Diagnostic Imaging of the Upper Airway

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Diagnostic imaging plays an essential role in the evaluation of disease processes that affect the upper airway. Imaging allows for the localization and characterization of various conditions that are often occult on physical examination. Plain radiography maintains a limited role in airway evaluation, whereas advanced imaging modalities, including computed tomography and magnetic resonance imaging, have emerged as indispensable tools in patient evaluation. Common disease entities affecting the upper airway in the adult population, including trauma, infectious/inflammatory diseases, and neoplastic diseases, as well as other common pathologic conditions are reviewed in this article.

Keywords: airway; computed tomography; magnetic resonance imaging; imaging

The upper airway is an extraordinarily complex anatomic region that may be affected by various disease states. The upper airway includes the nose, nasopharynx, oropharynx, hypopharynx, larynx, and trachea, and these structures may be involved by both focal and diffuse processes. There are also many adjacent bony and soft tissue structures that are no less complex in their anatomic arrangement. Lesions in these regions can also cause extrinsic compression resulting in a compromised airway (Figure 1).

Although the superficial or mucosal extent of lesions that affect the airway can be seen in a limited fashion on physical examination and more extensively with endoscopy, the submucosal and deeper morphology can be accurately evaluated only with imaging. As such, diagnostic imaging plays an important role in patient workup because of the ability to both localize and characterize conditions that are often occult on physical examination.

Although diagnostic imaging techniques and modalities have continued to advance over the years, especially with the development of cross-sectional imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), radiography still maintains a role, especially in the initial evaluation. Radiography is readily available and is frequently the initial test of choice in pediatric patients, often in the case of suspected foreign body aspiration. Adults are also frequently initially assessed with plain radiography to evaluate for retained foreign bodies or other causes of acute upper airway compromise.

CT is accessible, fast, provides superb detail of the airway and surrounding tissues, and is the mainstay of upper airway imaging. Intravenous contrast is generally recommended unless a clear contraindication exists, and the addition of intravenous contrast further enhances visualization of the vasculature and other soft tissue components. Current multidetector CT scanners have very fast scan times, which permits visualization of the entire airway and limits motion artifact. Additionally, current multidetector CT scanners allow for isotropic voxels, and these data can be displayed in different planes without loss of resolution. Three-dimensional post-processing of the raw CT data provides a different diagnostic perspective, with emerging imaging techniques including virtual bronchoscopy and virtual endoscopy. The frequent use of CT due to the ease of access and rapidity of results also raises concern for increased cumulative radiation exposure. This issue is perhaps of greatest concern in the pediatric population and in women of childbearing age.

MRI offers superior contrast resolution and is a useful problem-solving tool in more definitively characterizing soft tissue masses and other complex soft tissue lesions. As with CT, intravenous gadolinium contrast–based agents are generally recommended unless a clear contraindication exists. Although there are no associated risks of ionizing radiation with the use of MRI, images can be prone to motion artifact due to increased acquisition times that often require the patient to stay still for at least several minutes at a time.

In the remainder of this article, we discuss common disease entities affecting the upper airway in the adult population, including traumatic, infectious/inflammatory, and neoplastic diseases as well as other common pathologic conditions. Portions of this review were adapted from Reference 1.

LARYNGOTRACHEAL TRAUMA

Traumatic injuries of the airway include fractures of the thyroid and cricoid cartilages, cricoarytenoid and cricothyroid cartilage dislocations, laryngotracheal separation, endolaryngeal soft tissue damage, and epiglottic avulsion or dislocation. Although uncommon, these injuries must be kept in mind when evaluating patients involved in motor vehicle accidents or in the setting of penetrating trauma. Surrounding soft tissue and/or skeletal injuries commonly complicate the diagnosis and advanced imaging is nearly always required in the evaluation of traumatic pathology.

An airway must quickly be secured once a severe head and neck injury is identified (2). Clinical evaluation of suspected airway injury usually begins with physical inspection and flexible endoscopy, a technique that allows for direct mucosal visualization. Radiographs of the chest and cervical spine provide an important rapid evaluation of the airway and surrounding structures and may identify a number of critical findings that require immediate attention, including fractures or dislocations of the cervical spine or radiopaque foreign material related to penetrating trauma. Key findings on radiography include air within the prevertebral or deep cervical soft tissues, hyoid bone elevation suggesting cricotracheal separation, or less specific findings, such as persistent pneumothorax after chest tube placement (3, 4).

