Techniques in Laryngeal Imaging—The State of the Art and Beyond

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To date, computed tomography (CT) and magnetic resonance imaging (MRI) serve as the main techniques for imaging the larynx, although the use of positron emission tomography (PET) is increasing. Laryngeal trauma and evaluation of laryngeal malignancy represent the two most common indications for radiographic evaluation of the larynx. It is evaluation of the latter, however, to which the current preponderance of research effort has been dedicated. While CT and MRI are the most commonly used diagnostic media in laryngeal diseases, new techniques such as virtual laryngoscopy are allowing for non-invasive evaluation of the airway in detail that rivals that provided by traditional endoscopy.

Laryngeal Cancer

Laryngeal cancer is the most common non-cutaneous cancer in the head and neck. It is the 11th most commonly reported human malignancy, with more than 100,000 cases reported annually worldwide. Approximately 10,000 new cases are diagnosed in the US every year. Laryngeal cancer tends to affect adults in the fifth to eighth decades of life. Typical risk factors include alcohol and tobacco abuse. Men are traditionally more commonly affected, but the incidence among women is increasing as smoking in this group has become more common. Hoarseness is the most commonly affected, but the incidence among women is increasing as smoking in this group has become more common. Squamous cell carcinoma represents the highest in patients with stage I or II disease, with five-year survival of approximately 80%; five-year survival declines considerably to 60% or less for patients with stage III or stage IV disease.

Paramount to proper treatment selection is precise tumor staging. Staging is determined by the extent of the primary tumor and its impact on vocal fold function, the presence of regional nodal metastases, and the presence or absence of distant metastases. CT and MRI are important in the staging of the degree of laryngeal involvement by the tumor, particularly with regard to the presence or absence of cartilage invasion. The sensitivity and specificity of CT range from 46 to 64% and from 87 to 91%, respectively, while the sensitivity and specificity of MRI range from 89 to 95% and from 74 and 88%, respectively. Both modalities are often combined in order to obtain as accurate an estimation of stage as possible.

Tumors that invade the anterior commissure or the cartilage, that extend to more than one subsite of the larynx, or that impair vocal fold mobility (implying extensive invasion of the paraglottic space) represent advanced disease and may have a higher likelihood of radiation failure (see Figure 1). Because the efficacy of radiation therapy to control local disease is dependent on stage at presentation, accurate estimation of the tumor extent is critical in selecting the most appropriate therapy. It is generally accepted that cartilage invasion portends a worse prognosis and a higher risk for failure of radiation therapy to control the disease. Cartilage invasion has been shown to correlate with a higher local failure rate and is a factor that traditionally argues for surgery rather than radiation therapy.

Vocal fold immobility and tumor volume greater than 3cm³ have been shown to be strong predictors of local recurrence following initial treatment. Other MRI findings that have also been shown to be useful in predicting initial local control of glottic cancer include supra- or subglottic extension, extension to the pre-epiglottic space, and extralaryngeal tumor extension. However, the most significant predictors of treatment failure were those that correlated with cartilage invasion: abnormal signal intensity in cartilage and, more importantly, intermediate T2 signal intensity in cartilage. The overall reported sensitivity of MRI for the detection of neoplastic cartilage invasion is 89–94%, the specificity is 74–88%, and the negative predictive value (NPV) is 94–96%. Different criteria have been proposed to evaluate the extent of cartilage invasion by tumor, including extralaryngeal invasion: abnormal signal intensity in cartilage and, more importantly, intermediate T2 signal intensity in cartilage. The overall reported sensitivity of MRI for the detection of neoplastic cartilage invasion is 89–94%, the specificity is 74–88%, and the negative predictive value (NPV) is 94–96%. Different criteria have been proposed to evaluate the extent of cartilage invasion by tumor, including extralaryngeal...
tumor, sclerosis, tumor adjacent to non-ossified cartilage, serpiginous contour, erosion or lysis, obliteration of marrow space, cartilaginous blow-out, and bowing.\textsuperscript{17} Tumor seen on both sides of the cartilage is commonly accepted as the most unambiguous sign of cartilage invasion.\textsuperscript{18} Among these criteria, the combination of extralaryngeal tumor and erosion or lysis in the thyroid, cricoid, and arytenoids cartilage, coupled with sclerosis in the cricoid and arytenoids cartilage, offers an overall sensitivity of 82\%, an overall specificity of 79\%, and an overall NPV of 91\%.\textsuperscript{19}

