PICTORIAL ESSAY

To breathe or not to breathe: a review of artificial airway placement and related complications

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Abstract Artificial airway devices are commonly used to provide adequate ventilation and/or oxygenation in multiple clinical settings, both emergent and nonemergent. These frequently used devices include laryngeal mask airway, esophageal–tracheal combitube, endotracheal tube, and tracheostomy tube and are associated with various acute and late complications. Clinically, this may vary from mild discomfort to a potentially life-threatening situation. Radiologically, these devices and their acute and late complications have characteristic imaging findings which can be detected primarily on radiographs and computed tomography. We review appropriate positioning of these artificial airway devices and illustrate associated complications including inadequate positioning of the endotracheal tube, pulmonary aspiration, tracheal laceration or perforation, paranasal sinusitis, vocal cord paralysis, post-intubation tracheal stenosis, cuff overinflation with vascular compression, and others. Radiologists must recognize and understand the potential complications of intubation to promptly guide management and avoid long-term or even deadly consequences.

Keywords Artificial airway · Airway complications · Esophageal intubation · Laryngeal mask airway · Endotracheal tube · Tracheostomy tube

John Donatelli and Ayushi Gupta are co-first authors and have both worked equally on this project.

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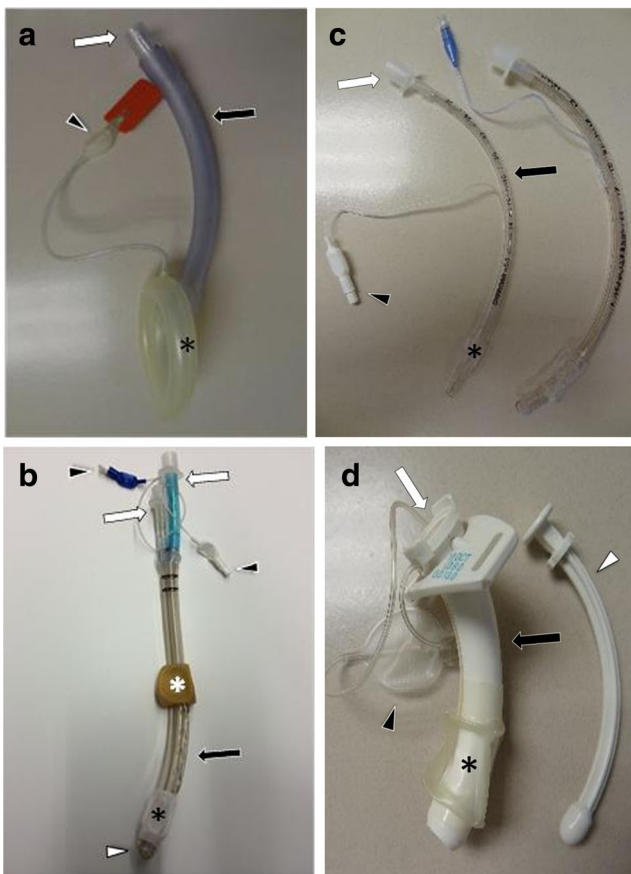e-mail: Alvaro_Macias@meei.harvard.edu

Introduction

Artificial airway devices are utilized in multiple clinical settings, both emergent and nonemergent. These artificially inserted airway devices create a pathway between the lungs and the outside world to allow patient ventilation and adequate oxygenation. While successful airway management is obtained in most cases, an incorrectly placed artificial airway device can lead to deadly consequences. Furthermore, complications presenting relatively late may have debilitating results. Therefore, in order to safely guide management and avoid potential consequences, an understanding of the proper imaging appearance of artificial airway devices and recognition of potential complications is necessary.
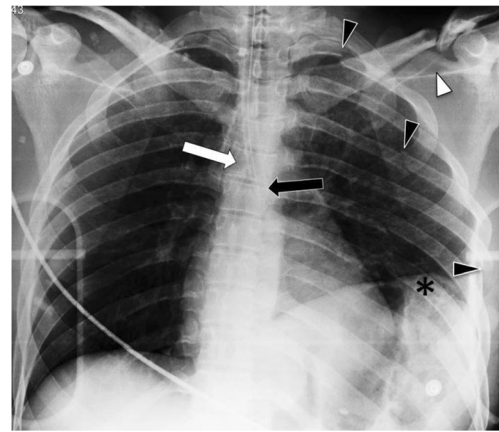
Airway management serves as both a primary life-preserving procedure and as an adjunct to facilitate complex patient care. Emergent intubation is more commonly performed for medical emergencies than for trauma [1].

Successful placement of the artificial airway device depends upon the situation, the airway equipment and devices available, and the medical professional performing the art of airway management. Complication rates of intubation vary by setting, reported higher in intensive care units and lower in operating rooms [1].