CT provides a more focused and definitive evaluation that helps to characterize complex pathology and plan therapeutic approaches. CT is excellent in identifying laryngeal fractures and associated soft tissue disruption and remains an essential component of evaluating patients who have suffered significant laryngeal trauma (5). These injuries frequently require surgical intervention and represent an important clinical scenario in which the management hinges on imaging findings. Specific surgical treatment algorithms have been developed wherein CT evaluation is a central feature (6).

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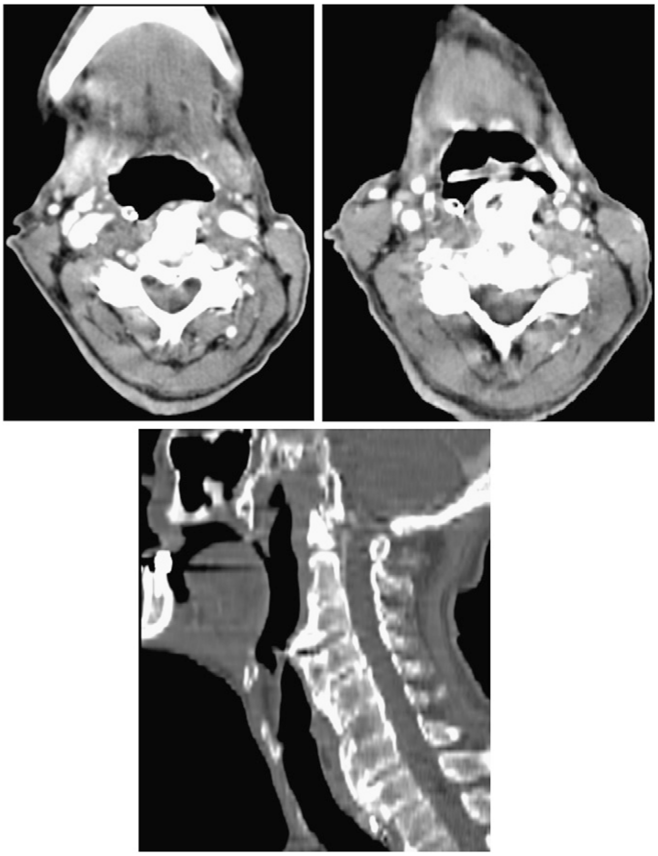

Figure 1. Osteophytes causing extrinsic compression of the airway. Contrast-enhanced axial computed tomography images and sagittal reformatted image demonstrating large degenerative anterior osteophytes from the cervical spine indenting the posterior aspect of the airway and causing extrinsic compression.

The most commonly fractured component of the larynx is the thyroid cartilage (7). Vertical and comminuted fractures are readily detected by CT. Horizontal fractures can be challenging to identify on axial imaging but are readily detected on multiplanar reformations, which are now regularly incorporated into image post-processing at most institutions. Fractures of the cricoid cartilage frequently manifest with two areas of disruption (8). Cricoarytenoid and cricothyroid cartilage dislocations usually present on imaging with joint asymmetry and are frequently accompanied by traumatic hematoma. Laryngotracheal separation is an entity that occurs in the setting of trauma due to relative cricotracheal membrane weakness. Endolaryngeal soft tissue damage may involve significant edema or hematoma on imaging. CT visualization of the mucosa in these cases is critical given the possibility of limited endoscopic visualization secondary to swelling. Epiglottic avulsion or dislocation involves compromise of the thyroepiglottic ligament.

Pitfalls are common in the CT evaluation of the upper airway. Various lines and tubes associated with trauma care create significant artifacts that may limit the full capacity of CT evaluation. Younger patients may have poorly visualized cartilaginous injuries due to incomplete mineralization. In such difficult cases, MRI may be considered for improved soft tissue detail.

