



Laryngeal imaging

David M. Yousem, MD^{a,*}, Ralph P. Tufano, MD^b

^a*The Russell H. Morgan Department of Radiology and Radiological Sciences, The Johns Hopkins Medical Institution,
600 North Wolfe Street, Phipps B-112, Baltimore, MD 21287, USA*

^b*Department of Otolaryngology–Head and Neck Surgery, The Johns Hopkins Medical Institution,
601 North Caroline Street, Baltimore, MD 21287, USA*

To understand the issues that are involved with imaging of the larynx in patients with squamous cell carcinoma, radiologists should start by examining the treatment modalities for these tumors. In many cases, the treatments will vary depending on whether the patient has a supraglottic, glottic, or subglottic carcinoma and the volume and extent of that tumor. Because a person's voice plays a large role in the ability to communicate and in a person's self-image, the decision to remove all or portions of the larynx has heavy psychosocial overtones; therefore, therapeutic decisions are usually based on a combination of concerns for the patient's long-term survival and functional outcome. For the most part, the treatment options include surgery, radiotherapy, chemotherapy, and selected combinations thereof.

Radiation therapy

Several studies of radiation therapy for supraglottic and glottic carcinomas have demonstrated that one of the critical factors determining tumor-free survival and/or local control is tumor volume. For this reason, many imaging centers perform volumetric analyses of all laryngeal carcinomas. Because spiral CT scanning has allowed millimeter to submillimeter scan thicknesses and radiation therapists often plan portals based on CT images, CT is the most common modality used to compute volumes. Freeman et al [1] found that there was a statistically significant difference in

local control for supraglottic tumors less than 6 mL (83%) versus tumors greater than or equal to 6 mL (46%) that was independent of pre- or paraglottic tumor extent. Lee et al [2] found that T3 glottic cancers with a volume of 3.5 mL or less had a local control rate of 92%, whereas tumors greater than 3.5 mL had a local control rate of only 33%. In Lee et al's study, other important factors influencing local control by radiation were involvement of the mucosa of the arytenoid cartilage and degree of paraglottic invasion. Castelijns et al [3] have stated that a laryngeal carcinoma more than 5 mL in volume with associated abnormal signal intensity on MR imaging in the thyroid cartilage has a high rate of tumor recurrence if treated solely by radiotherapy. Castelijns et al [4] found that cord mobility, tumor volume, and cartilage invasion as seen at MRI determined the chance for cure by radiation therapy. However, the effect of tumor volume was negligible in one study that assessed T2 glottic cancers [5]. In many cases, tumor volume correlates with T staging of the laryngeal carcinoma (Tables 1–3). Thus, volume and T stage may be related dependent variables. Nonetheless, most of the literature suggests that volume alone does appear to be an independent contributor to patient survival from laryngeal carcinoma.

Besides tumor volume, what are the other predictors of local control by radiation? CT or MR imaging criteria of transglottic spread, more than 25% preepiglottic space involvement, cord mobility, and extensive paralaryngeal spread should be considered as factors when contemplating radiation therapy as the primary modality for treating laryngeal carcinomas [6]. Clinical T stage, and tumoral invasion of the thyroid cartilage on MR

* Corresponding author.

E-mail address: yousem@rad.jhu.edu (D.M. Yousem).

Table 1
T staging of supraglottic carcinoma

Stage	Description
T1	Tumor limited to one subsite of supraglottis with normal vocal cord mobility
T2	Tumor invades mucosa of more than one adjacent subsite of supraglottis or glottis or region outside the supraglottis (eg, mucosa of base of tongue, vallecula, medial wall of pyriform sinus) without fixation of the larynx
T3	Tumor limited to larynx with vocal cord fixation and/or invades any of the following: postcricoid area, pre-epiglottic tissues, paraglottic space, and/or minor thyroid cartilage erosion (eg, inner cortex)
T4a	Tumor invades through the thyroid cartilage and/or invades tissues beyond the larynx (eg, trachea, soft tissues of neck including deep extrinsic muscle of the tongue, strap muscles, thyroid, or esophagus)
T4b	Tumor invades prevertebral space, encases carotid artery, or invades mediastinal structures

Data from American Joint Committee on Cancer. Cancer staging handbook. 6th edition. New York: Springer; 2002, with permission of the American Joint Committee on Cancer (AJCC®), Chicago, IL.

imaging also are predictors of radiation treatment failure at 5 years for glottic tumors [7].

In the past, any form of cartilaginous invasion also precluded radiation therapy, because the conventional wisdom was that to eradicate the tumor that had invaded the cartilage with radiotherapy risks chondroradionecrosis. In many cases, the chondronecrosis may not be caused by the radiation per se but a superimposed infection into a predisposed ulcerated field where immunologic protection is violated. More recently, however, focal nonbulky cartilaginous invasion (seen as laryngeal sclerosis) has been treated with targeted radiation therapy with excellent local control [8]. This has led to a revision of the staging of laryngeal carcinoma to allow focal inner wall cartilage invasion as still a curable criterion. Other authors have suggested that even minor cartilaginous invasion demonstrated by imaging should preclude radiation therapy for cure [9]. Patients who require breaks during the radiation therapy, either for pulmonary complications or mucositis, tend to do more poorly than those who complete the radiation therapy protocol within the standard guidelines.

The other consideration when deciding between a surgical versus radiotherapeutic approach is the

Table 2
T staging of glottic carcinoma

Stage	Description
T1	Tumor limited to the vocal cord(s) (may involve anterior or posterior commissure) with normal mobility
T1a	Tumor limited to one vocal cord
T1b	Tumor involves both vocal cords
T2	Tumor extends to supraglottis and/or subglottis and/or with impaired vocal cord mobility
T3	Tumor limited to the larynx with vocal cord fixation and/or invades paraglottic space, and or minor thyroid cartilage erosion (eg, inner cortex)
T4a	Tumor invades through the thyroid cartilage and/or invades tissues beyond the larynx (eg, trachea, soft tissues of neck including deep extrinsic muscle of the tongue, strap muscles, thyroid, or esophagus)
T4b	Tumor invades prevertebral space, encases carotid artery, or invades mediastinal structures

Data from American Joint Committee on Cancer. Cancer staging handbook. 6th edition. New York: Springer; 2002, with permission of the American Joint Committee on Cancer (AJCC®), Chicago, IL.

status of the lymph nodes of the neck. Whereas it is unusual for glottic carcinoma to have large bulky neck disease, this is not the case with supraglottic carcinomas. Therefore, with large-volume neck disease, the impetus may be to have a surgical

Table 3
T staging of subglottic carcinoma

Stage	Description
T1	Tumor limited to the subglottis
T2	Tumor extends to vocal cord(s) with normal or impaired mobility
T3	Tumor limited to larynx with vocal cord fixation
T4a	Tumor invades cricoid or thyroid cartilage and/or invades tissues beyond the larynx (eg, trachea, soft tissues of neck including deep extrinsic muscles of the tongue, strap muscles, thyroid, or esophagus)
T4b	Tumor invades prevertebral space, encases carotid artery, or invades mediastinal structures

Data from American Joint Committee on Cancer. Cancer staging handbook. 6th edition. New York: Springer; 2002, with permission of the American Joint Committee on Cancer (AJCC®), Chicago, IL.

approach to both the primary tumor and the nodal disease. Often in this case, postoperative radiation therapy (PORT) will follow to eradicate microscopic disease.