The most commonly used devices for airway management are laryngeal mask airway (LMA), endotracheal tube (ETT), and tracheostomy tube. The esophageal–tracheal combitube (combitube) is very seldom used in the hospital setting in the United States particularly due to the high risk of complications. Oropharyngeal and nasopharyngeal airway devices, although frequently used, are considered outside the scope of this review. Clinically, complications related to airway
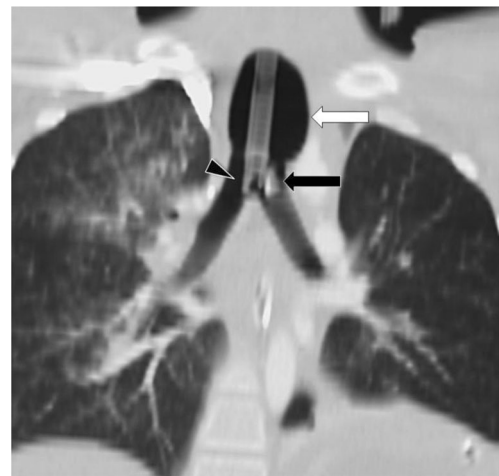

Fig. 2 A 32-year-old female patient admitted after a motor vehicle collision and intubated for difficulty breathing. Upright AP chest radiograph demonstrates left mainstem intubation of the endotracheal tube with the tip of the endotracheal tube (*black arrow*) distal to the carina (*white arrow*). Also note the left hemidiaphragm elevation (*asterisk*) due to diaphragmatic injury, left clavicle fracture (*white arrowhead*), and multiple left rib fractures (*black arrowheads*, only a few are labeled)

management vary in severity, many of which have characteristic imaging findings. In this review, we discuss the appropriate positioning of these artificial airway devices and associated acute and late complications.

Airway devices

Supraglottic airway devices

A laryngeal mask airway (Fig. 1a) is a supraglottic device that carries almost a 100 % success in ventilating a patient. It

Fig. 1 **a** Picture of a laryngeal mask demonstrates the airway connector (*white arrow*), airway tube (*black arrow*), valve and pilot balloon (*black arrowhead*), and cuff (*asterisk*). **b** Picture of a combitube demonstrates the twin lumens (*white arrows*), airway tube with side holes for ventilation (*black arrow*), distal opening (*white arrowhead*), two valves and pilot balloons (*black arrowheads*), proximal cuff (*white asterisk*), and distal cuff (*black asterisk*). **c** Picture of a pediatric (*left*) and an adult (*right*) endotracheal tube demonstrates the airway connector (*white arrow*), airway tube (*black arrow*), valve (*black arrowhead*), and cuff (*asterisk*). **d** Picture of a tracheostomy tube demonstrates the airway connector (*white arrow*), airway tube or cannula (*black arrow*), valve and pilot balloon (*black arrowhead*), and cuff (*asterisk*). Note the obturator is removed (*white arrowhead*)

Fig. 3 A 40-year-old female patient admitted after a motor vehicle collision and intubated due to neurologic deterioration. Coronal CT image of the chest demonstrates a foreign body at the carina (*black arrow*). This was subsequently removed with bronchoscopy and identified as a tooth related to traumatic endotracheal intubation. Also note the low position of the endotracheal tube at the carina (*black arrowhead*) and the overinflation of the cuff beyond the lumen of the distal trachea (*white arrow*)

allows for ventilation without securing the airway. The appropriate positioning of the LMA is with the proximal portion of the cuff against the tongue base and the sides within the piriform fossae. The distal portion of the cuff rests against the upper esophageal sphincter usually with the tip at the cricopharyngeus muscle. Goudsouzian et al. evaluated proper LMA position by magnetic resonance (MR) in infants and children demonstrating the proximal portion most commonly lies at the C1 or C2 level and the distal portion is seen between the C4 and T1 levels, with posterior deflection of the epiglottis in 37 of 46 patients [2]. Nandi et al. evaluated the proper position by lateral neck soft tissue radiograph in elderly men, which demonstrates inclusion of the epiglottis within the LMA in two thirds of patients without clinical evidence of airway compromise [3].

A combitube (Fig. 1b), referred to as an esophageal–tracheal double-lumen airway, is also a supraglottic device used primarily in the emergent setting and inserted blindly. A combitube consists of two lumens within the tube with a proximal cuff inflated behind the posterior margin of the hard palate and a distal cuff inflated within the proximal trachea or esophagus. Location of the distal aspect of the tube should be noted as appropriate utilization of the device varies upon esophageal or tracheal intubation.