INFLAMMATORY DISEASES

Various inflammatory processes affect the airway and/or the adjacent soft tissues. Common conditions include tonsillar/peritonsillar abscess and pharyngeal abscess. Other entities include acute laryngitis, laryngeal abscess, and lymphoid hyperplasia (Figure 2). Early diagnosis and treatment are of critical importance in avoiding potentially life-threatening complications, especially in the case of peritonsillar abscess. This condition is frequently seen in young adults and imaging demonstrates typical findings that include large fluid collections with enhancing margins in or adjacent to the tonsils, with associated mucosal and submucosal edema that may extend into the parapharyngeal space, oro/hypopharynx, and larynx. This is not to be confused with severe tonsillitis, which may show multiple small hypodense foci within the tonsils. Advanced cases of tonsillar/peritonsillar abscess may also involve the deep neck spaces. Because of its ability to demonstrate the full extent of disease, imaging is frequently used in choosing between conservative or invasive therapy (9, 10). Acute laryngitis can be seen in both adult and pediatric populations. Airway compromise is very rare in this setting and may be seen in infants. Laryngeal abscesses may be encountered after surgical instrumentation or trauma. On CT, laryngeal abscesses appear as hypodense mass lesions with enhancing walls and associated edema.

A variety of rarer entities may also manifest within the larynx, including tuberculosis, syphilis, leprosy, sarcoidosis, and Wegener granulomatosis. These findings are generally nonspecific and may present as bilateral diffuse soft tissue swelling of the larynx. Laryngeal involvement by tuberculosis is a well-described entity and has been characterized on CT by diffuse soft tissue swelling, free margin epiglottic thickening, and relative preservation of the preepiglottic/paraglottic spaces (11).

Angioedema is another entity affecting the upper airway that can be fatal when the airway is compromised, and it typically presents with sudden attacks of swelling and discomfort. Angioedema can be hereditary or acquired, or can be related to angiotensin-converting enzyme inhibitor therapy. Angiotensin-converting enzyme inhibitor–related angioedema is a relatively frequent cause of angioedema, which usually presents within a few weeks after the initiation of therapy, although cases have also been reported months or even years later. Findings on CT typically manifest as diffuse swelling of the mucosa and submucosa of the upper airway, including the soft tissue structures and tongue, which can be accompanied by narrowing of the airway itself (Figure 3) (12).

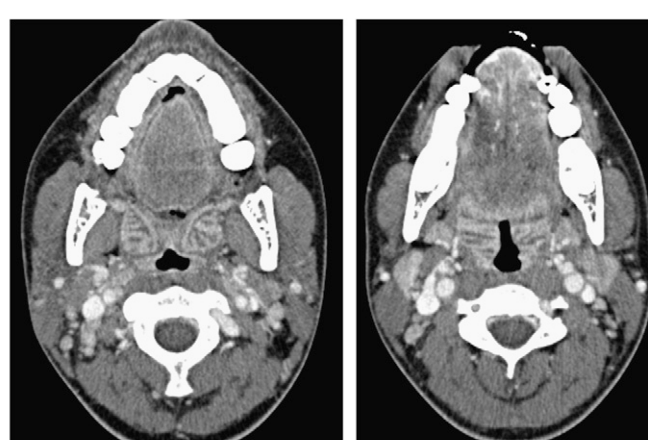

Figure 2. Acute tonsillitis. Enlargement of the bilateral palatine tonsils with fluid exudation into the tonsillar crypts resulting in a striped appearance.

NEOPLASTIC DISEASES

Malignant disease of the head and neck is more common than benign neoplastic disease. Squamous cell carcinoma is the most common malignancy of the head and neck (Figure 4). Although a dedicated discussion of squamous cell carcinoma is beyond the scope of this article, it should be recognized that imaging has established a pivotal role in staging these malignancies and provides a wealth of information that aids in determining the best therapeutic approach. Nodal involvement with squamous cell carcinoma is classically manifested as enlarged lymph nodes with central necrosis (Figure 5). Nodal involvement with other malignancies can also present with lymph node enlargement and central necrosis (Figure 6). Lymphoma is another common malignancy of the head and neck that also frequently involves the nasopharynx, oropharynx, and hypopharynx (Figure 7). Imaging characteristics that are suggestive of lymphoma include a bulkier appearance of pathologic lymph nodes and higher T2 signal intensity on MRI images when compared with squamous cell carcinoma. Malignancy of the laryngeal cartilages is very rare (Figure 8). Multiple myeloma is another example of an entity that may occasionally involve the airway cartilages.