In interpreting the images of a patient with laryngeal carcinoma who is being considered for radiotherapy, the physician should be attentive to the following issues: (1) tumor volume; (2) presence of and/or degree of cartilaginous invasion; (3) invasion by the tumor into supraglottic, glottic and subglottic compartments; (4) preepiglottic, paraglottic and soft tissue dissemination; and (5) extent of nodal disease. For laryngeal carcinoma, a maximum of 3-mm-thick sections, either with MR imaging or CT, is recommended to address these issues. In some head and neck cancer centers, submillimeter-thick images are being performed via spiral CT or 3D Fourier transformation (3DFT MR) imaging to increase staging accuracy and to produce the most accurate volumetric analysis.

Surgical treatments

Supraglottic carcinomas

Small supraglottic carcinomas of the epiglottis can be removed via endoscopic or open approaches with preservation of laryngeal integrity. For those patients with more extensive supraglottic carcinomas, a horizontal supraglottic laryngectomy or endoscopic supraglottic laryngectomy may be necessary. In classic horizontal supraglottic laryngectomy surgery, the plane of resection is across the laryngeal ventricle, with removal of a portion of the thyroid cartilage and supraglottic structures. If a patient is a candidate for this procedure, the voice quality postsurgery tends to be excellent because both arytenoids and the vocal cords are preserved. Any transglottic carcinoma or carcinoma that has paraglottic extension, or extensive invasion of the thyroid, cricoid, or arytenoid cartilages, would contraindicate this surgery. These tumors may also be approached by a supracricoid laryngectomy with cricohyoidopexy, which is discussed later.

Glottic carcinomas

Very small unilateral glottic carcinomas or carcinomas in situ have been treated endoscopically with laser therapy and/or local resection where the superficial mucosa is removed. Nonetheless, in healthy individuals, most physicians would advocate radiation therapy for T1 carcinomas,

early T2 carcinomas of the glottic larynx, and bilateral carcinoma in situ. Because of their impact on the quality of the voice, glottic carcinomas tend to present earlier than supraglottic carcinomas; therefore, the disease has smaller volume, and is amenable to radiotherapy.

For selected T1 and T2 carcinomas of the glottis that do not cross over the midline beyond one third of the contralateral vocal cord, a vertical hemilaryngectomy can be performed. This procedure removes the ipsilateral vocal cord and can remove up to one third of the contralateral vocal cord along with the thyroid cartilage on that side. The cricoid and arytenoid cartilages and the epiglottis are preserved.

When one has more extensive disease and/or glottic carcinoma that also extends into the supraglottis, arytenoid cartilage, or paraglottic space, supracricoid laryngectomies with cricohyoido (epiglottopexy) can be performed. These two surgeries effectively remove all of the thyroid cartilage and, if needed, one arytenoid cartilage, while preserving the hyoid bone, tongue base, cricoid cartilage, and one arytenoid cartilage, which are sutured together. The mobile arytenoid, pulled up by the pexy between hyoid bone and cricoid cartilage apposes against the tongue base for sphincter control against aspiration. In the case of a cricohyoidoepiglottopexy (versus the cricohyoidopexy), a portion of the epiglottis is preserved to assist sphincteric function. The voice quality after these procedures is fair to good, but in most cases, the only other surgical option is a total laryngectomy. The contraindications for supracricoid laryngectomies include bulky pre-epiglottic fat invasion leading to hyoid bone involvement, interarytenoid disease, bilateral arytenoid cartilage involvement, cricoid cartilage involvement, or subglottic extension of the carcinoma of more than 1 cm.

Subglottic carcinoma

If the subglottis is involved one cm below the vocal cords, either by direct extension from glottic or supraglottic carcinomas or as the primary site, the only surgical option is a total laryngectomy. A trial of radiotherapy with “salvage total laryngectomy” in the case of a radiation failure may be attempted. A total laryngectomy followed by PORT in most cases has a 10% to 20% better 5-year survival than a laryngectomy performed after radiation therapy failure. Nonetheless, the possibility of maintaining the patient’s voice box is present in the latter approach.

In those patients contemplating surgical treatment of the laryngeal carcinoma, some of the critical issues include the following: (1) the extent of the tumor across the midline (vertical hemilaryngectomy), (2) the presence of and degree of pre-epiglottic fat or hyoid invasion (supracricoid laryngectomy and supraglottic laryngectomy) [10], (3) transglottic or paraglottic spread (horizontal supraglottic laryngectomy), (4) interarytenoid or bilateral arytenoid invasion (supracricoid laryngectomy), (5) subglottic carcinomatous extension (all laryngeal conservation surgeries), and (6) cricoid cartilage invasion (all laryngeal conservation surgeries).

The effect of tumor volume has only recently been assessed with regard to surgical success rates. Mukherji et al [11,12] have found that supraglottic tumor volume correlates with local control rates for those patients treated surgically. The local surgical control rate for tumors with volumes of less than 16 cm³ was 98%, compared with 40% for tumors with volumes of more than 16 cm³ ($P < 0.05$).

Some patients with laryngeal carcinomas that require total laryngectomies have a good functional outcome. Esophageal speech, electrolaryngeal devices, and trachea-esophageal puncture speech devices can usually allow the patient to communicate with family and friends, although issues regarding tracheal care, stoma hygiene, and so forth make this a less desirable option. Swimming and other such activities must be curtailed. However, the rehabilitation for swallowing is less onerous after a total laryngectomy because the airway is protected via the tracheostomy. After laryngeal conservation surgery, rehabilitation organized by a skilled speech therapist is required to teach the patient to swallow without aspirating and to maximize phonatory function.

Pharynx

Posterior extension to the pharynx or upper esophageal segment is another critical step in the evaluation of a patient with laryngeal carcinoma. The functional outcome in an individual who must have both a laryngectomy and a partial or total pharyngectomy is much less optimistic than with laryngeal surgery alone. With extensive pharyngeal or esophageal disease, gastric pull-up procedures and jejunal interpositions must be contemplated if primary closure is not possible. Tubed pectoralis or free flaps, often from the radial forearm region, may also be introduced.

Chemotherapy and radiation therapy

Recently, several chemotherapy protocols have shown potential for providing improved survival when combined with radiation therapy [eg, cisplatin (+/–bleomycin sulfate) and fluorouracil] [13,14]. Thus far, these chemotherapeutic agents alone are ineffective as cures for disease (ie, without radiotherapy); however, they do seem to potentiate the benefit of radiation therapy, either by sending the cells into a more vulnerable cell-cycle stage of reproduction or merely by reducing the volume of disease radiation therapy must eliminate. Often the chemotherapy either predates or occurs concomitantly with the radiation therapy protocol. The possibility of retaining a patient's larynx when treating stage III or IV disease with this combined approach makes these types of protocols worth exploring. Clayman et al [13] concluded that whereas local control may be significantly compromised with combination chemotherapy and radiation therapy, there is no compromise in overall survival when combined with prompt surgical salvage. Prompt surgical salvage is often not possible, however, because chemotherapy- and radiation-field changes often make it difficult to detect early recurrences or to heal well after surgery.

Imaging

Compartmental spread

Because of the previously described considerations, a fundamental understanding of the anatomy of the larynx is critical to the head and neck radiologist who interprets scans of patients with laryngeal carcinoma. The distinction between supraglottic structures (epiglottis, aryepiglottic folds, false vocal cords, laryngeal ventricle, and superior superficial mucosa of the arytenoids) and glottic structures (vocal cords, anterior and posterior commissures) must be made (Fig. 1). The subglottis begins below the level of the true vocal cords and extends to the first tracheal ring.