Infraglottic airway devices

An endotracheal tube (Fig. 1c) represents an infraglottic device for tracheal intubation. Used in most settings, these tubes are often the preferred method to secure the airway in trauma, medical emergencies, short-term complex patient care, as well as out-of-hospital cardiac arrest [4]. The tube consists of a semi-rigid single lumen, usually with a tracheal cuff.

Radio-opaque markers along the length of the ETT or just at the distal tip are often present. The tip should be located approximately 5 cm, ±2 cm, from the carina at the time of placement [5]. On average, inward movement of the tube
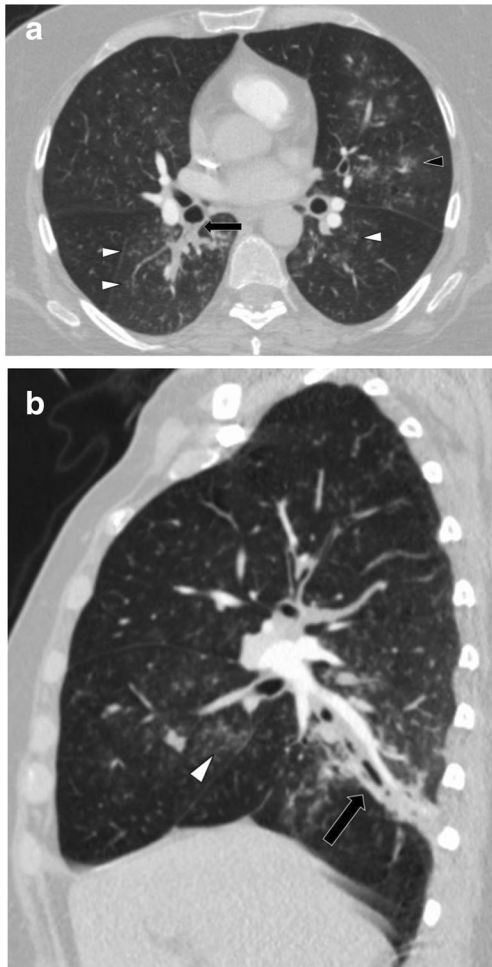
Fig. 4 A 49-year-old female patient intubated for anaplastic meningioma resection with difficultly weaning off of the ventilator. Axial (**a**) and sagittal (**b**) CT images of the chest demonstrate filling defects within superior segment of the right lower lobe and airway thickening (*black arrows*) related to aspiration of secretions. Note the tree-in-bud nodularity (*white arrowheads*) and centrilobular ground glass opacities (*black arrowhead*) which can also be seen with aspiration
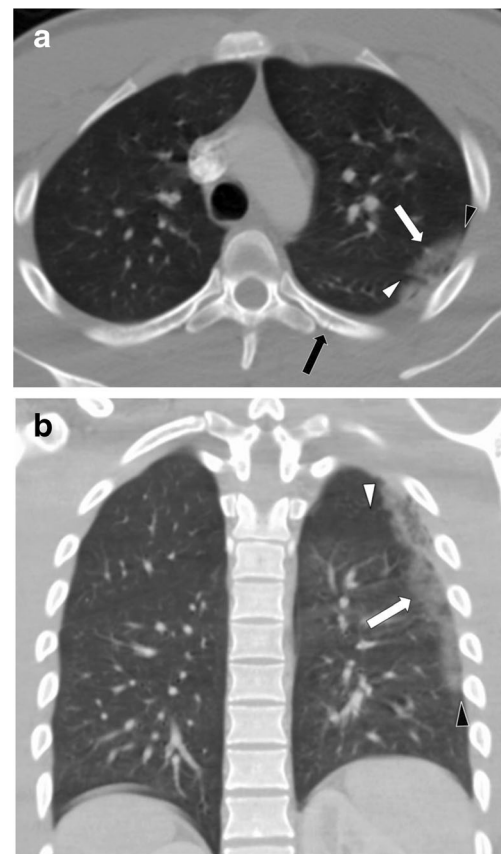
Fig. 5 A 19-year-old male pedestrian hit by a motor vehicle subsequently developed respiratory distress and required intubation. Axial (**a**) and coronal (**b**) CT images of the chest demonstrate peripheral area of ground glass opacity (*white arrow*) in the left lung which crosses the major fissure (*white arrowheads*) and exhibits subpleural sparing (*black arrowheads*), consistent with contusion. One of the rib fractures is visualized on (**a**) (*black arrow*). Compare these findings with Figure 4a and b

(shortening of the distance between the ETT tip and the carina) results from neck flexion (mean=−5.5 mm), whereas outward movement occurs with neck extension (mean= 6.3 mm). Neck rotation can also affect the location of the ETT [6]. Therefore, in the anterior-posterior (AP) projection on neutral position (mandible projecting over C5–C6) the tip of the tube should measure 5 cm, ±2 cm, from the carina; with flexion (mandible projecting over T1 or below), the tip should measure 3 cm, ±2 cm, from the carina; and upon extension (mandible projecting over C3–C4), the tip should measure 7 cm, ±2 cm, from the carina [7, 8]. Occasionally, when the carina is obscured, an ETT tip projecting at the T2–T4 level in the neutral position is appropriate [7].