Recurrence of laryngeal cancer following initial chemoradiotherapy represents a particularly challenging diagnostic dilemma. Treatment induces several changes, including mucosal edema, perichondritis, and chondroradionecrosis.\textsuperscript{20} Diagnostic laryngoscopy and biopsy have a high false-negative rate, possibly due to the fact that recurrent tumors may be submucosal and multifocal.\textsuperscript{21} Endoscopy may accurately stage the extent of recurrence only in up to 50\% of cases, with the ability of CT and MRI to evaluate the extent of recurrence being as low as 24\%.\textsuperscript{22}

Laryngeal Trauma

Blunt force trauma to the anterior neck can cause fractures of the thyroid and cricoid cartilages, as well as soft-tissue injuries to the interior of the larynx (see Figure 2). These types of injury were more common in the pre-seatbelt era, wherein the unrestrained passenger would strike the steering wheel with the neck in an extended position. Penetrating trauma to the neck can also injure the larynx, generally with concomitant trauma to surrounding structures such as the esophagus or carotid artery. Prior to radiographic evaluation, intubation or tracheostomy may be necessary to stabilize the patient's airway prior to scanning, as the airway may be compromised secondary to edema, aspiration of blood, or laryngotracheal separation. Airway edema and resulting airway compromise may present later, however, and the radiologist should be alert to this possibility when patients with a suspected laryngeal fracture and an unsecured airway are referred to the radiology department for scanning. It is better to secure the airway semi-electively in a controlled environment such as the operating or emergency room rather than emergently in the confines of the CT scanner.

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CT remains the radiographic study of choice owing to its superior resolution of the laryngeal cartilaginous framework and the degree of airway compromise.\textsuperscript{23} Subtle fractures may be difficult to detect owing to the incomplete or heterogeneous pattern of calcification of the thyroid cartilages. In the presence of subcutaneous emphysema, laryngeal injury should be highly suspected even when a grossly displaced fracture is not evident. In addition, there must be a high degree of suspicion for concomitant injury to the cervical spine and esophagus in the setting of laryngeal trauma, as a frontal blow to the neck transmits blunt force posteriorly to these structures as well.

Traumatic intubation of the larynx can cause dislocation of the cricoarytenoid joint, which endoscopically can mimic a vocal fold paralysis. In cricoarytenoid subluxation, axial and sagittal non-contrast views of the larynx will demonstrate anterior and inferior displacement of the arytenoid in relation to the cranial aspect of the cricoid ring, distinguishing this from true vocal fold paralysis.\textsuperscript{24} In true vocal fold paralysis, the ipsilateral pyriform sinus may appear widened, the arytenoid may appear to be displaced anteriorly over the true vocal fold, and the vocal fold itself may appear bowed. Atrophy of the paraglottic musculature can help to distinguish an acute vocal fold paralysis from a chronic, long-standing paralysis.

Positron Emission Tomography

Positron emission tomography (PET), particularly when combined with CT, has become an important tool in the staging of laryngeal cancer, particularly with regard to regional lymph node metastases and distant metastases.\textsuperscript{25-27} 18F-deoxyglucose (FDG) concentrates within tissues in which glucose uptake is increased, corresponding to elevated metabolic activity. The rapid cell division seen in most malignancies produces an intensely enhanced signal compared with that seen in the surrounding normal tissues. The addition of CT to the evaluation allows a direct anatomical correlation with the signal seen on PET, and can help to localize particular activity to a specific site, such as a lymph node.
Laryngeal Imaging

False-positive findings in the larynx can be seen for a variety of reasons. Unilateral vocal fold paralysis produces intense uptake in the contralateral mobile vocal fold. Teflon granuloma has also been shown to produce an intense signal on PET. Injected calcium hydroxylapatite, which is used to medialize a paralyzed vocal fold and also to restore glottic competency following partial laryngectomy, produces intense uptake of 18-FDG at the injection site, a finding that can last for at least one year from the time of injection.

Plain Radiographs
Despite advances in CT and MRI, there remains a role for traditional plain radiography in the imaging of the larynx, particularly in imaging infectious disorders of the airway. Epiglottitis, a life-threatening infection secondary to Haemophilus influenza, can cause rapid and progressive edema of the supraglottic larynx with consequent airway obstruction and respiratory arrest. The lateral soft-tissue neck X-ray can be performed in the emergency room and may demonstrate the ‘thumb-print sign,’ which is pathognomonic of epiglottitis (see Figure 3). Unlike in the remote confines of the CT scanner, the patient can remain under the direct supervision of a physician, and airway intervention can be administered emergently if needed.