Airway compromise secondary to mass effect from benign lesions is less common than that of malignant lesions. Advanced cases of benign focal nodular or diffuse thyroid enlargement are a commonly encountered potential source of airway encroachment. Ultrasound-guided fine needle aspiration is generally used to differentiate benign from malignant thyroid lesions as imaging findings can be equivocal (13). Despite this, the diagnosis remains challenging, and even fine needle biopsy has been reported to be nondiagnostic in as many as 20% of cases (14). Other examples of benign lesions that may manifest in or adjacent to the airway include hemangiomas, lipomas, schwannomas, and chondromas. Laryngeal hemangioma may present as a submucosal mass with a predilection for the supraglottic

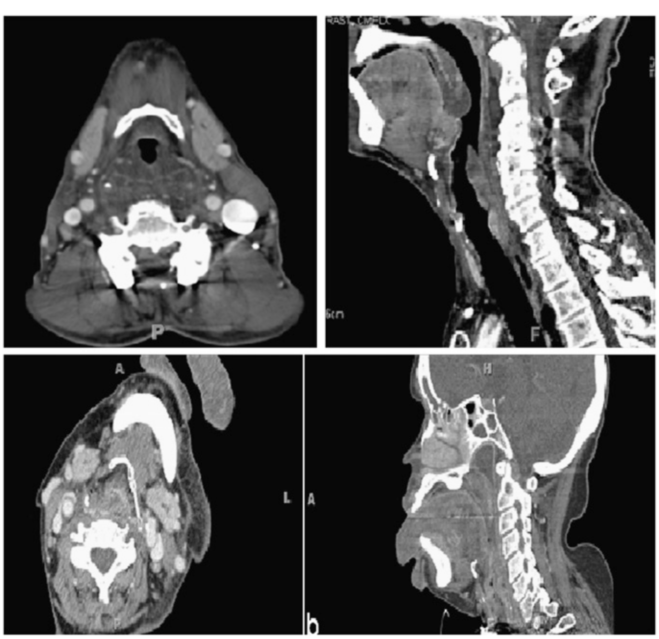

Figure 3. Angiotensin-converting enzyme inhibitor–related angioedema in two patients. Diffuse mucosal and submucosal edema is seen on these contrast-enhanced axial and sagittal computed tomography images through the upper airway. Mild narrowing of the airway is seen in the first patient (*top left and right*) and complete occlusion of the airway is seen in the second patient (bottom left and right).

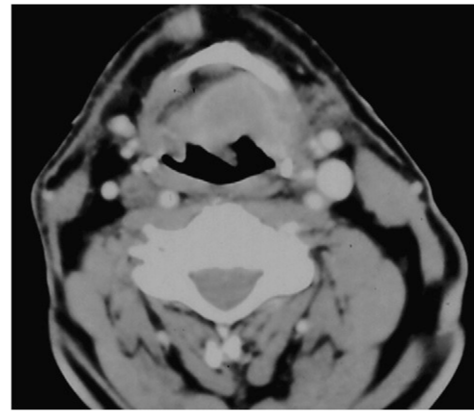

Figure 4. Squamous cell carcinoma. Contrast-enhanced axial computed tomography images demonstrating abnormal nodularity and enhancement of the epiglottis with invasion of the pre-epiglottic fat.

and glottic regions. This is in contradistinction to the relatively less common pediatric lesion that is typically located in the subglottic region. Superficial hemangiomas may be apparent on physical examination, whereas deeper lesions are indistinguishable from other mass lesions on physical inspection. On CT, hemangiomas appear as well-defined, avidly enhancing masses. Hemangiomas may be even more conspicuous on MRI, with classic very bright T2 signal intensity in addition to features seen on CT. Hemangiomas may also exhibit characteristic small phlebolith-type calcifications. Glomus tumors are very rare in the larynx but also may present as a strongly enhancing mass, with vascular tributaries from the external carotid artery. Lipomas have classic imaging features of fat density on CT and high nonenhancing T1 signal intensity (Figure 9). These lesions are typically homogeneous, and if a significant soft tissue component is identified liposarcoma should be considered in the differential diagnosis. Pedunculated lipomas have been described and have the potential for acute airway obstruction. Schwannomas near the airway may originate from the sympathetic ganglia, carotid sheath, or cranial nerves. On imaging, schwannomas appear as well-defined, enhancing homogeneous

Figure 5. Squamous cell carcinoma with nodal metastases. Contrast-enhanced axial computed tomography image demonstrating a right tongue base mass with abnormally enlarged nodes with central necrosis typical of squamous cell carcinoma nodal metastasis.

Figure 6. Nodal metastasis from thyroid cancer. Axial computed tomography image demonstrating marked enlargement of a left neck lymph node with cystic components and mural nodularity.