A tracheostomy tube (Fig. 1d) is an infraglottic device used in the setting of prolonged ventilation or inability or contradiction to placing one or more of the other airway devices. The tracheostomy tube is a curved tube with the stoma inserted at the second or third tracheal ring and curves inferiorly with the tip located in the trachea. Similar to the ETT, the tracheostomy tube should project at the T2–T4 level, although there is no movement with head position.

Complications

Complications accompanying these artificial airway devices are generally seen in older patients and more commonly in the emergent setting [9]. Difficult intubation (three or more attempts by a skilled professional or poor visualization of the vocal cords) has been associated with increased risk of complications [10, 11]. Complications can be divided into acute and late depending on the time of onset.
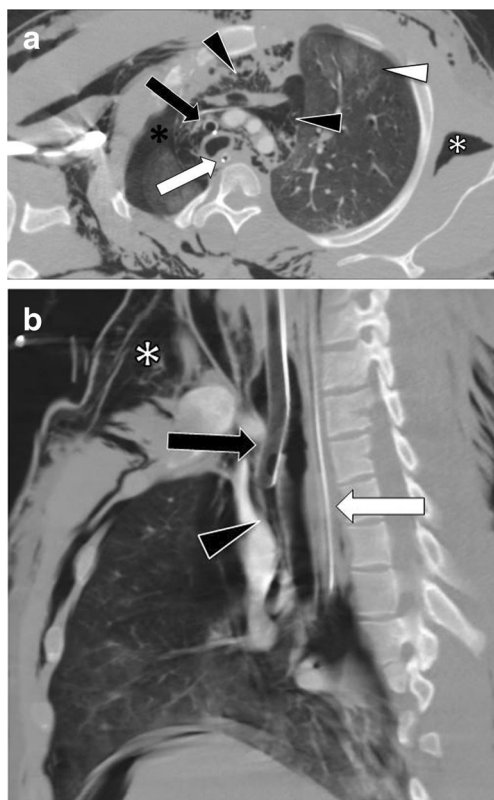
Fig. 6 a A 35-year-old male patient in a motor vehicle collision was intubated in the field. Axial CT image of the chest demonstrates extratracheal location of the endotracheal tube (*black arrow*) with pneumomediastinum (*black arrowheads*), pneumothorax (*black asterisk*), and diffuse subcutaneous emphysema (*white asterisk*) due to tracheal rupture during intubation. Also note pulmonary contusions (*white arrowhead*) and nasogastric tube within the esophagus (*white arrow*). b Sagittal CT image of the chest in the same patient demonstrates the endotracheal tube tip extending into the anterior mediastinum through the trachea (*black arrow*) and containing internal debris likely representing blood products. Again note the subcutaneous emphysema (*white asterisk*) and nasogastric tube within the esophagus (*white arrow*)
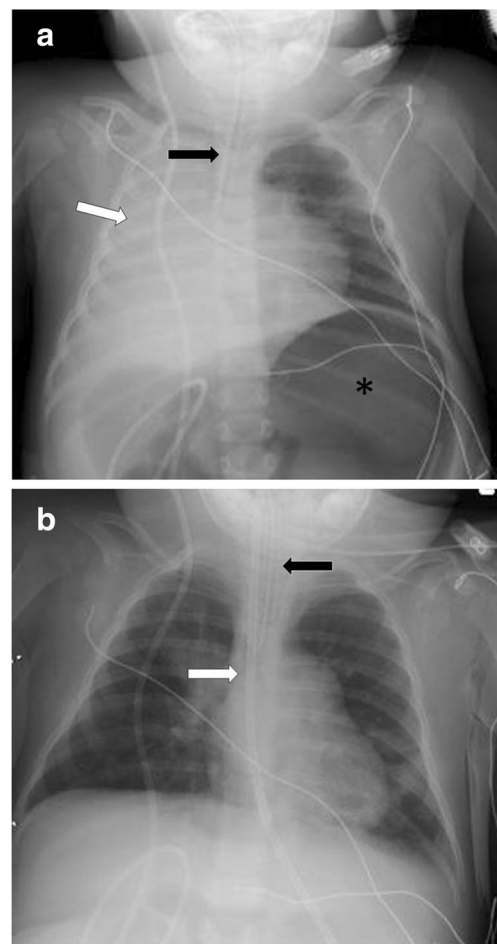
Fig. 7 a A 4-year-old boy intubated for acute shortness of breath. Supine AP chest radiograph demonstrates inadvertent esophageal intubation (*black arrow*) resulting in overdistension of the stomach (*asterisk*) and collapsed right lung (*white arrow*). b Supine AP chest radiograph in the same patient after repositioning of the endotracheal tube resulted in improved aeration of the lungs and gastric decompression with subsequent orogastric tube placement (*white arrow*). Note the relatively medial position of the endotracheal tube (*black arrow*) and compare it with Fig. 6a

Acute complications

Acute complications vary in severity with minor problems often overlooked. Traumatic injury to lips, tongue, nose, teeth, pharynx, and larynx are often minor and rarely require dedicated imaging [12].

