Noncardiac Devices and Central Venous Catheters

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Intensive and critical care units provide specialized care for the most complex and critically ill patients in hospitals. Such specialized care often involves the invasive deployment of various noncardiac devices and central venous catheters (CVCs). These devices are necessary to treat a host of otherwise life-threatening conditions and to monitor the response of various treatments until the patients have stabilized and they are no longer critically ill. Although necessary for the appropriate care and management of these patients, deployment of such devices may be associated with its own untoward complications that impact emergent patient care and, in some cases, even patient survival. It is imperative that all radiologists who interpret imaging studies on ICU and critically ill patients not only know the clinical indications for such devices but can also confidently recognize the appropriate and, more importantly, inappropriate placement of such invasive devices. The latter could harm a patient or adversely impact their outcome if not urgently recognized and clinically addressed.

The increasing use of noncardiac monitoring and life support devices is pervasive. In fact, in a 1-day prevalence survey of six large urban teaching hospitals in the United States, up to 29% of adult inpatients had CVCs. At these six hospitals, 43–80% (mean, 59.3%) of patients admitted to the ICU and 7–39% (mean, 27.3%) of patients hospitalized on non-ICU wards had CVCs [1].

In one multicenter observational prospective study of adult patients in both medical and surgical ICUs in the United States, up to 60% of critically ill patients required endotracheal (ET) intubation during the course of their hospitalization [2]. Malnutrition itself is an independent risk factor for morbidity and mortality among critical care patients. Nearly 40% of such patients meet the standards for having malnutrition. As a result, a significant number of these patients require enteric tubes for nutritional supplementation [3].

Another frequently placed noncardiac device is the thoracostomy tube (TT), or chest tube, which is used in the treatment of pleural effusions with various causes and both iatrogenic and noniatrogenic pneumothoraces. The literature reveals that chest tubes were placed in more than 2 million adults in the United States in 1 year alone [4–6]. Pottier et al. [7] reported that among 893 patients in the ICU setting who required invasive procedures in a 1-year period, 150 (16.7%) required chest tube placement.

It is clear, based on these limited prevalence points, that noncardiac devices and CVCs are essential in the management of critical care patients. Their use, the potential complications related to their use, and appropriate monitoring are paramount. The American College of Radiology (ACR) Appropriateness Criteria for portable chest radiography performed for patients in the ICU setting states that it is usually appropriate to order portable chest radiography at admission or upon transfer of the patient to the ICU. It may be appropriate (disagreement without consensus) to obtain portable chest examinations for patients in the ICU whose condition is stable but who have experienced no change in clinical status. Consensus has been reached that it is usually appropriate to perform portable chest radiography for patients in the ICU when their clinical status worsens and/or after deployment of any new life support or monitoring device. It may also be appropriate to perform portable chest radiography after removal of a chest tube or mediastinal tube [8]. Being conscientious regarding these criteria is part of being a responsible health care provider.

This chapter will now focus on the clinical indications for intubation, tracheostomy tube, nasogastric and enteric feeding tube, TT, and CVC placements. Expected and unexpected device deployments on imaging, the recognition of such, and potential complications associated with malpositioning of these devices will be highlighted through illustrative case examples.

Endotracheal Tubes

The primary clinical indications for intubation include respiratory failure (hypoxia or hypercapnia); apnea; a reduced level of consciousness (Glasgow Coma Scale score, ≤ 8); rapid change in mental status; airway injury or impending airway compromise; high risk for aspiration; trauma, including penetrating injuries to the neck, chest, and abdomen; and general anesthesia [9, 10]. Contraindications to ET tube (ETT) placement include severe airway trauma or obstruction preventing safe intubation. If an ETT cannot be safely placed but the airway needs to be secured, then a surgical airway is indicated [9, 10].

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The distal tip of the ETT is most optimally positioned 5.0 cm above the carina, with the head and neck in a neutral position [9–11] (Fig. 1A). An allowance of plus or minus 2.0 cm is permitted for flexion and extension of the head and neck. Radiologists should be cognizant that an ETT may descend up to 2.0 cm with neck flexion. Alternatively, with neck extension, an ETT may ascend as much as 2.0 cm [9–11]. In cases in which the carina is not optimally delineated, the T4 vertebra is an acceptable alternative landmark for optimal deployment [9–11] (Fig. 1B).