The cartilaginous structures of the epiglottis, thyroid cartilage, arytenoid cartilage, and cricoid cartilage can be easily distinguishable on imaging. The cricoid cartilage is the only intact ring of the larynx, having a complete posterior component. The inferior margin of the arytenoid cartilage with its vocal process marks the border of the true vocal cord. The cricoarytenoid joint therefore is a readily distinguishable structure both on CT and MR

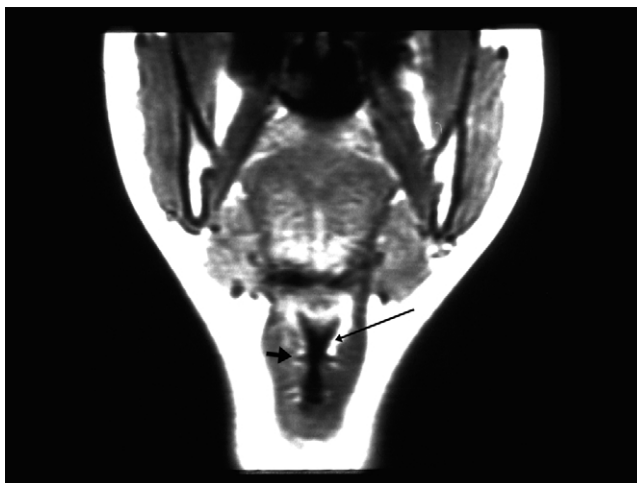


Fig. 1. Normal anatomy. This coronal T1-weighted scan shows the separation of the supraglottis from the glottis by the laryngeal ventricle (*short arrow*). Note that the paraglottic tissue at the level of the false vocal cords and above is high-intensity fat (*long arrow*). Below the ventricle, the paraglottic tissue is low-intensity muscle.

imaging that demarcates glottic from supraglottic and subglottic structures.

The paraglottic tissues can be separated into the pre-epiglottic fat, the paraglottic fat, and the thyroarytenoid muscle of the true vocal cord. Therefore, on both CT scanning (where fat is dark) and T1-weighted MR imaging (where fat is bright), the separation of pre-epiglottic and paraglottic fat of the supraglottic larynx can be distinguished from the muscular density (soft tissue on CT) or intensity (intermediate on T1-weighted MR imaging) of the thyroarytenoid muscle of the glottic larynx. The differentiation between preepiglottic fat and paraglottic fat is important from the standpoint of some of the T-staging issues that require addressing the preepiglottic fat [10]. Nonetheless, the thin septum that separates paraglottic from preepiglottic fat is often invisible on imaging studies, and therefore the border zone between these two tissues can be blurred. The significance of preepiglottic fat invasion lies in the potential need to address the base of the tongue in surgical resection and the danger to the hyoid bone, which is required in the supracricoid surgeries. Fortunately, MR imaging is a highly effective (sensitivity, 100%; specificity, 84%; accuracy, 90%) means for evaluating the preepiglottic space for tumor spread [10] (Fig. 2).

Fixation of the cord is one of the T-staging criteria for laryngeal carcinoma. While this is best assessed endoscopically, the imaging correlates to tumoral fixation are cricoarytenoid joint involvement, interarytenoid disease, and paraglottic spread [15].

Because transglottic extension is critical to the differentiation between supraglottic laryngectomy surgery for supraglottic carcinomas and vertical hemilaryngectomy surgeries for glottic carcinomas, coronal reconstructions and/or direct coronal scanning is highly recommended as part of the laryngeal imaging protocol with any modality (Fig. 3). Often, the spread is not along the mucosa (where it is evident to the endoscopist) but is in the paraglottic space and/or submucosal space where the disease may be invisible, even to the trained eye [16]. For the radiologist, the source of the tumor (whether from a glottic or supraglottic origin) may not be as obvious as at endoscopy; however, the deep spread from one compartment to the other is apparent on these imaging modalities. With laryngeal imaging multidetector CT scanning (thickness <2 mm) and the resultant excellent coronal reconstructions, the perceived benefits of direct coronal scanning by MRI can be reduced but not overcome, given the superior soft tissue resolution of MR imaging [17]. Swallowing and motion artifacts on MR imaging are more of an issue than with the ultrafast spiral CT scanning now available, where scan times are less than a minute [18].

Laryngeal cartilage invasion

For research on laryngeal cartilage invasion, credit must be given to European authors who have extensively reviewed the CT, MR imaging, and pathologic findings associated with

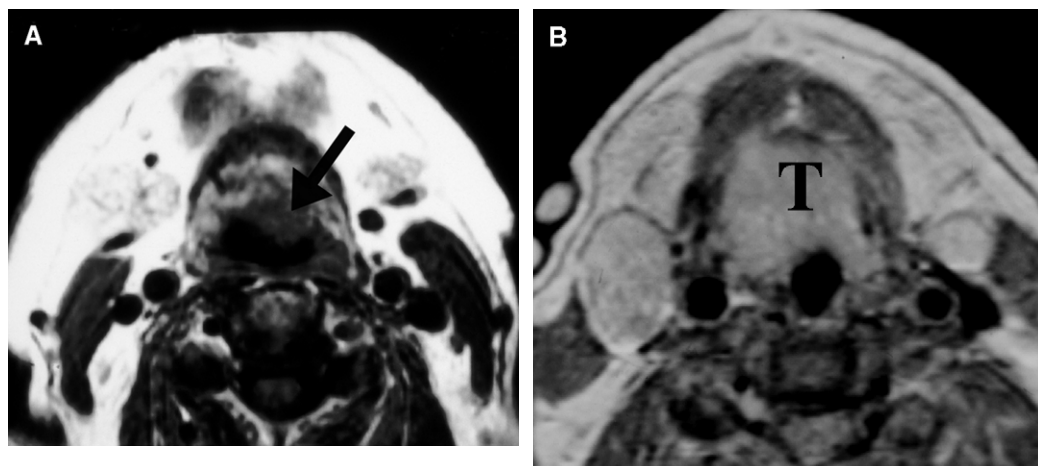


Fig. 2. Supraglottic carcinomas. (A) There is a small T1 epiglottic carcinoma (*arrow*) on a T1-weighted image with preservation of epiglottic fat. The strandiness is related to minor salivary gland tissue in this location, a source of false-positive studies. (B) On this proton density-weighted scan, soft tissue (*T*) is seen filling the space anterior to the epiglottis and posterior to the hyoid bone, the preepiglottic space. Note also the bilateral enlarged lymph nodes. Hyoid bone invasion may prohibit the supracricoid laryngectomy surgeries because the hyoid bone is needed as part of the “pexy” procedure.

cartilaginous invasion [3,16,19–29]. Because the thyroid cartilage may be either chondrified or ossified, it is the most difficult cartilage of the larynx to evaluate for tumor erosion (Fig. 4). The density of nonossified cartilage is similar to squamous cell carcinoma and has similar intensity on

T1-weighted scans. Becker et al [20] looked at several CT findings, including sclerosis of cartilage, erosion of cartilage, lysis of cartilage, irregular border to cartilage, extra laryngeal tumor beyond the



Fig. 3. Transglottic carcinoma. Coronal T1-weighted scan shows a mass (*T*) that crosses the plane of the supraglottic and glottic larynx, extending in a paraglottic location into the thyroarytenoid muscle. Note the width of the paraglottic soft tissue on the left side compared with the right side. This lesion was seen only as a supraglottic mucosal lesion, and the extent across the plane of the laryngeal ventricle was unexpected.