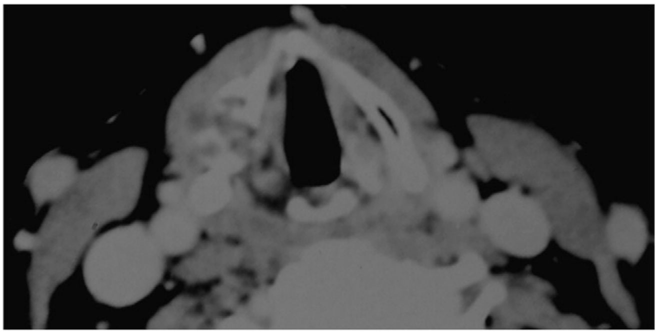

Figure 8. Chondrosarcoma of the thyroid cartilage. Axial contrast-enhanced computed tomography image demonstrating destruction of the thyroid cartilage with a soft tissue mass with associated chondroid matrix typical of chondrosarcoma.

masses. However, it is not uncommon to observe areas of internal cystic change or focal nonenhancement. Laryngeal schwannomas are rare and generally occur in a supraglottic location. Another neural-based neoplasm that may affect the airway is plexiform neurofibroma in patients with neurofibromatosis type I. These lesions typically affect multiple tissue planes with infiltrative margins and have rare potential for sarcomatous transformation. Laryngeal chondromas most commonly arise from the cricoid cartilage. CT imaging characteristics include a heterogeneously calcified chondroid matrix that may be indistinguishable from the appearance of a low-grade chondrosarcoma (15–17). Parotid neoplasms, especially when they involve the deep lobe of the parotid, can occasionally extend to the airway and exert mass effect and cause extrinsic compression (Figure 10).

LARYNGOTRACHEAL STENOSIS

Laryngotracheal stenosis is a chronic condition with significant associated morbidity that varies widely in etiology and distribution (18). Focal stenosis is most commonly caused by prior intubation or may be seen in the setting of trauma. Occasionally, this can also present idiopathically. Postintubation stenosis in particular represents the most common indication for tracheal surgery (19). Diffuse airway stenosis may be seen in the setting of granulomatous or other inflammatory conditions, including tuberculosis, histoplasmosis, Wegener granulomatosis, and relapsing polychondritis. Surgical planning is complex and necessitates a thorough evaluation with different modalities. Fiberoptic bronchoscopy is widely regarded as the gold standard given its ability to directly visualize the airway mucosa and glottic function. However, not all patients can tolerate this procedure, and high-grade stenoses may significantly limit bronchoscopic assessment. CT with multiplanar reformations and virtual bronchoscopy offer excellent noninvasive visualization in the evaluation of laryngotracheal stenosis. Taha and colleagues reported superior intraoperative correlation with CT findings compared with fiberoptic bronchoscopy in a small series of patients, further underscoring that CT is a valuable alternative to bronchoscopy in specific cases and can be a useful adjunct for follow-up (19–22). Virtual bronchoscopy has also been demonstrated to have strong correlation with pulmonary function tests in cases of tracheobronchial stenosis (23).

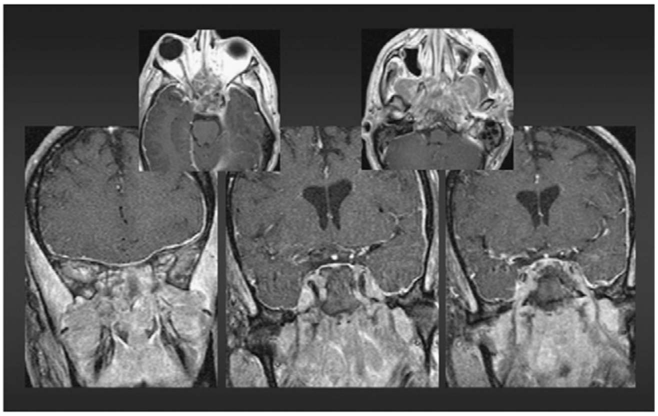

Figure 7. Nasopharyngeal lymphoma with intracranial extension. Postgadolinium T1-weighted magnetic resonance images in the coronal and axial plane demonstrating abnormal nodularity and enhancement centered in the nasopharynx, with extension through the skull base foramina.

