.
Figure 5. Retropharyngeal internal carotid arteries. (a) Axial enhanced CT image shows a retropharyngeal course of both internal carotid arteries (arrows) behind the constrictor muscles. (b) Axial T2-weighted fat-suppressed MR image of a different patient shows the relationship of normal lateralized internal carotid arteries (arrows) to the constrictor muscles (arrowheads).

Table 3
Radiologic Findings That Serve as Contraindications for Use of TORS to Treat Head and Neck Cancers

<table>
<thead>
<tr>
<th>Tonsillar carcinoma</th>
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<tbody>
<tr>
<td>Retropharyngeal course of the ipsilateral internal carotid artery</td>
<td></td>
</tr>
<tr>
<td>Extension to the eustachian tube orifice</td>
<td></td>
</tr>
<tr>
<td>Invasion of prevertebral muscles</td>
<td></td>
</tr>
<tr>
<td>Extension into the pterygoid bone/pterygoid muscle</td>
<td></td>
</tr>
<tr>
<td>Extension into the mandible</td>
<td></td>
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<tr>
<td>Involvement of the osseous skull base</td>
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<table>
<thead>
<tr>
<th>Tongue base carcinoma</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Tumors crossing the midline base of the tongue endophytically</td>
<td></td>
</tr>
<tr>
<td>Extension into the extrinsic muscles of the tongue</td>
<td></td>
</tr>
<tr>
<td>Extension into the genioglossus muscle</td>
<td></td>
</tr>
<tr>
<td>Large endophytic tumors of the glossoptonsillar sulcus because of risk to the carotid artery</td>
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</table>

<table>
<thead>
<tr>
<th>Supraglottic carcinoma</th>
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<tbody>
<tr>
<td>Invasion of cartilage</td>
<td></td>
</tr>
<tr>
<td>Extension to or across the midline</td>
<td></td>
</tr>
<tr>
<td>Involvement of the mucosa over both arytenoid cartilages</td>
<td></td>
</tr>
<tr>
<td>Invasion of the glottis at the commissures or through the laryngeal ventricle</td>
<td></td>
</tr>
<tr>
<td>Involvement of the tongue base closer than 1 cm to the circumvallate papillae</td>
<td></td>
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<table>
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<tr>
<th>Hypopharyngeal carcinoma</th>
<th></th>
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<tbody>
<tr>
<td>Involvement of cartilage, extralaryngeal spread</td>
<td></td>
</tr>
<tr>
<td>Extension to or across the midline</td>
<td></td>
</tr>
<tr>
<td>Extension to the retrocricoid region</td>
<td></td>
</tr>
<tr>
<td>Absence of a plane of normal tissue between the carotid artery and piriform sinus tumor</td>
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</table>
The observation of a preserved retropharyngeal fat plane between the constrictor muscles and the prevertebral muscles at CT or MR imaging usually indicates lack of tumor fixation (Fig 4a, 4b) (49). Attenuation of the retropharyngeal fat in the absence of radiologic evidence of tumor extension is a finding consistent with surgical change or necrosis. Patients with radiologic evidence of gross extension into the prevertebral muscles (47,48) or those with pharyngeal cancers that are fixed to the precervical fascia are not surgical candidates. The observation of a preserved retropharyngeal fat plane between the constrictor muscles and the prevertebral muscles at CT or MR imaging usually indicates lack of tumor fixation (Fig 4a, 4b) (49). Attenuation of the retropharyngeal fat in the absence of radiologic evidence of tumor extension is a finding consistent with surgical change or necrosis. Patients with radiologic evidence of gross extension into the prevertebral muscles (47,48) or those with pharyngeal cancers that are fixed to the precervical fascia are not surgical candidates. The observation of a preserved retropharyngeal fat plane between the constrictor muscles and the prevertebral muscles at CT or MR imaging usually indicates lack of tumor fixation (Fig 4a, 4b) (49). Attenuation of the retropharyngeal fat in the absence of radiologic evidence of tumor extension is a finding consistent with surgical change or necrosis. Patients with radiologic evidence of gross extension into the prevertebral muscles (47,48) or those with pharyngeal cancers that are fixed to the precervical fascia are not surgical candidates.

Figure 6. Oropharyngeal SCCA in a 62-year-old woman. Axial T1-weighted MR image shows a tumor (T) on the right and an adjacent metastatic retropharyngeal lymph node (N). There is attenuation of the right prevertebral fat (white arrow), compared with the normal left side (black arrow).