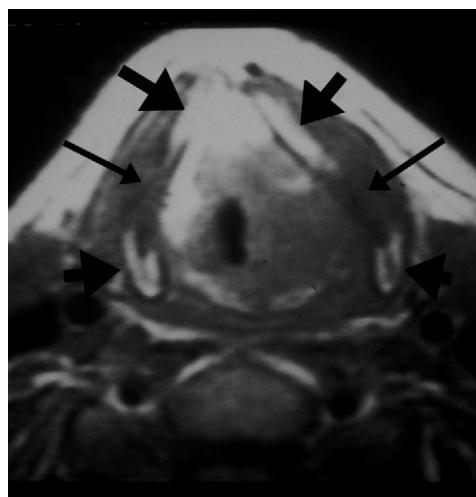


Fig. 4. This supraglottic carcinoma had both a mucosal lesion and a deep submucosal mass on the left side. Note that the thyroid cartilage, which is normal, shows areas of high signal intensity on the T1-weighted scan, representing ossification (*short arrows*), and areas of lower signal intensity, representing chondrification (*long arrows*). On a fast-spin echo T2-weighted scan or T1-weighted scan with fat suppression, all of these areas would be dark.

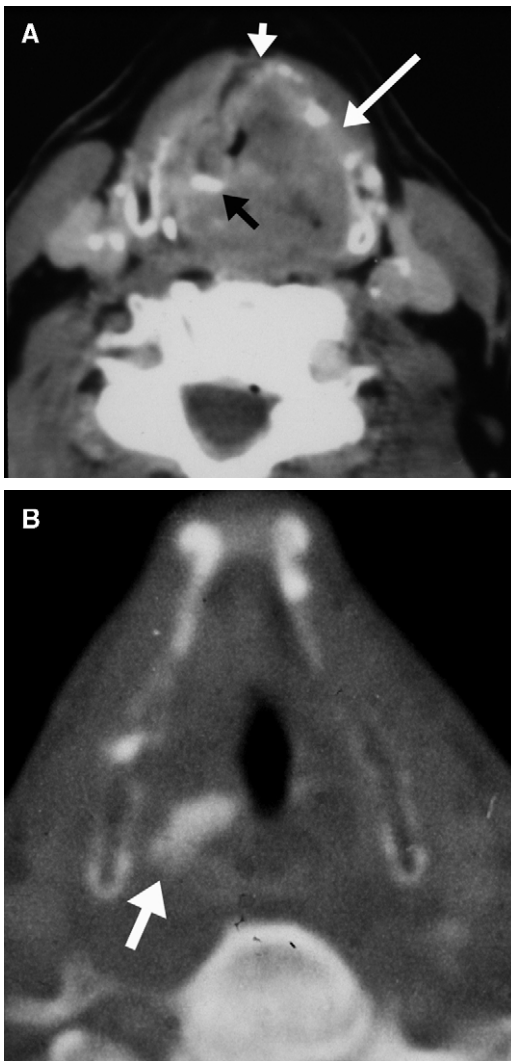


Fig. 5. (A) This transglottic carcinoma, which was located bilaterally, shows some of the features of cartilage invasion on CT scan. The arytenoid cartilage on the right is sclerotic (*black arrow*). The thyroid cartilage on the left is bowing outward (*long white arrow*). There are focal erosions and low-density areas in the midline near the thyroid notch (*short white arrow*). (B) Although this arytenoid cartilage was sclerotic (*arrow*), tumor had only extended to the perichondrium. The changes were from inflammatory reactive change rather than neoplastic infiltration from the true vocal cord cancer. (C) Note the eroded edges (*short arrow*) of the cricoid cartilage to the right of midline, with a sclerotic area (*long arrow*) to the left of midline. This was an extensive supraglottic carcinoma which spread transglottically and posteriorly.

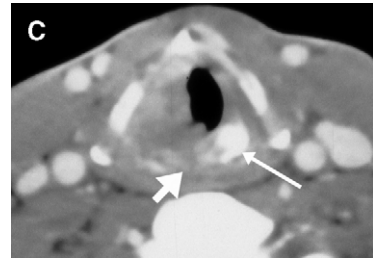


Fig. 5 (*continued*)

cartilage, and cartilage expansion, to determine which of these factors had the highest degree of reliability in evaluating the thyroid, cricoid, and arytenoid cartilage (Fig. 5). Whereas sclerosis was the most sensitive (83%) criterion in all of the cartilages, histopathologically it often corresponded to reactive inflammation, particularly in the thyroid cartilage (specificity, 40%). Becker et al [20] found that extralaryngeal tumor and erosion or lysis of cartilage yielded the highest specificity (83% specificity with a sensitivity of 71%) for thyroid cartilage invasion. The identification of tumor adjacent to nonossified cartilage, a serpiginous contour, and obliteration of marrow space also were relatively specific (86–95%) findings for arytenoid and cricoid cartilage invasion (but not for the thyroid cartilage with 41–55% specificity). These criteria alone were not sensitive signs (7–55% sensitivity) of invasion in the arytenoid and cricoid cartilage and were non-specific in the thyroid cartilage. Combining the effects of extralaryngeal tumor, sclerosis, and lysis provided the highest degree of accuracy in Becker et al's [20] studies, approximately 80% for the thyroid cartilage. In contrast, the authors found the accuracy rates for cricoid and arytenoid cartilage invasion were much higher than that of thyroid cartilage invasion, given findings of sclerosis or lysis. No single criterion showed both sensitivity and specificity of more than 90%. Combining criteria enabled an overall sensitivity for cartilaginous invasion of 91% (with an associated specificity of 68%) or an overall specificity of 79% (with an associated sensitivity of 82%) [20].

Others have previously reported that sclerosis of cartilage may be a reactive change to adjacent tumor without truly reflecting cartilaginous invasion by tumor. The positive predictive value of sclerosis of cartilage for pathologic invasion was approximately 50% in a study by Munoz et al [30].

For MR imaging findings, high signal intensity within the cartilage on fat-suppressed fast-spin echo T2-weighted scans and/or cartilaginous