Bronchial intubation during placement of the ETT or migration of a previously placed tube is a serious complication. It can be identified on an AP chest radiograph by visualization of the ETT tip distal to the carina (Fig. 2). This can quickly lead to atelectasis of the contralateral lung and barotrauma leading to tension pneumothorax. Due to a shorter distance to the carina, bronchial intubation is more common in women [13, 14]. Right mainstem bronchial intubation occurs more frequently due to the relatively vertical orientation. Note is made that in rare clinical scenarios, a double lumen tube can be placed to isolate one of the lungs. Clinical and surgical history is needed in these cases to adequately interpret the diagnostic images.

Pulmonary aspiration related to an artificial airway placement is defined as a new pulmonary parenchymal opacity seen on postprocedural imaging. Occasionally, an aspirated tooth or tooth fragments can be identified in the airway, especially in the setting of complicated emergent intubations (Fig. 3). Due to the lack of a tight seal around the airway with LMAs, pulmonary aspiration is the most common radiographically evident complication related to their use [10]. Imaging appearance of aspiration includes airspace disease on chest radiographs. On CT, aspiration can be identified as filling defects in the airway, tree-in-bud nodularity, centrilobular ground glass opacities, and airspace consolidation [15] (Fig. 4a, b). As most of these patients are supine, aspiration typically involves the posterior segment of the right upper lobe and superior and posterior segments of the right lower lobe.

In the setting of trauma, it is important to differentiate aspiration from pulmonary contusions [16]. Pulmonary contusions classically present as ground glass opacities or airspace consolidation with a peripheral distribution in the regions of trauma. The pulmonary parenchymal abnormalities typically cross fissures, involve adjacent lobes, and demonstrate subpleural sparing (Fig. 5a, b). Associated findings of adjacent rib fractures or other signs of chest wall injury can aid in the diagnosis.

Tracheal perforation can be seen after multiple vigorous attempts, cuff overinflation, or anatomic alterations [17]. Visualization of disruption of the tracheal wall or tracheal cartilage with associated findings of pneumomediastinum and subcutaneous emphysema on CT are highly suggestive of a perforation (Fig. 6a, b). Additional findings include balloon overdistention of greater than 2.8 cm, spherical endotracheal tube cuff, herniation of the endotracheal balloon outside of the trachea, or extratracheal location of the endotracheal or tracheostomy tube [16, 18].

Esophageal intubation is a relatively common complication seen with endotracheal tubes [11]. Although physical
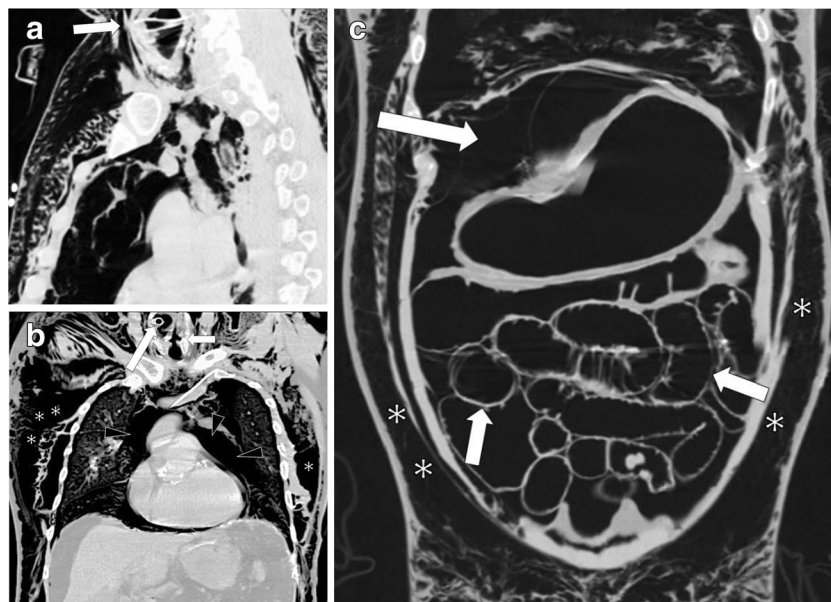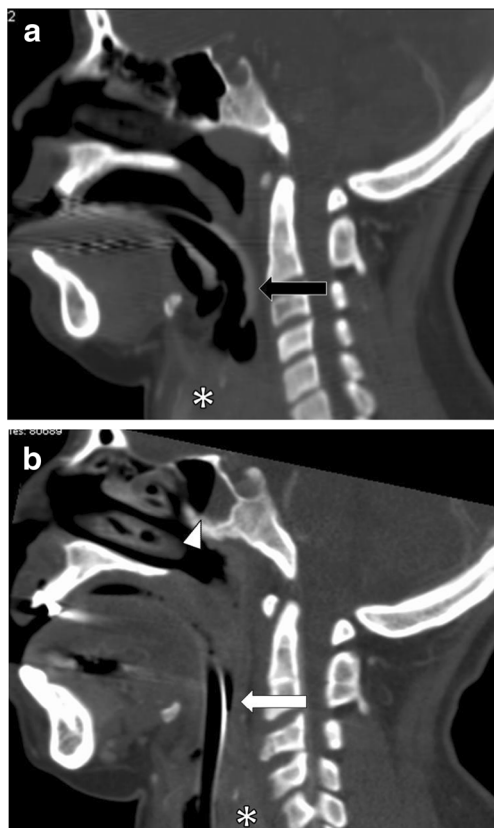