Figure 7. Stage T1 right base of tongue carcinoma in a 44-year-old patient identified on T2-weighted images with fat suppression. (a) Axial T2-weighted MR image shows a small confined carcinoma (arrow) that involves the right base of the tongue. (b, c) Axial T2-weighted MR images obtained 3 weeks after TORS show areas of T2 hyperintensity (*), a finding consistent with surgical change in the parapharyngeal space, along the lateral oropharyngeal wall, and in the glossotonsillar sulcus. Note the retraction (arrow) in the surgical bed of the base of the tongue.
changes in the muscles is not indicative of fixation (47) (Fig 6), however, and in patients who are otherwise surgical candidates, the presence of fixation should be determined intraoperatively. In addition to assessing the lateral neck for lymph node metastases, in patients with tonsillar carcinomas, the radiologist should look for and identify retropharyngeal nodal metastases, if present, so that the surgeon can resect them at the time of TORS (Fig 6).

Most stage T1 and T2 as well as some stage T3 tumors at the base of the tongue are amenable to TORS (Table 2) (Figs 7, 8). For patients with SCCA that arises from the tongue base or from the glossotonsillar sulcus or that involves the tongue base and tonsil, additional clinical blind spots must be addressed by the radiologist; some of these are discussed as follows. Neoplastic extension into the extrinsic tongue muscles of the floor of the mouth (ie, genioglossus, hyoglossus, styloglossus muscles) or tumor invasion of the mylohyoid muscle that forms the floor of the oral cavity are contraindications to TORS (Fig 9a, 9b). Other tongue base tumors not amenable to TORS include those that cross the midline endophytically (Fig 10), because of the functional losses and risk of aspiration created by sacrificing both lingual arteries and hypoglossal nerves. Some tongue base tumors that extend close to the midline may be treated with TORS if the surgeon can spare two-thirds of the opposite tongue base and the neurovascular bundle. Finally, patients with large tumors of the glossotonsillar sulcus are not good candidates for TORS because of the potential risk to the carotid artery, which cannot be covered if exposed during surgery (Table 3).
Figure 9. Tongue base tumors not amenable to TORS. (a, b) Axial T2-weighted MR images show normal anatomy: midline genioglossus muscles (G), lateral hyoglossus (H) and mylohyoid (M) muscles, lingual artery (straight arrow), midline lingual septum (arrowhead), circumvallate papillae (*), sublingual glands (S), epiglottis (curved arrow), and tongue base (B). (c–e) Axial enhanced CT images of a 48-year-old patient with SCCA of the right tonsil (T) and tongue base (B) shows tumor extension anterior to the circumvallate papillae (arrow in d) into the oral cavity tongue and invasion of the hyoglossus and mylohyoid muscles (arrowheads in e). (f) Axial enhanced T1-weighted MR image, obtained with a fast multiplanar spoiled gradient-echo sequence in a 60-year-old patient, shows a tongue base tumor that invades the extrinsic tongue muscles (arrowhead) and the genioglossus muscle (arrow).
Figure 10. Axial T2-weighted fat-suppressed image shows a left base of tongue and tonsillar tumor (T) with endophytic growth into the extrinsic muscles of the tongue and extension across the midline septum to the right side of the tongue (arrow).

Figure 11. Supraglottic carcinoma treated with TORS supraglottic partial laryngectomy. Axial enhanced CT image shows a confined horseshoe-shaped stage T2 SCCA of the epiglottis and aryepiglottic folds (*), with normal pre-epiglottic fat (arrowheads).

Figure 12. Supraglottic carcinoma that invades the pre-epiglottic and paraglottic space and requires open supraglottic laryngectomy. Axial T1-weighted image shows a large horseshoe-shaped stage T3 SCCA of the epiglottis and aryepiglottic folds (*). It shows extensive involvement of the left pre-epiglottic space (black arrows), compared with the normal right pre-epiglottic fat (arrowheads) and paraglottic space (white arrow). N = level III nodal metastasis.