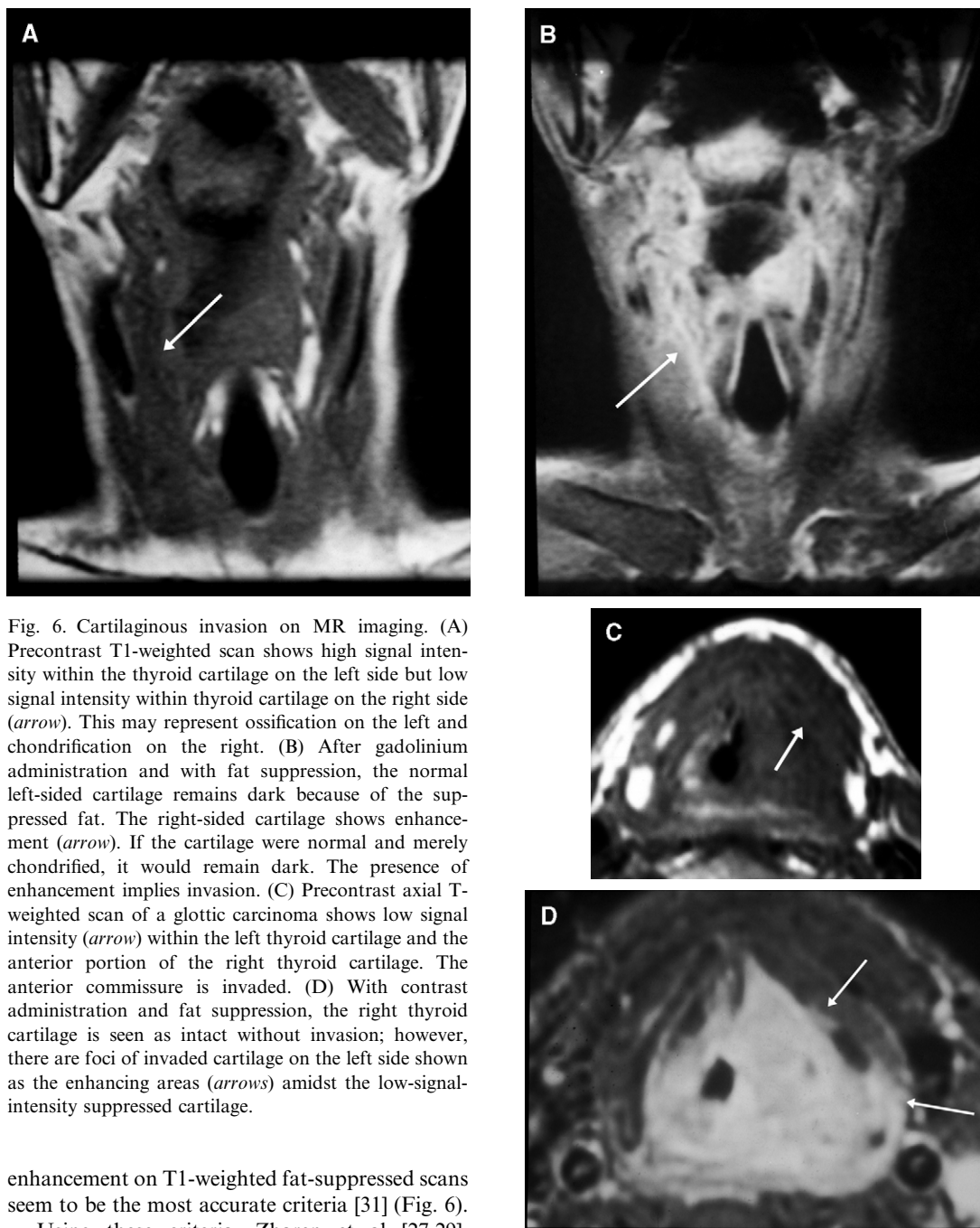


Fig. 6 (continued)

enhancement on T1-weighted fat-suppressed scans seem to be the most accurate criteria [31] (Fig. 6).

Using these criteria, Zbaren et al [27,29], Becker et al [20,21], and Castelijns et al [22,25] have demonstrated, in radiologic-pathologic studies of laryngeal cartilage invasion, that MR imaging (89%) is more sensitive than CT (64%) for the detection of tumoral infiltration of the laryngeal cartilage (Tables 4, 5). Unfortunately, such sensitivity (92%) comes at a cost of decreased specificity

(79%). The specificity of CT is higher than MR imaging in all reported studies. When the overall accuracy is computed, MR imaging is more accurate than CT by 2% to 10% in side-by-side

Table 4
Meta-analysis of ability of MRI to assess laryngeal cartilage^a

Reference	True positive	False positive	True negative	False negative
Zbaren et al, 1997 [29]	59	25	81	3
Becker et al, 1995 [21]	55	22	118	7
Zbaren et al, 1996 [28]	52	24	69	3
Zbaren et al, 1997 [27]	44	30	94	3
Castelijns et al, 1988 [24]	33	5	38	4
Total	243	106	400	20

^a Sensitivity, 92.4%; specificity, 79.1%; accuracy, 83.6% (643 of 769).

comparisons; however, the differences are not statistically significant. If one performs a meta-analysis of the major studies (see Tables 4, 5), the accuracy of MR imaging is better than CT scanning on a McNemar test with a *p* value of 0.06 (see Table 4). Many authors therefore recommend MR imaging as the primary means of evaluating the cartilage in patients with laryngeal carcinomas [4,9,22,32–35].

The ramifications of these comparative studies are that use of MR imaging will contribute to the number of false-positive cases, leading to removal of the larynx or the suspected cartilage in some cases where there is no tumor found on subsequent pathology. This is because the inflammatory/reactive changes associated with adjacent neoplasm, which may cause high signal intensity on T2-weighted scan and even contrast enhancement into the cartilage, are the same findings as those of direct tumoral invasion. Thus, some individuals would be counseled to have a total laryngectomy or supracricoid laryngectomy when they could be treated sufficiently with other, cartilage-sparing voice conservation surgeries. CT, however, by virtue of a preponderance of false-negative studies, could lead to residual tumor being left behind and recurrence after conservation surgery. Combining the two modalities (eg, when the MR scan is positive for cartilage invasion, a corroborating CT scan is performed) may be the most effective

strategy for evaluating a patient with laryngeal carcinoma [16]. If the MR scan is negative for cartilage invasion, CT is unnecessary because the risk of a false-negative MR imaging result is less than 10%. In some reports, no false-negative studies have been found [32].

Other important imaging findings

There are other pertinent findings that should be searched for in a patient who has laryngeal carcinoma. Involvement of the anterior commissure is clinically significant because the violation of the Broyle's ligament between the anterior commissure and the thyroid cartilage when the former is invaded leads to a higher rate of cartilaginous infiltration (Fig. 7). The anterior commissure should be pencil-point thin, and there should be no soft tissue in the interthyroidal notch. Spread here should lead to close scrutiny of the thyroid cartilage for changes.

Subglottic extension of tumors and/or cricoid cartilage invasion virtually ensures that the patient will require a total laryngectomy (Fig. 8). The Delphian node seen anterior to the trachea is another indicator of subglottic extension of laryngeal carcinoma and/or a subglottic primary tumor. The level II and level III jugular chains are the most common lymph node groups to be involved with laryngeal carcinomas, usually supraglottic in primary origin.

Table 5
Meta-analysis of ability of CT to assess laryngeal cartilage^a

Reference	True positive	False positive	True negative	False negative
Zbaren et al, 1997 [29]	40	12	94	22
Becker et al, 1995 [21]	41	9	131	21
Zbaren et al, 1996 [28]	37	12	81	18
Zbaren et al, 1997 [27]	34	17	107	13
Castelijns et al, 1988 [24]	17	4	39	20
Total	169	54	452	94

^a Sensitivity, 64.3%; specificity, 89.3%; accuracy, 80.8% (621 of 769).



Fig. 7. Anterior commissure invasion. At the level of the true vocal cords, the anterior commissure (C) should be less than 1- to 2-mm thick. This lesion extends across midline to the contralateral left side vocal cord. The patient may still be a candidate for a vertical hemilaryngectomy, because the posterior two thirds of the contralateral true vocal cord is still intact.

Spread through the cricothyroid membrane may lead to cancer abutting on the carotid sheath structures. Whereas the jugular vein is easily removed as part of a neck dissection, the medial placement of the internal and or common carotid artery may put it at jeopardy with aggressive laryngeal carcinomas; however, this is more common with piriform sinus hypopharyngeal carcinomas [27,36]. If the carotid artery is circumferentially involved by tumor by more than 225° to 270° of its circumference, it is likely that it will not be able to be salvaged at the time of primary tumor resection [37,38]. Temporary balloon occlusion in advance of surgical extirpation of the encased carotid or other treatment modalities may be recommended.