ETT malpositioning occurs in up to 15% of new intubations [12, 13]. Despite malpositioning, breath sounds may still be transmitted to both lungs in up 60% of cases [12, 13]. Thus, physical auscultation alone is not sufficient to confirm optimal deployment. Accurate positioning must always be confirmed with chest radiography. Owing to the orientation of the carinal angle, in patients older than 12 years old, the ETT preferentially passes into the right mainstem bronchus [12, 13] (Fig. 1C). Unanticipated right mainstem bronchial intubation occurs in up to 5–28% of initial intubation attempts. In patients younger than 12 years old, there is no lobar predilection. In other words, inadvertent selective deployment into the right and left mainstem bronchus occurs with relatively equal frequency [12, 13]. When selective bronchial intubation occurs, resultant segmental, lobar, and even total lung collapse of the nonventilated lung may develop, the rate of which is Fio2 (fraction of inspired oxygen) dependent. That is, higher levels of Fio2 are associated with more rapid atelectasis. For example, in the setting of right mainstem bronchial intubation with occlusion of airflow to the left lung, the entire left lung may become atelectatic in as little as 5 minutes if the patient is receiving 100% oxygen [14, 15] (Fig. 1D). Additional imaging features associated with inadvertent selective bronchial intubation may include

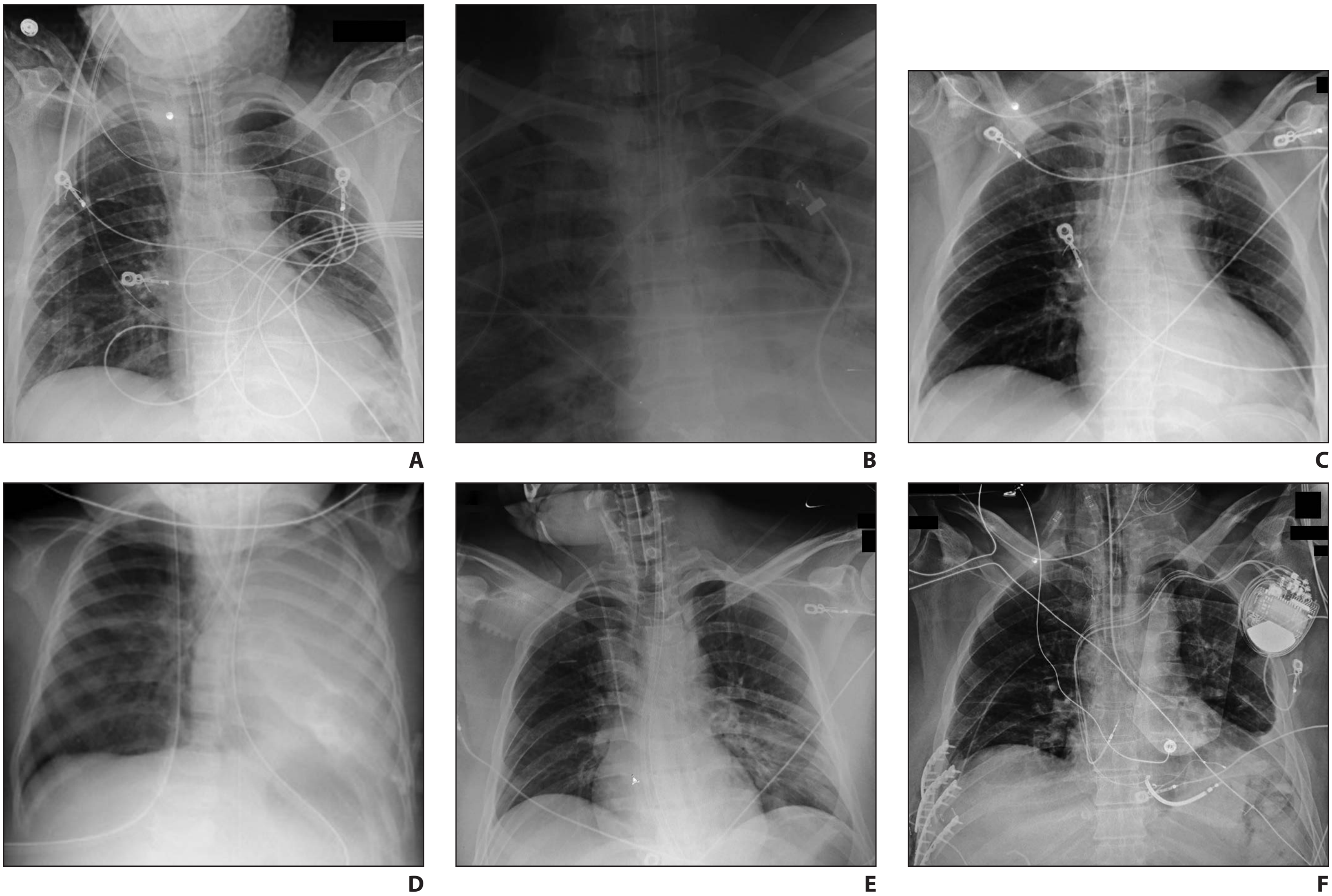

Fig. 1—Well-positioned and malpositioned endotracheal tubes (ETTs) as shown on anteroposterior portable chest radiographs of six patients.
A, Radiograph shows well-positioned ETT terminating 3.9 cm above carina with head and neck in neutral position.
B, Radiograph shows well-positioned ETT terminating at T4 spinous level with head and neck in neutral position.
C, Radiograph shows malpositioned ETT coursing into right mainstem bronchus. Emergent recognition and withdrawal of 4.0 cm is indicated.
D, Radiograph shows malpositioned ETT coursing into bronchus intermedius and occluding airflow to left mainstem bronchus, resulting in whiteout of left hemithorax from complete left lung atelectasis. Note additional indirect signs of left hemithoracic volume loss, including ipsilateral diaphragmatic elevation and mediastinal displacement.
E, Radiograph shows malpositioned ETT positioned much too high in tracheal air column, with tip terminating at C7–T1 level resulting in ineffective ventilation of both lungs. Urgent correction of positioning is indicated.
F, Radiograph shows well-positioned double-lumen ETT with selective intubation of left mainstem bronchus. This should not be confused with inadvertent left mainstem bronchial intubation by single-lumen ETT. Note balloon cuff of ETT proper terminates 3.0 cm above carina.

overinflation of the affected lung and underinflation of the contralateral lung (with varying degrees of increasing radiopacity resulting from evolving atelectasis) as well as concomitant ipsilateral mediastinal displacement and diaphragmatic elevation as indirect signs of volume loss (Fig. 1D). Left uncorrected, barotrauma and spontaneous pneumothorax may ensue.

Alternatively, the ETT inadvertently may be positioned too proximal in the tracheal air column (Fig. 1E). Such positioning is associated with ineffective ventilation of both lungs. Furthermore, positioning of the ETT that is too proximal heightens the risk of air leakage from a poor cuff seal (i.e., look for an overinflated balloon cuff), inadvertent extubation, slippage of the tube into the hypopharynx, potential vocal cord injury, and laryngeal fracture [12–15]. Such malpositioning requires urgent correction.