Supraglottic Laryngeal and Hypopharyngeal Carcinoma

Laryngeal conservation surgeries are performed to maintain the patient’s voice and eradicate laryngeal and hypopharyngeal tumors. External voice-preserving surgeries are performed routinely. Integration of cross-sectional imaging findings with endoscopic findings is required for accurate T staging. The mucosal surface and vocal cord mobility are best assessed clinically with endoscopy. The role of CT and MR imaging is to demonstrate the extent of submucosal tumor. A clear understanding of laryngeal anatomy is fundamental to image interpretation. Clinical blind spots in the larynx and important parameters that influence patient management that should be evaluated with CT or MR imaging include the tongue base, valleculae, pre-epiglottic space, arytenoid cartilages, postcricoid region, hypopharynx, thyroid cartilage, and subglottis.

Transoral supraglottic partial laryngectomy (SGPL) with laser surgery or TORS has been used increasingly instead of open surgical approaches (19,20,22,50). Because there is no open incision with these newer techniques, patients often do not need a breathing tube and recovery times are quicker (45,48). Some patients are able to start swallowing within days of surgery, compared with weeks when open surgical approaches are used (19,22,51). Patients with most stage T1 and T2, and some stage T3, supraglottic cancers are candidates for TORS SGPL (Fig 11). The entire epiglottis and pre-epiglottic space, as well as both aryepiglottic folds and false vocal cords, are resected. The thyroid cartilage is maintained, rather than being partially resected as is done in a standard supraglottic laryngectomy. It is important to ascertain the inferior extent of a supraglottic cancer as well as to evaluate the pre-epiglottic space (Fig 12) (52). A standard TORS SGPL is feasible to treat...
only those tumors confined to the supraglottis that do not involve the laryngeal ventricle or the arytenoid cartilages and that have no arytenoid or true vocal cord fixation (Fig 13). Cartilage invasion, involvement of the mucosa of both arytenoid cartilages, invasion of the glottis at the commissures or through the laryngeal ventricle, and involvement of the tongue base closer than 1 cm to the circumvallate papillae are contraindications to TORS SGPL (Table 3). Transoral laser SGPL provides excellent visualization and successful resection of many supraglottic carcinomas (50). However, the location of some supraglottic cancers may be technically challenging, and use of TORS in these cases provides an alternative to open surgery and conventional SGPL (53). Advantages of TORS SGPL include improved line-site visualization of some cancers and an en bloc resection of neoplasms with wide surgical margins, which cannot always be obtained with transoral laser surgery (19).

Robotic-assisted transoral partial laryngohypopharyngectomy can be performed for most stage T1 and T2 tumors and for some stage T3 tumors of the piriform sinus or the posterior wall of the hypopharynx (Fig 14) (54). The piriform sinus, aryepiglottic fold, and sometimes the ipsilateral arytenoid cartilage are resected. Contraindications for transoral robotic-assisted hypopharyngectomy include all stage T4 tumors (cartilage invasion, extralaryngeal spread), tumors that extend to or across the midline, and neoplastic extension to the postcricoid region. Other contraindications for TORS of hypopharyngeal tumors include tumors that extend to the apex of the piriform sinus (54). For these tumors, the relationship of the tumor relative to the hyoid bone and the carotid artery is important: If no clear plane of normal tissue exists between the tumor and the carotid artery, TORS is contraindicated because the artery cannot be covered in this location (Table 3).

Postoperative Imaging
Familiarity with the expected normal postoperative imaging appearances of the oropharynx, larynx, and the surrounding structures after TORS is important for a radiologist to be able to differentiate normal surgical changes from persistent or recurrent disease, as well as to diagnose possible second primary malignancies. In a lateral oropharyngectomy, the tonsil; anterior and posterior tonsillar pillars; and portions of the soft palate,
tongue base, and the posterior pharyngeal wall are resected. Imaging during the first 8–12 weeks after surgery shows distortion of the fat planes around the medial pterygoid muscle and the pterygomandibular raphe related to surgical change (55) (Fig 4d). Over months, progressive retraction of the left lateral oropharyngeal wall occurs related to scar tissue, and this retraction also often results in “tilting” of the soft palate and uvula toward the surgical bed (Fig 4e, 4f). In primary tongue base carcinoma, TORS resection often includes the half of the tongue base on the side of the tumor