Fig. 8 a A 70-year-old male patient who was found down, emergently intubated in the field, and subsequently brought to the hospital. Sagittal CT image of the chest demonstrates a kinked and anteriorly directed endotracheal tube (*white arrow*) located in the proximal esophagus. b Coronal CT image of the chest in the same patient demonstrates a malpositioned endotracheal tube in the proximal esophagus (*long white arrow*) which resulted in esophageal perforation, pneumomediastinum (*black arrowheads*), and subcutaneous emphysema (*white asterisks*). Note the partially imaged larynx to the left of the esophagus (*short white arrow*). c Coronal CT image of the abdomen in the same patient demonstrates gastric and small bowel distention (*short white arrows*), pneumoperitoneum (*long white arrows*), and extensive subcutaneous emphysema (*white asterisks*) secondary to gastric perforation after esophageal intubation

examination and widespread use of capnography decreases the incidence, immediate postprocedural imaging can detect unrecognized cases [19]. The esophagus is located posterior and to the left of the trachea; therefore, a right posterior oblique chest radiograph with the head rotated to the right is the ideal projection to detect esophageal intubation. Additionally, upon visualization of the ETT tip lateral to the trachea, distention of the distal esophagus and stomach with air, and often rightward deviation of the trachea by the device in the esophagus can be seen (Fig. 7a, b).

Esophageal laceration and perforation can occur as a rare complication during tracheostomy placement by perforation of the posterior wall of the trachea or as unrecognized esophageal intubation of an ETT. Esophageal rupture during combitube placement has also been documented by multiple studies [20]. However, nonspecific imaging findings of pneumomediastinum and subcutaneous emphysema are most commonly seen [20, 21] (Fig. 8a, b). If prolonged, gastric rupture ensues with radiographic findings of pneumoperitoneum, distended bowels, and possibly extraluminal gastric contents (Fig. 8c).

Multiple additional clinically significant adverse effects deserve mention, although majority of these are not radiologically evident. Hemodynamic instability, including hypertension, tachycardia, arrhythmias, and less frequently hypotension and bradycardia, may occur due to autonomic stimulation during intubation [10]. Bronchospasms can present due to tracheal irritation during intubation resulting in decreased air movement into the lungs [10]. Neurologic deficits from spinal cord injury during intubation, albeit rare, may occur particularly in patients with unknown cervical spine injury [22]. Other adverse effects include coughing and increased intracranial pressure and intraocular tension.

Late complications

Late complications are generally related to endotracheal or tracheostomy tubes as LMAs and combitubes are not utilized long term. Many of these complications can be visualized on imaging and are usually more evident on CT than radiographs.