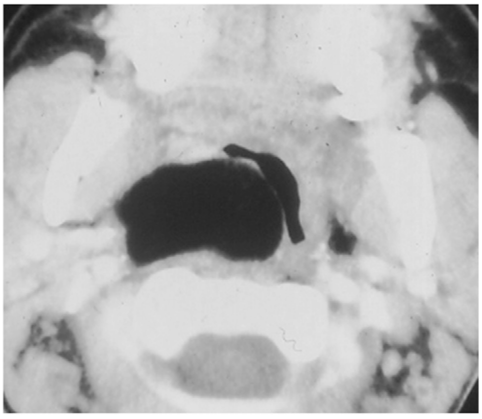

Figure 9. Lipoma in retropharyngeal space. Axial contrast-enhanced computed tomography image demonstrating curvilinear fat attenuation in the retropharyngeal space with mild associated mass effect compatible with a lipoma.

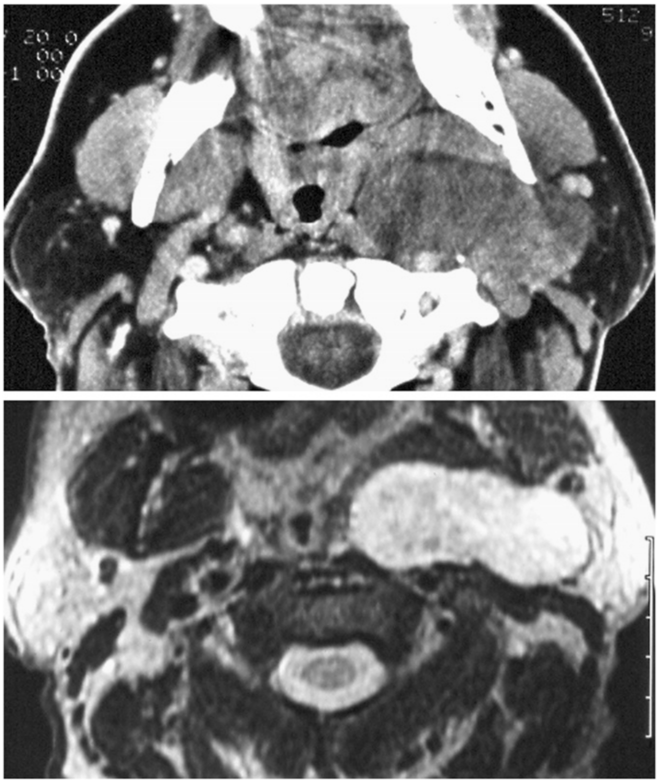

Figure 10. Pleomorphic adenoma. Contrast-enhanced axial computed tomography image demonstrating a lobular mass with heterogeneous enhancement involving both the superficial and deep lobes of the parotid with mass effect, effacing the parapharyngeal fat and causing extrinsic airway compression (*top*). Axial T2-weighted magnetic resonance image demonstrating the T2 hyperintense nature of this mass (*bottom*).

OBSTRUCTIVE SLEEP APENA

Obstructive sleep apnea (OSA) is repetitive partial or complete obstruction of the airway during sleep associated with specific nocturnal and diurnal symptoms. Nocturnal symptoms include snoring, gasping, hypopnea/apnea, and associated arousal from sleep (24, 25). Diurnal symptoms include excessive drowsiness, fatigue, and memory problems (26). Patients with OSA are also at increased risk for coronary artery disease, stroke, and involvement in motor vehicle accidents (25). Obesity is generally believed to be the primary risk factor for OSA, although a variety of other factors, including structural and functional abnormalities of the airway, older age, male sex, and alcohol consumption, must also be taken into consideration (26). Although the majority of patients have contributory structural abnormalities, the precise pathogenesis of OSA is not fully understood and deficient neuromuscular activation may also play a role. Advanced imaging modalities are frequently used to gain better insight into the structural and functional status of the airway, although this is predominantly performed in the awake patient (27–29). A variety of more elaborate imaging techniques are also being developed, including computational flow dynamics (27). Common structural findings in patients with OSA include retroposed mandibles, inferiorly positioned hyoid bones, and high/narrow hard palates. Additional findings on CT and MRI studies include increased volume of retropalatal soft tissue, increased parapharyngeal fat, enlarged tongue, enlarged soft palate, and diminished posterior airway space. A number of parameters have been suggested in the imaging assessment of obstructive sleep apnea, of which the minimal pharyngeal airway measurement is likely the most practical (30). The cross-sectional area of the retropalatal airway has been demonstrated to independently predict both the diagnosis and severity of OSA in obese patients. Koren and colleagues have suggested soft palate–tongue contact and the pharyngeal narrowing ratio (ratio of the airway cross-section at the level of the hard palate to the narrowest cross-section from the level of the hard palate to the epiglottis) from a small patient series as strong predictors of OSA (31). Each patient case is unique and imaging may significantly impact the specific course of therapy.