Post-treatment imaging

Radiation therapy

During or after radiation therapy, the entire laryngopharyngeal architecture may be swollen [39]. The normal fat in the pre-epiglottic fat planes and the paraglottic fat may have a stippled appearance with edema and/or dilated lymphatics. The epiglottis and aryepiglottic folds and arytenoids commonly are swollen after radiation therapy; however, usually they maintain their normal shapes. The true vocal cord structures and the subglottic larynx by and large do not show the same

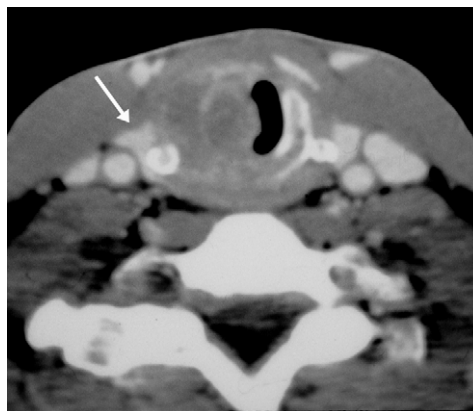


Fig. 8. Subglottic carcinoma. This mass has eroded the cricoid cartilage and compromises the airway. Note also that there is extralaryngeal spread into the soft tissues medial to a faintly enhancing thyroid gland (arrow). Based on the extension below the true vocal cords and the invasion of the cricoid cartilage, the patient will require a total laryngectomy.

degree of mucositis as the supraglottic structures (Fig. 9).

Degeneration and lysis of the laryngeal cartilage and collapse of the normal architecture mark chondronecrosis. The airway may be compromised. Superimposed infection with air trapped within the interstices of the necrotic cartilage may be seen in this instance. Fragmentation, sclerosis, sloughing, and lysis may be seen on CT or MR imaging in a patient with chondronecrosis [40]. The differentiation of recurrent carcinoma from chondroradionecrosis is nearly impossible at that stage [41], although positron emission tomography scans may suggest tumoral recurrences if hot on 2-[F-18]fluoro-2-deoxy-D-glucose. Even in the detection of recurrent tumor, imaging is often unsatisfactory and endoscopy remains the preferred imaging method for mucosal recurrences [25,42]. Deep recurrences rely on a comparison of follow-up imaging studies.

An absence of response of the laryngeal tumor on postradiotherapy follow-up CT or lesions that are reduced by 50% or less at 4 months are highly suspicious for treatment failure [43].

Surgical treatment

After laryngeal conservation surgery, the normal architecture of the larynx is grossly distorted. In many cases, a single arytenoid from the supracricoid laryngectomy is used to appose to the base

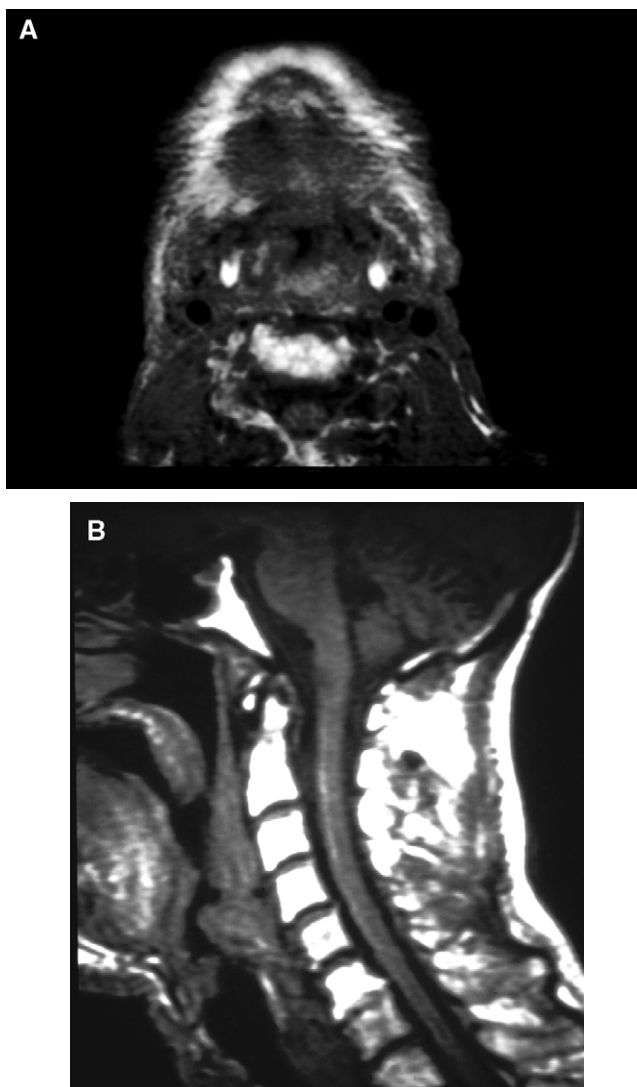


Fig. 9. Radiation effect. (A) After radiation, the supraglottic mucosa is often very thick and the subcutaneous tissue shows stranding from edema and prominent lymphatics. This effect is even more dramatic if the patient has had neck dissections, because the normal lymphatic drainage through the nodes is no longer present. Dilated dermal lymphatics can be striking. (B) The sagittal scan shows the telltale signs of radiation in the vertebral bodies and the diffuse thickening of the pharynx and larynx without a focal mass.

of the tongue or epiglottis to create a sphincter for speech and airway protection. The thyroid cartilage and usually the epiglottis will have been removed unless a cricohyoidoepiglottopexy has been performed. The cricoid cartilage is elevated. Redundant mucosa and a narrowed laryngeal airway are common in the postoperative setting of this surgery.

After a total laryngectomy, the normal cartilaginous structures of the larynx will have been

removed. In its place is the “neopharynx,” which is derived by suturing the two open ends of the hypopharyngeal and/or pharyngeal tissues together into a tube to be used for swallowing. This mucosa would preoperatively have been in contiguity with the laryngeal mucosa, and therefore marginal recurrences are possible (Fig. 10).

A stoma is usually placed at the third or fourth tracheal rings, and this usually has uniform thickness in its walls. Recurrences at the stoma or

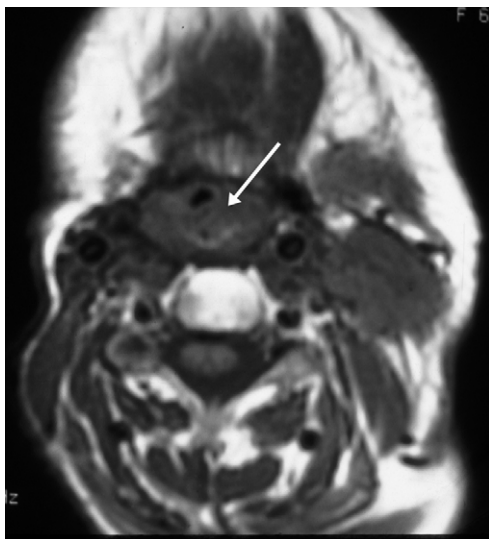


Fig. 10. Recurrent carcinoma. After a total laryngectomy, a collapsed air-containing structure, the neopharynx, should be seen. In this case, the posterior wall of the neopharynx on the left side is bulging (arrow), representing recurrent tumor. Note also that the patient has had bilateral neck dissections and there is a large nodal mass on the left side.

within the neopharynx are identified as focal areas of nodularity, intraluminal soft tissue, exophytic masses, or areas of necrosis. These will typically occur at the cut margins of the surgery where the tumor previously had been. Stomal recurrences portend a negative prognosis with limited surgical options for cure [44,45]. Risk factors for stomal recurrence include those patients with salvage laryngectomy, advanced T- or N-stage disease, subglottic involvement, or preoperative requirement of a tracheotomy. Stomal recurrences arising from the superior part of the stoma are treated with a mediastinal node dissection and the transfer of a myocutaneous flap. Superior recurrences have a more favorable prognosis than those that recur along the lower stomal border. These latter recurrences, and those invading the esophagus or extending into the mediastinum, have limited survivability, even over the short term [46].