Esophageal intubation occurs not infrequently in approximately five of every 100 intubations (incidence, approximately 5.4%). Unrecognized esophageal intubation may be complicated by hypoxemia and brain damage and has the potential to be fatal. Clinically, 90% and 96.25% of cases of esophageal intubation may be diagnosed via auscultation of bilateral lung apices or the epigastrium, respectively. During inadvertent esophageal ventilation, abdominal distention may be observed in up to 87.5% of cases, but expected chest excursion is typically absent. End-tidal CO_2 ($EtCO_2$) monitoring and capnography are the most reliable techniques to exclude potential esophageal intubation. $EtCO_2$ monitoring is the most rapid clinical indicator of ventilatory compromise, whereas capnography assesses the movement of air in and out of the lungs [16]. Radiologic signs of potential esophageal intubation include positioning of the ETT lateral to the tracheal air column, an oblique rather than vertical course of the ETT, visualization of the ETT lateral to an indwelling enteric tube within the esophagus, projection of the ETT below the carina, air distention of the esophagus, and/or gaseous distention of the stomach [17].

Once appropriate ETT positioning has been confirmed on imaging, the radiologist should also assess whether the balloon cuff is appropriately distended or inadvertently overdistended (Fig. 1E). The balloon cuff functions to fill in the space around the ETT, preventing air from escaping around the tube and through the upper airway, and to deliver air to the lungs proper. On imaging, the balloon cuff should fill but should not expand the tracheal walls. The normal cuff diameter should be 26 mm or less. Balloon cuff overinflation may be associated with mucosal pressure necrosis, with complicating tracheomalacia, tracheal stenosis, and even tracheoesophageal fistulas as sequelae [18].

Double-lumen ETTs are designed to segregate the lungs anatomically and/or physiologically. It is important not to confuse the contours of a double-lumen ETT with inadvertent mainstem bronchus intubation with a single-lumen tube (Fig. 1F). Double-lumen ETT intubation is clinically indicated when one lung is ventilated preferentially, avoiding contamination from one lung to the other (e.g., for active hemoptysis, infectious secretions); when attempting whole lung lavage (e.g., for pulmonary alveolar proteinosis); or when controlling ventilation to each lung respectively [19].

Tracheostomy

There are four main clinical indications for tracheostomy in the ICU setting: failure or inability to wean a patient from the ventilator, the need for long-term mechanical ventilation, upper airway obstruction, and airway protection (e.g., inability to handle secretions, angioedema, recurrent aspiration). The preferable timing of tracheostomy is 7–15 days after intubation [20]. The most common clinical indications for elective tracheostomy placement include prolonged ventilator dependence, the need to clear and remove secretions from the airway, the need to bypass an obstructed upper airway (e.g., for head and neck cancer treatment), obstructive sleep apnea that is refractory to other treatments, chronic aspiration, neuromuscular disease, and subglottic stenosis [19, 20].