Parainfluenza and influenza may produce acute laryngotracheobronchitis, or croup. Edema in the subglottic region produces the characteristic ‘steeple sign’—a caudal to rostral tapering of the airway shadow that can best be appreciated on an anteroposterior radiographic view. Beta hemolytic streptococci and Staphylococcus aureus pharyngitis can be complicated by the formation of a retropharyngeal abscess, a suppuration of the lymph nodes located in the region between the posterior pharyngeal wall and the pre-vertebral fascia. Edema in this region causes anterior displacement of the retropharyngeal tissues, compression of the pharynx and laryngotrachea, dysphagia, and, ultimately, airway compromise. A lateral neck radiograph can readily demonstrate this swelling and help to distinguish the condition from acute epiglottitis.

Incidental Findings in Head and Neck Imaging
While CT and MRI improve the physician’s ability to detect and characterize pathology, normal anatomical variations and incidental findings of little to no clinical consequence are revealed as well. Often there is a need to correlate clinically what is seen on radiographic imaging with direct visualization, usually endoscopic, of the area in question. Up to 38% of patients who undergo MRI of the brain will show abnormalities of the paranasal sinuses. In a recent study by Bruzzi et al. examining the rate of incidental findings in patients who were undergoing PET CT for recently diagnosed non-small-cell lung cancer, up to 20% of patients had an incidental finding in the head and neck. Brain MRI may also reveal abnormalities in the mastoid or, less commonly, middle ear space. Most of these will represent some form of inflammatory disease, and most will require evaluation and possible treatment by an otolaryngologist.

High-frequency Endolaryngeal Ultrasound
Ultrasound evaluation of cervical lymph nodes in patients undergoing evaluation for head and neck carcinoma has long been in use. There has been emerging interest, however, in the use of endolaryngeal ultrasound for the evaluation of laryngeal tumors. An excellent description of the technique is provided by Kraft and Arens. Briefly, with the patient under general anesthesia and the endotracheal tube advanced to just above the carina, saline is instilled into the airway and the endolaryngeal ultrasound probe is advanced into the lumen of the airway under endoscopic guidance. High resolution and a depth of penetration of up to 25mm can provide important details regarding tumor extent. Evaluation of such critical findings as cartilage invasion and extension of disease to the paraglottic and supraglottic spaces is possible with endolaryngeal ultrasound. The technique is non-invasive, eliminates radiation exposure to the patient, is less expensive than CT or MRI, does not require contrast, eliminates respiration and swallowing artifacts, and can be performed simultaneously with operative laryngoscopy. The necessary equipment may not be carried in all hospitals, however, and image acquisition and interpretation may be highly dependent on the experience of the examiner.

Virtual Laryngoscopy
A variety of software platforms are capable of deriving volume data from images acquired from CT and MRI and rendering 3D images of the internal anatomy of the larynx. These images can be linked together to generate a ‘fly-through’ view of the airway. The overall effect is one of ‘virtual endoscopy’—images generated radiographically that are comparable in anatomical detail to those generated by rigid or fiber optic endoscopes. Images are usually acquired from the patient in a supine position, breathing quietly. Intravenous contrast can be used, but is not required. Images are acquired with a helical CT scanner, collimation...
Virtual laryngoscopy may afford several advantages over conventional laryngoscopy: it is minimally invasive, does not require general anesthesia, may be useful in patients who are poor surgical candidates, and can be used in patients with anatomical features that may prove a barrier to conventional endoscopy (e.g., trismus, extreme kyphosis). In addition, the ability to generate 3D renderings of internal airway anatomy and its pathological variations may prove to be a useful tool in surgical training and simulation.

Summary

CT and MRI are the most commonly used radiographic modalities for assessing laryngeal pathology, although the plain lateral neck radiograph still serves a useful purpose in the diagnosis of such infectious lesions as epiglottitis, retropharyngeal space abscess, and croup. PET and combined PET–CT are proving indispensable in the staging of advanced laryngeal cancer and in the detection of persistent or recurrent disease. Endolaryngeal ultrasound, although described almost 15 years ago, has yet to emerge as a common diagnostic modality, but its accuracy and low cost may make this an attractive alternative to conventional CT and MRI, especially when performed in conjunction with operative laryngoscopy. Finally, virtual laryngoscopy offers the promise of a high-resolution 3D depiction of the laryngotracheal complex in a minimally invasive fashion, with an accuracy that may rival that of traditional rigid and flexible endoscopy. A rich armamentarium of radiographic modalities is currently in use in the diagnosis and management of laryngeal disease, and advances in these techniques will clearly be of great benefit to future physicians.

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