VOCAL CORD PARALYSIS

Vocal cord paralysis (VCP) is most commonly iatrogenic or related to tumor infiltration. A clear etiology is not always found and recurrent laryngeal nerve injury may occur secondary to a number of pathologic processes, including vascular events, infections, drug toxicity, metabolic disturbances, or radiation therapy (32). Although VCP is readily detected on physical examination in symptomatic patients, a significant proportion of patients with unilateral VCP may be asymptomatic with incidental findings on imaging. CT findings include medial positioning of the ipsilateral aryepiglottic fold, ipsilateral pyriform sinus dilatation, thickening of the ipsilateral aryepiglottic fold, and ipsilateral dilatation of the laryngeal ventricle (Figure 11) (33). Ipsilateral pharyngeal constrictor muscle atrophy may be seen and is suggestive of contributory central vagal neuropathy (33). Combining information from the clinical history and physical examination generally reveals the underlying cause in roughly half of patients (34).

Imaging plays a role both in elucidating occult lesions and in further characterizing pathology detected on physical examination. MRI is particularly useful in cases wherein cranial nerves are affected and a skull base lesion is suspected. Isolated recurrent laryngeal nerve paralysis is more likely caused by an extracranial lesion, which can be detected on either CT or MRI. Imaging studies in this instance should specifically address the brain stem, skull base, and neck. In cases of right VCP, the thoracic inlet should also be included, whereas the aorticopulmonary window should be included in cases of left VCP. Common neoplasms identified as sources of VCP on imaging include thyroid neoplasms, lung carcinoma, esophageal carcinoma, lymphoma, skull base paragangliomas, and skull base schwannomas. Other causes include aortic aneurysms and inflammatory processes such as sarcoidosis and tuberculosis. Idiopathic VCP is a diagnosis of exclusion and a potential viral

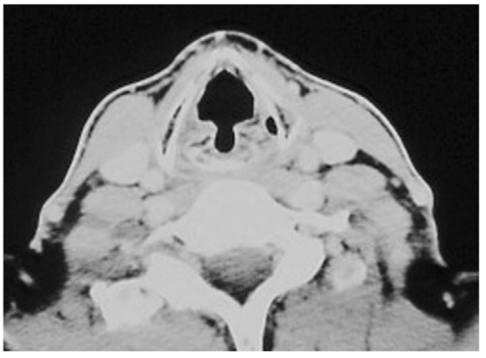

Figure 11. Bilateral vocal cord paralysis. Contrast-enhanced axial computed tomography image demonstrating enlargement of the laryngeal ventricle and anteromedial displacement of the arytenoid cartilage.

cause has been considered given the association with preceding upper respiratory infections (35).

Surgical treatment is primarily targeted at vocal cord medialization, and this may be accomplished in a number of ways. Vocal cord injection may incorporate different materials with variable appearance on CT, including hyperdense (silastic, Teflon, hydroxyapatite, and Gore-Tex), isodense (Cymetra), and hypodense (autologous fat) attenuations. Another means of vocal cord medialization is the use of a prosthesis. Complications of surgical treatment that may be identified on imaging include foreign body reactions (particularly with Teflon) and laryngeal edema/hematoma (36). Prostheses migration or displacement may also be detected on imaging evaluation.

SUMMARY

The upper airway is both anatomically and functionally complex and contains multiple vital structures in close proximity. Pathology within this area harbors the potential for catastrophic consequences if not correctly and rapidly identified. Diagnostic imaging provides a number of invaluable tools in efficiently localizing and characterizing the broad spectrum of pathology that may affect the upper airway. Although plain radiography maintains a role in the initial evaluation, more definitive evaluation typically requires CT and MRI in the initial diagnosis, in evaluating the extent of disease, and in the staging of neoplastic processes. Newer developments, including virtual bronchoscopy and virtual endoscopy, continue to show promise in that they more closely approximate traditional endoscopic views. In addition, the ability to post-process axial data and reconstruct it in multiple planes allows for a more thorough understanding of the pathology and complex anatomic interactions within this region.

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