Other tumors

Squamous cell carcinoma accounts for more than 90% of malignant neoplasms in the larynx; however, in the appropriate setting, plasmacytomas or amyloidomas may be found in individuals

who may have systemic multiple myeloma. In general, these lesions are submucosal in location and therefore do not have the same endophytic growth pattern as squamous cell carcinoma. Lymphoma of the larynx may also occur and is nondescript in its appearance.

A specific diagnosis can be made when dealing with a chondroid lesion of the larynx. The most common site for chondrosarcomas of the larynx is the cricoid cartilage, and these present with the “popcorn”-style calcifications seen with most chondroid lesions (Fig. 11). These are slow-growing tumors with a good prognosis; however, because they infiltrate the cricoid cartilage, the patient often ultimately requires a complete laryngectomy.

Benign neoplasms of the larynx include neurogenic tumors, minor salivary gland tumors, such as pleomorphic adenomas (all usually seen as submucosal masses), and laryngotracheal polyps. Adenoid cystic carcinoma and adenocarcinoma are the most common minor salivary gland malignancies. Examples of perineural spread, known to be a significant risk factor in association with adenoid cystic carcinoma, have not been well described in the larynx.

Summary

Knowing the surgical options for treating laryngeal carcinomas and the factors that are used to select patients for radiation therapy leads to a more comprehensive interpretation of neck scans in patients with laryngeal tumors (Table 6). Critical factors include tumor volume; cartilaginous invasion; spread across supraglottic-glottic-subglottic

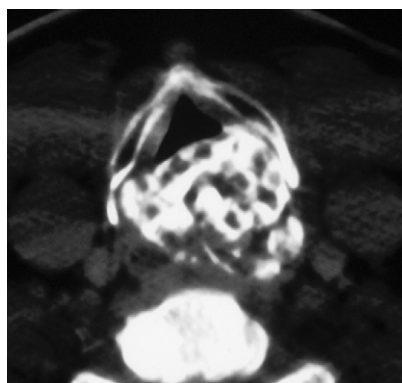


Fig. 11. Chondrosarcoma of the cricoid cartilage. The “popcorn”-style chondroid matrix of this mass and its relative lack of invasion confirm the diagnosis of chondrosarcoma.

Table 6

Review of surgical options for laryngeal cancer

Supraglottic lesions

Suprahypoid epiglottic lesions without extension to tongue base: laser endoscopic epiglottectomy, open epiglottectomy
 Suprahypoid epiglottic lesion with minimal extension to vallecula and tongue base: open epiglottectomy with tongue base resection

Epiglottic, aryepiglottic folds and false cord involvement: endoscopic laser supraglottic laryngectomy, open standard supraglottic laryngectomy^a

Supraglottic lesion with extension to true vocal folds or one arytenoid cartilage or paraglottic space and ability to preserve the hyoid bone: supracricoid partial laryngectomy with CHP preserving at least one functional arytenoid

Glottic lesions

Lesion confined to midcord: endoscopic partial cord excision

Lesion involves true cord without extension to arytenoids cartilage or anterior commissure: endoscopic laser cordectomy, open cordectomy, vertical partial laryngectomy

Lesion involves true cord and extends to anterior commissure, but not beyond contralateral anterior one third of cord: extended vertical partial laryngectomy, epiglottic laryngoplasty

Lesion involves true vocal cord and extends to involve more than one third of contralateral cord or one arytenoid cartilage or paraglottic space: supracricoid partial laryngectomy with CHEP preserving at least one functional arytenoid

Subglottic lesions

Any lesion that extends more than 1 cm into the subglottis requires total laryngectomy. In these cases, the cricoid cartilage would not be able to be preserved. It is an essential foundation for any organ preservation surgery.

Contraindications to organ preservation laryngeal surgery

1. Extralaryngeal spread or involvement of outer perichondrium of thyroid cartilage^b
2. Cricoid cartilage involvement
3. Interarytenoid or posterior commissure involvement
4. >1 cm subglottic extension
5. Involvement of the hyoid bone is a contraindication to supracricoid partial laryngectomy

^a If pre-epiglottic space involvement extends to involve hyoid bone, resect the hyoid bone.

^b Thyroid cartilage involvement is not a contraindication to supracricoid partial laryngectomy because all of the thyroid cartilage is removed.

Abbreviations: CHP, cricohyoidopexy; CHEP, cricohyoidepiglottopexy.

boundaries; infiltration of preepiglottic, paraglottic, and pharyngeal planes; and nodal disease. MR imaging offers greater sensitivity to cartilaginous invasion than CT but leads to a high rate of false-positive studies, which decreases its overall accuracy. Thin-section CT with multiplanar capability is competitive with direct coronal MR scanning and benefits from high specificity and submillimeter section thickness, if multidetector units are employed. Overall, the head and neck radiologist plays an invaluable role in assessing the extent of disease and therefore influences the appropriate selection from the available treatment options.

References

- [1] Freeman DE, Mancuso AA, Parsons JT, et al. Irradiation alone for supraglottic larynx carcinoma: can CT findings predict treatment results? *Int J Radiat Oncol Biol Phys* 1990;19:485–90.
- [2] Lee WR, Mancuso AA, Saleh EM, et al. Can pretreatment computed tomography findings predict local control in T3 squamous cell carcinoma of the glottic larynx treated with radiotherapy alone? *Int J Radiat Oncol Biol Phys* 1993;25:683–7.
- [3] Castelijns JA, van den Brekel MW, Tobi H, et al. Laryngeal carcinoma after radiation therapy: correlation of abnormal MR imaging signal patterns in laryngeal cartilage with the risk of recurrence. *Radiology* 1996;198:151–5.
- [4] Castelijns JA, van den Brekel MW, Smit EM, et al. Predictive value of MR imaging-dependent and non-MR imaging-dependent parameters for recurrence of laryngeal cancer after radiation therapy. *Radiology* 1995;196:735–9.
- [5] Mukherji SK, Mancuso AA, Mendenhall W, et al. Can pretreatment CT predict local control of T2 glottic carcinomas treated with radiation therapy alone? *AJNR Am J Neuroradiol* 1995;16:655–62.
- [6] Isaacs JH Jr, Mancuso AA, Mendenhall WM, et al. Deep spread patterns in CT staging of T2–4 squamous cell laryngeal carcinoma. *Otolaryngol Head Neck Surg* 1988;99:455–64.