Figure 14. Stage T2 piriform sinus carcinoma in a 70-year-old patient. (a) Axial enhanced CT image shows a 2.0-cm carcinoma of the left piriform sinus (T). (b–d) Axial T1-weighted MR images obtained 12 weeks after robotic-assisted partial left hypopharyngectomy reveal the surgical absence of the left piriform sinus and aryepiglottic fold, the normal right aryepiglottic fold (arrow) and piriform sinus (P), and the epiglottis (E). Focal decreased signal in the left thyroid cartilage (arrowhead) is likely related to stripping of the inner perichondrium and should not be mistaken for tumor. Note mild distortion of the adjacent strap muscles.
Figure 15. Stage T1 base of tongue carcinoma treated with TORS in a 51-year-old man. Axial T2-weighted MR image (a) and enhanced T1-weighted MR image (b), obtained with a fast multiplanar spoiled gradient-echo sequence 6 months after TORS, show retraction of the left base of the tongue surgical bed (arrow in a) without masslike enhancement.

to the level of the midline vallecula, with anterior dissection to the circumvallate papillae and lateral dissection to include the inferior tonsillar fossa. During the first weeks to months after surgery, changes in CT attenuation and MR signal intensity are present in the surgical bed of the tissues resected, and retraction of the tongue base bed is noted and persists (Fig 7b, 7c). Solid enhancement is typically not present 3 months after surgery (Fig 15). New or progressive solid enhancement in the oropharyngeal surgical bed or in areas contiguous or adjacent to the surgical bed is highly suggestive of tumor recurrence (Fig 16).

An understanding of the morphologic changes that occur in the larynx and hypopharynx after robotic-assisted transoral partial laryngectomies will enable the radiologist to distinguish recurrent disease and second primary carcinomas from expected postsurgical changes. After TORS SGPL, imaging (and clinical examination) may show redundant mucosa that covers the arytenoid cartilages. The remaining supraglottic structures are surgically absent, and the glottic and subglottic structures appear normal. In a robotic-assisted transoral partial laryngo-hypopharyngectomy, one piriform sinus and the aryepiglottic fold are resected (Fig 14).

New Frontiers for Robotics in Head and Neck Cancer

Recent advances in TORS have extended to the resection of submucosal soft-tissue tumors below the skull base that arise in the prestyloid parapharyngeal space (Fig 17), as well as to the resection of retropharyngeal lymph nodes (Fig 18) (44,45). Although application of this technique at the skull base is new, early results of transoral robotic resection show a tremendous improvement over the standard open surgical procedures that often require large open cervical incisions or split-lip mandibulotomy to provide access to the tumor for resection. Select tumors of the salivary gland, including circumscribed small and medium-sized tumors in the prestyloid parapharyngeal...

Figure 16. Three patients with recurrent carcinoma after TORS lateral oropharyngectomy. (a) Axial enhanced CT image of a patient with previously treated stage T2 right tonsillar carcinoma shows recurrent carcinoma involving the posterolateral oropharyngeal wall and tongue base, with invasion into the floor of the mouth (arrows). (b–d) In a different patient, axial enhanced T1-weighted MR image (b), obtained with a fast multiplanar spoiled gradient-echo sequence 1 year after left lateral oropharyngectomy, shows a normal vallecula (V) and epiglottis (E). Axial T1-weighted MR images obtained 1.5 years after TORS, without (c) and with (d) enhancement, show development of circumferential masslike enhancement in the left vallecula (arrows), a finding consistent with neoplastic recurrence. (e) Axial enhanced CT image, obtained 6 months after TORS lateral oropharyngectomy in a 59-year-old man, shows recurrent carcinoma (arrowheads) in the pterygoid muscle (arrow). Recurrent carcinoma developed at the site where the constrictor muscle was incised and extended into the retropharynx (medial arrowheads).
space, may be amenable to TORS performed by experienced hands (Fig 17). Contraindications to TORS for prestyloid parapharyngeal space tumors include those tumors that extend into the stylomandibular tunnel, owing to the risk of neoplastic rupture and spillage of tumor with resultant incomplete resection; a medial course of the internal carotid artery; and involvement of the bone at the skull base (44,45). The proximity of the internal carotid artery to tumors in the prestyloid parapharyngeal space, as well as to retropharyngeal tumors, is important. A retropharyngeal course is usually a contraindication to TORS because the constrictor muscles must be cut, which puts this artery at risk.