Fig. 9 A 26-year-old female patient with upper esophageal adenocarcinoma. Sagittal CT images of the neck demonstrates an appropriately positioned LMA (a) (black arrow) above the level of the vocal cords (not visualized). Note the partially visualized esophageal mass (asterisk). Subsequently, an appropriately positioned endotracheal tube (b) (white arrow) with development of air–fluid level in the sphenoid sinus (arrowhead) is seen, consistent with acute sinusitis. Note the radiopaque marker along the ETT

Fig. 10 a A 56-year-old female patient with post-extubation hoarseness due to prior endotracheal tube. Axial CT image of the neck demonstrates anteromedial position of the left arytenoid cartilage (black arrow) and a dilated left laryngeal ventricle (white asterisk) compatible with left vocal cord paralysis. b Coronal CT image of the neck in the same patient demonstrates slight prominence of the ipsilateral piriform sinus (white asterisk) due to the left vocal cord paralysis and mild proximal tracheal stenosis (black arrows)

Sinusitis may present early or late, is often incidentally identified, and is more commonly associated with nasotracheal intubation [10, 23]. The presence of air–fluid levels and opacification of the paranasal sinuses on radiographs or CT is consistent with sinusitis, infectious or noninfectious (Fig. 9a, b). Abscess formation can result most commonly in the retropharyngeal and nasal septal regions [10]. Computed tomography demonstrates low-attenuation collections with enhancing wall, frequently with foci of gas, and surrounding fat stranding.

Post-intubation hoarseness has a broad etiology which includes vocal cord and epiglottic hematoma, vocal cord mucosal injury, vocal cord paralysis due to injury to the recurrent laryngeal nerve, arytenoid dislocation, or granuloma formation [10]. Most symptoms reverse within several weeks; therefore, findings of persistent hoarseness suggest vocal cord paralysis, arytenoid subluxation, or granuloma formation.

Vocal cord paralysis is associated with traumatic intubation, prolonged intubation, large cuff size, cuff placement close to the vocal cords, and high cuff pressures [24]. Computed tomography and MR demonstrate lateral positioning of the vocal cord, dilatation of the ipsilateral piriform sinus

and laryngeal ventricle (sail sign), anterior and medial position of the arytenoid cartilage, atrophy and fatty replacement of the thyroarytenoid muscle, and medial rotation of the aryepiglottic fold [25, 26] (Fig. 10a, b).

Arytenoid subluxation is a rare complication often associated with underlying risk factors including prior arthritides, retrognathia, dental malocclusions, or large tongue base [24]. Computed tomography and MR may demonstrate similar findings to vocal cord paralysis; however, the displacement of the arytenoid cartilage is often seen to a greater degree than with vocal cord paralysis. If prolonged, cricoarytenoid muscle atrophy can result. Coronal CT images may reveal difference in the vocal cord heights and ill-defined cricoarytenoid joint [27]. The similarities in the imaging features often render these entities indistinguishable.

Granuloma formation is a response to initial tracheal injury or ulceration with attempted healing. The corniculate cartilage, the muscular process of the arytenoid, and the interarytenoid space most frequently develop scar formation. Radiographs and CT will reveal an attached soft tissue nodular density projecting into the tracheal lumen (Fig. 11a, b). It is important to differentiate secretions and tumors when possible, as these can mimic granulation tissue [28]. On CT
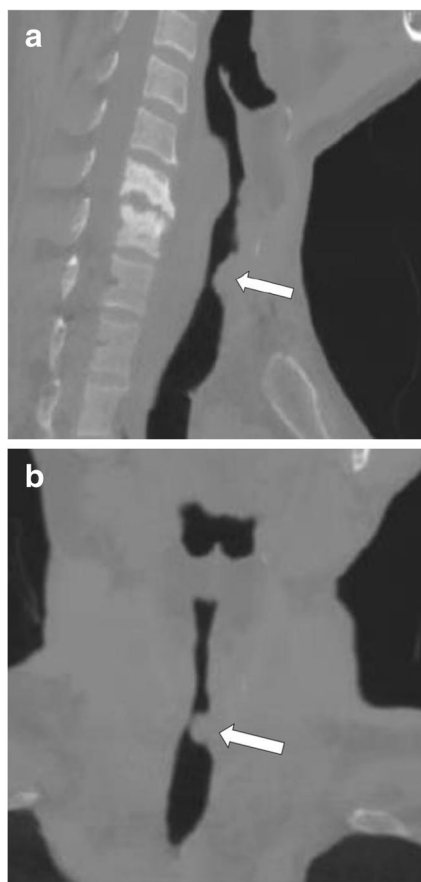
Fig. 11 A 55-year-old male patient with post-extubation hoarseness due to prior tracheostomy tube. Sagittal (a) and coronal (b) CT images of the neck demonstrate a tracheal granuloma (white arrows) in the left anterior wall of trachea resulting in luminal narrowing
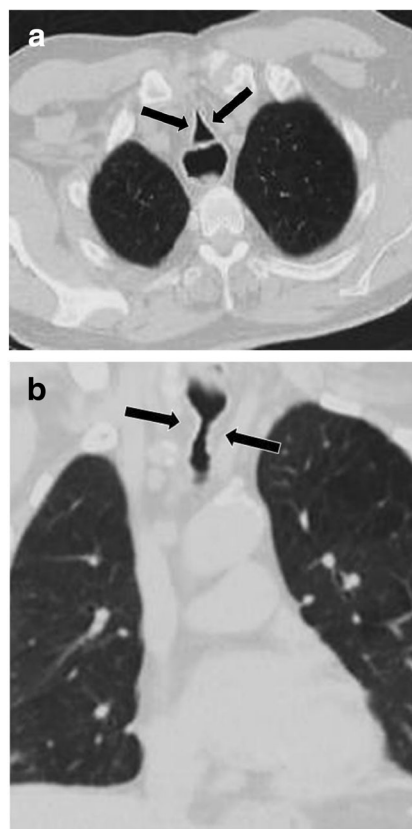
Fig. 12 A 54-year-old male patient with a history of a tracheostomy now with progressive difficulty breathing. Axial (a) and coronal (b) CT images of the chest demonstrate stenosis of the upper anterolateral tracheal wall (black arrows)
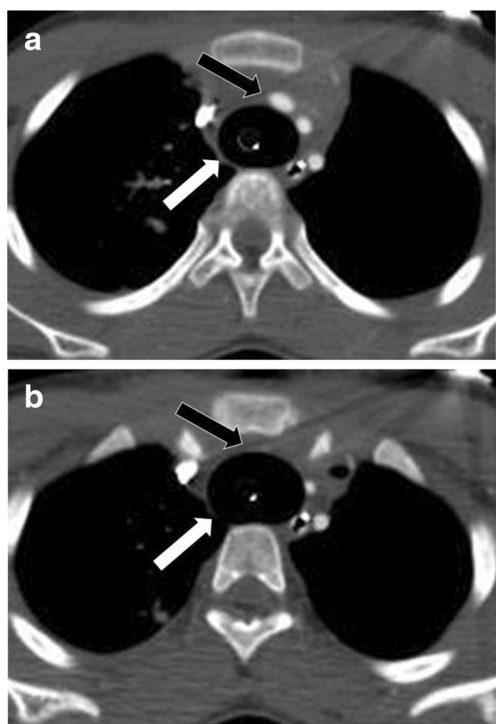
imaging, the dependent location and measured low density (0–10 HU) of the filling defect in the airway suggests secretions. The interval change in location or resolution on follow-up examination is diagnostic for secretions. The clinical history may be key in differentiating granulation tissue from small neoplasms.