- [7] Murakami R, Baba Y, Furusawa M, et al. Early glottic squamous cell carcinoma. Predictive value of MR imaging for the rate of 5-year local control with radiation therapy. *Acta Radiol* 2000;41:38–44.
- [8] Tart RP, Mukherji SK, Lee WR, et al. Value of laryngeal cartilage sclerosis as a predictor of outcome in patients with stage T3 glottic cancer treated with radiation therapy. *Radiology* 1994; 192:567–70.
- [9] Castelijns JA, Golding RP, van Schaik C, et al. MR findings of cartilage invasion by laryngeal cancer: value in predicting outcome of radiation therapy. *Radiology* 1990;174:669–73.
- [10] Loevner LA, Yousem DM, Montone KT, et al. Can radiologists accurately predict preepiglottic space invasion with MR imaging? *AJR Am J Roentgenol* 1997;169:1681–7.
- [11] Mukherji SK, O'Brien SM, Gerstle RJ, et al. Tumor volume: an independent predictor of outcome for laryngeal cancer. *J Comput Assist Tomogr* 23;50–4.
- [12] Mukherji SK, O'Brien SM, Gerstle RJ, et al. The ability of tumor volume to predict local control in surgically treated squamous cell carcinoma of the supraglottic larynx. *Head Neck* 2000;22: 282–7.
- [13] Clayman GL, Weber RS, Guillaumondegui O, et al. Laryngeal preservation for advanced laryngeal and hypopharyngeal cancers. *Arch Otolaryngol Head Neck Surg* 1995;121:219–23.
- [14] Shirinian MH, Weber RS, Lippman SM, et al. Laryngeal preservation by induction chemotherapy plus radiotherapy in locally advanced head and neck cancer: the M. D. Anderson Cancer Center experience. *Head Neck* 1994;16:39–44.
- [15] Mancuso AA, Tamakawa Y, Hanafee WN. CT of the fixed vocal cord. *AJR Am J Roentgenol* 1980; 135:7529–34.
- [16] Becker M. Diagnosis and staging of laryngeal tumors with CT and MRI [In German]. *Radiologe* 1998;38:93–100.
- [17] Korkmaz H, Cerezci NG, Akmansu H, et al. A comparison of spiral and conventional computerized tomography methods in diagnosing various laryngeal lesions. *Eur Arch Otorhinolaryngol* 1998; 255:149–54.
- [18] Mukherji SK, Castillo M, Huda W, et al. Comparison of dynamic and spiral CT for imaging the glottic larynx. *J Comput Assist Tomogr* 1995;19:899–904.
- [19] Becker M. Larynx and hypopharynx. *Radiol Clin North Am* 1998;36:891–920.
- [20] Becker M, Zbaren P, Delavelle J, et al. Neoplastic invasion of the laryngeal cartilage: reassessment of criteria for diagnosis at CT. *Radiology* 1997;203: 521–32.
- [21] Becker M, Zbaren P, Laeng H, et al. Neoplastic invasion of the laryngeal cartilage: comparison of MR imaging and CT with histopathologic correlation. *Radiology* 1995;194:661–9.
- [22] Castelijns JA, Gerritsen GJ, Kaiser MC, et al. Diagnosis of laryngeal cartilage invasion by cancer: comparison of CT and MRI. *Radiology* 1988;167: 199–206.
- [23] Castelijns JA, Gerritsen GJ, Kaiser MC, et al. MRI of normal or cancerous laryngeal cartilages: histopathologic correlation. *Laryngoscope* 1987;97: 1085–93.
- [24] Castelijns JA, Gerritsen GJ, Kaiser MC, et al. Invasion of laryngeal cartilage by cancer: comparison of CT and MR imaging. [published erratum appears in *Radiology* 1988;168:582]. *Radiology* 1988;167:199–206.
- [25] Castelijns JA, Kaiser MC, Valk J, et al. MR imaging of laryngeal cancer. *J Comput Assist Tomogr* 1987;11:134–40.
- [26] Castelijns JA, Kaiser MC, Valk J, et al. Diagnosis of laryngeal carcinoma using proton spin resonance tomography [In Dutch]. *Ned Tijdschr Geneesk* 1989;133:1268–73.
- [27] Zbaren P, Becker M, Lang H. Pretherapeutic staging of hypopharyngeal carcinoma. Clinical findings, computed tomography, and magnetic resonance imaging compared with histopathologic evaluation [published erratum appears in *Arch Otolaryngol Head Neck Surg* 1998;124:231]. *Arch Otolaryngol Head Neck Surg* 1997;123:908–13.
- [28] Zbaren P, Becker M, Lang H. Pretherapeutic staging of laryngeal carcinoma. Clinical findings, computed tomography, and magnetic resonance imaging compared with histopathology. *Cancer* 1996;77:1263–73.
- [29] Zbaren P, Becker M, Lang H. Staging of laryngeal cancer: endoscopy, computed tomography and magnetic resonance versus histopathology. *Eur Arch Otorhinolaryngol Suppl* 1997;1:S117–22.
- [30] Munoz A, Ramos A, Ferrando J, et al. Laryngeal carcinoma: sclerotic appearance of the cricoid and arytenoid cartilage—CT-pathologic correlation. *Radiology* 1993;189:433–7.
- [31] Sakai F, Sone S, Kiyono K, et al. MR evaluation of laryngohypopharyngeal cancer: value of gadopentetate dimeglumine enhancement. *AJNR Am J Neuroradiol* 1993;14:1059–69.
- [32] Declercq A, Van den Hauwe L, Van Marck E, et al. Patterns of framework invasion in patients with laryngeal cancer: correlation of in vitro magnetic resonance imaging and pathological findings. *Acta Otolaryngol* 1998;118:892–5.
- [33] Giron J, Joffre P, Serres-Cousine O, et al. Magnetic resonance imaging of the larynx. Its contribution compared to x-ray computed tomography in the pre-therapeutic evaluation of cancers of the larynx. Apropos of 90 surgical cases [In French]. *Ann Radiol (Paris)* 1990;33:170–84.
- [34] Steinkamp HJ, Heim T, Maurer J, et al. The value of magnetic resonance tomography and computed tomography in the tumor staging of laryngeal and hypopharyngeal carcinomas [In German]. *Rofo*

- Fortschr Geb Rontgenstr Neuen Bildgeb Verfahr 1993;158:437–44.
- [35] Wenig BL, Ziffra KL, Mafee MF, et al. MR imaging of squamous cell carcinoma of the larynx and hypopharynx. *Otolaryngol Clin North Am* 1995; 28:609–19.
- [36] Larsson S, Mancuso A, Hoover L, et al. Differentiation of pyriform sinus cancer from supraglottic laryngeal cancer by computed tomography. *Radiology* 1981;141:427–32.
- [37] Takashima S, Takayama F, Wang Q, et al. Differentiated thyroid carcinomas. Prediction of tumor invasion with MR imaging. *Acta Radiol* 2000; 41:377–83.
- [38] Yousem DM, Hatabu H, Hurst RW, et al. Carotid artery invasion by head and neck masses: prediction with MR imaging. *Radiology* 1995;195:715–20.
- [39] Mukherji SK, Mancuso AA, Kotzur IM, et al. Radiologic appearance of the irradiated larynx. Part I. Expected changes. *Radiology* 1994;193:141–8.
- [40] Hermans R, Pameijer FA, Mancuso AA, et al. CT findings in chondroradionecrosis of the larynx. *AJNR Am J Neuroradiol* 1998;19:711–8.
- [41] Briggs RJ, Gallimore AP, Phelps PD, et al. Laryngeal imaging by computerized tomography and magnetic resonance following radiation therapy: a need for caution. *J Laryngol Otol* 1993;107:565–8.
- [42] Baba Y, Furusawa M, Murakami R, et al. Role of dynamic MRI in the evaluation of head and neck cancers treated with radiation therapy. *Int J Radiat Oncol Biol Phys* 1997;37:783–7.
- [43] Mukherji SK, Mancuso AA, Kotzur IM, et al. Radiologic appearance of the irradiated larynx. Part II. Primary site response. *Radiology* 1994;193: 149–54.
- [44] Krespi YP, Wurster CF, Sisson GA. Immediate reconstruction after total laryngopharyngoesophagectomy and mediastinal dissection. *Laryngoscope* 1985;95:156–61.
- [45] Sisson GA, Goldman ME. Pectoral myocutaneous island flap for reconstruction of stomal recurrence. *Arch Otolaryngol* 1981;107:446–9.
- [46] Sisson GA. Mediastinal dissection—resectability and curability of stomal recurrence after total laryngectomy. *Auris Nasus Larynx* 1985;12(Suppl): S61–6.