The techniques used in TORS in the head and neck have been adapted for use with other surgeries that are not performed transorally, but rather through external incisions in “cosmetically silent areas.” Robotic-assisted thyroidectomy has the potential for many advantages over conventional open thyroidectomy and endoscopic thyroidectomy. Since its initial description in 2008 (56), surgeons have reported success in the use of a gasless axillary approach to robotic-assisted thyroidectomy (57). Early results suggest that the “trifecta” of thyroid cancer surgery (cancer control, safety, and quality of life) may be achieved with this technique (58). A meta-analysis suggests that with increasing experience, robotic-assisted thyroidectomy may be as safe and as effective as open and endoscopic approaches and may result in shorter lengths of hospitalization and satisfactory cosmetic outcomes (59). Currently, longer operating times and an increase in temporary hypoparathyroidism have been reported. Potential

Figure 17. Pleomorphic adenoma of the left prestyloid parapharyngeal space in a 16-year-old girl. (a) Axial T1-weighted MR image shows a tumor (T) that is circumferentially surrounded by hyperintense prestyloid parapharyngeal fat (arrows). The tumor does not extend to the stylomandibular tunnel (short angled line). The internal carotid artery (arrowhead) is posterior and lateral to the tumor. (b) Photograph after en bloc resection of the mass shows the gross surgical specimen of the pleomorphic adenoma. Scale is in centimeters. (c) Axial T1-weighted MR image 1.5 years after TORS shows the normal left prestyloid parapharyngeal space (*).
Figure 18. Recurrent papillary thyroid carcinoma involving the retropharyngeal lymph nodes in a 42-year-old man. (a) Axial enhanced CT image shows a 2.2-cm right retropharyngeal nodal metastasis (arrow). The internal carotid artery (arrowhead) is posterior and lateral to the lymph node. *E* = external carotid artery, *V* = internal jugular vein. (b) Photograph obtained after en bloc resection shows the gross surgical specimen of the metastatic node (*N*). A second 6-mm metastatic retropharyngeal lymph node was identified intraoperatively and was resected.

Complications of robotic-assisted thyroidectomy, over and above those resulting from standard approaches, include tracheal injury and brachial plexus neuropathy.

Robotic-assisted neck dissections that use a retroauricular or modified facelift approach have been described. This procedure is viewed as safe and technically feasible, with satisfactory cosmetic results, for low-risk patients with early stage head and neck cancer (clinically negative nodes), as well as for patients with differentiated thyroid cancer and lateral regional metastases (60,61). Long-term results with respect to oncologic safety and functional outcomes must be studied to establish the validity of this potential “frontier” in treatment.

Conclusions

The evolution of surgical oncologic technology has moved toward reducing patient morbidity and mortality without compromising resection or oncologic outcomes. Transoral, minimally invasive, organ-preserving techniques remove cancers from the upper aerodigestive tract without use of external incisions. These procedures may spare patients from undergoing adjuvant treatment altogether or allow the use of deintensified chemoradiation therapy in patients with pathologic risk factors. The introduction of TORS improves upon current transoral techniques and has advanced the capabilities of head and neck surgeons with lightning speed. Robotic-assisted surgery has evolved from being used by just a few surgeons in 2009 to being used globally in daily practice. With the rapid advances in technology and informatics, it is not inconceivable that robotic-assisted surgery could be done remotely through cyberspace in the not too distant future. Determining surgical candidacy requires thorough radiologic evaluation together with clinical and intraoperative assessment. Understanding the role of imaging in the preoperative period, and knowledge of the expected postoperative imaging appearances and patterns of recurrent disease, are essential for all radiologists involved in the care of these patients. Robotic-assisted surgery is rapidly evolving, necessitating the continual learning of radiologists who will play an important part in these treatment frontiers.


References


Transoral Robotic Surgery in Head and Neck Cancer: What Radiologists Need to Know about the Cutting Edge

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Page 1763
TORS has been shown to be an effective procedure with excellent functional outcomes that has led to a paradigm shift, reverting back to primary surgical management of oropharyngeal SCCA.

Page 1764
At this time, the common application of TORS includes resection of most small and medium-sized tumors (T1 and T2) in the oropharynx (tonsil and base of the tongue), larynx (supraglottis), and hypopharynx (piriform sinus).

Page 1764
Cervical lymph node metastases that are not resectable because of invasion of or fixation to adjacent soft tissues or encasement of the carotid artery are contraindications to TORS.

Page 1765
A retropharyngeal course of the internal carotid artery is a contraindication to robotic lateral oropharyngectomy because the surgeon and robot must cut through the constrictor muscles, which would put this artery at risk.

Page 1772
Familiarity with the expected normal postoperative imaging appearances of the oropharynx, larynx, and the surrounding structures after TORS is important for a radiologist to be able to differentiate normal surgical changes from persistent or recurrent disease, as well as to diagnose possible second primary malignancies.