Tracheal pathology is usually identified immediately or weeks to months after extubation. Tracheal stenosis develops due to fibrosis of underlying tracheal injury. Occasionally, the stenosis can occur in the larynx as well. Although both radiographs and CT may show narrowing of the trachea, evaluation with CT is necessary as additional valuable information including the position, length, and severity of the stenosis as well as external tracheal compression can be identified (Fig. 12a, b).

Tracheomalacia or tracheobronchomalacia is an infrequent complication which results from ischemic injury followed by necrosis of the cartilage [24]. Tracheobronchomalacia promotes the collapse of the compliant airway wall on expiration leading to air trapping. Dynamic CT in the inspiratory and expiratory phases are key to diagnosis, particularly to differentiate from stenosis, and reveals greater than 50 % decrease in tracheal and bronchial diameters in expiration [29].

Tracheo-innominate and tracheo-esophageal fistulas are rare complications. Tracheo-innominate fistula primarily

develops at the stoma from a low-positioned tracheostomy tube [24]. Pressure can severely narrow the right brachiocephalic artery with potential for fistula formation (Fig. 13a, b). Tracheo-esophageal fistula can be due to direct tracheal injury during the procedure or due to excessive cuff pressure resulting in erosion and fistula development. Chest radiograph demonstrates esophageal and gastric dilatation distal to the fistula. A barium esophagram can delineate the approximate location and size of the fistula. Computed tomography will demonstrate inflammatory changes, loss of the fat plane between the trachea and esophagus, dilatation of the esophagus distal to the location, and possibly visible soft tissue density between the trachea and esophagus indicating the location.

Conclusion

With all artificial airway devices, failure to properly secure the airway and provide appropriate ventilation and oxygenation leads to hypoxia, brain damage, cardiovascular failure, and ultimately death [10]. Unrecognized complications have the potential to exponentially worsen the situation. Many complications are dependent upon the chosen device, the setting, the disease process requiring airway management, and the level of difficulty with which the airway device was placed. Therefore, prompt identification of acute and late complications is essential in improving patient outcome.

Conflict of interest The authors declare that they have no conflict of interest.

Fig. 13 A 9-year-old female patient admitted after motor vehicle collision and intubated due to neurologic impairment due to subdural hemorrhage. Axial CT images (**a**, **b**) of the chest with contrast demonstrate an overinflated cuff (*white arrows*) compressing the brachiocephalic trunk (*black arrows*). The patient subsequently developed intracranial ischemia due to decreased right cerebral perfusion

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