Uncuffed and cuffed tracheostomy tubes are available. Uncuffed tubes allow airway clearance but do not provide airway protection from aspiration. Uncuffed tubes are used for a stable stoma, pediatric patients, upper airway obstruction from either a mass or neuromuscular disorder with vocal cord palsy or paralysis, or any of these factors in combination. Cuffed tubes allow secretion clearance and thereby provide some protection from aspiration while also allowing more effective positive pressure ventilation [15, 18–20].

Ideally, the tracheostomy tube tip should be positioned at one-half to one-third the distance from the stoma to the carina [15, 18]. As opposed to ETTs, tracheostomy tubes do not shift position with head and neck flexion and extension [15, 18]. However, radiologists should be aware that migration out of the stoma can occur [6, 7]. This is best appreciated on serial review of examinations and can result in inadvertent extubation. Like ETTs, radiologists should inspect the tracheostomy balloon cuff for overinflation and potential complications related to overinflation. Radiologists should also be aware that newly placed tracheostomy tubes may be complicated by extraluminal air collections, including pneumomediastinum, subcutaneous air, or pneumothorax, with the latter seen in 2–5% of patients [15, 18]. Such extraluminal air collections may be indicative of traumatic tracheostomy placement and potential aerodigestive tract injury. Radiologists need to be attentive to changes in mediastinal contour after new tracheostomy tube deployments, as such changes may be indicative of postprocedural hematoma from an occult vascular injury. Not unexpected minor bleeding occurs in 3–20% of patients after percutaneous tracheostomy placement and in 1–80% of patients after open surgical placement and usually is self-limited. This normally occurs within the first 48 hours after surgery and is typically related to traumatic injury of anterior jugular or inferior thyroid veins, systemic coagulopathy, erosions secondary to tracheal suction, bronchopneumonia, or a combination of these [21]. Major bleeding is much less common and occurs in 0–10% of new tracheostomy placements and may complicate either percutaneous or open techniques. Tracheoinnominate fistula fortunately is only seen after 0.1–1% of surgical tracheostomies, with its peak incidence occurring 7–14 days after surgery. Hemorrhage occurring 3 days to 6 weeks after surgical tracheostomy represents a tracheoinnominate fistula until proven otherwise and warrants clinical investigation This can be a potentially fatal complication if not recognized and emergently treated. Tracheoinnominate fistula manifests clinically with hemoptysis and or bright red blood from the tracheostomy or stoma itself and manifests radiographically with acute eccentric mediastinal contour changes and or effacement of the tracheal air column [21] (Fig. 2).

Nasogastric and Feeding Tubes

The most common clinical indication for nasogastric tube (NGT) placement is decompression of the stomach (e.g., distal bowel obstruction or ileus). Other common indications include management of intractable nausea or emesis (e.g., medications, intoxication, and other factors); administration of medications, activated charcoal (e.g., overdose) and oral radiographic contrast media; or nutrition in patients who have a functional gastrointestinal tract but are unable to tolerate oral intake (e.g., impaired swallowing, stroke), and management of massive hematochezia (i.e.,15% have an upper gastrointestinal source) [22, 23]. On imaging, NGTs are 1.0 cm in diameter and appear as a single radiopaque linear strip. A radiolucent break is visible at the proximal side port located 6.0 cm from its distal tip. Appropriate placement requires at least 10.0 cm of tubing within the stomach, with the proximal side port well beyond the esophagogastric junction [18, 24]. The most common complications associated with placement include incomplete insertion, coiling within the hypopharynx or esophagus, and inadvertent malpositioning in the airway [18, 22, 24] (Figs. 3A and 3B).

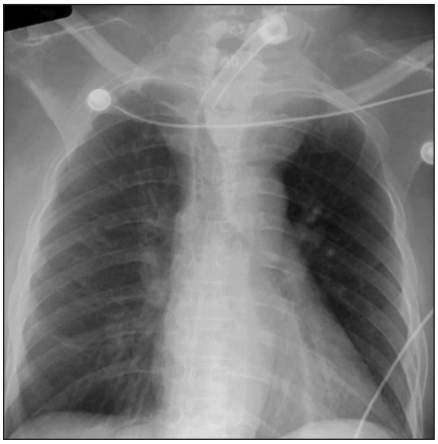

Fig. 2—Tracheoinnominate fistula complicating surgical tracheostomy placement. Note large eccentric left-sided mediastinal mass that is consistent with large mediastinal hematoma grossly effacing tracheal air column and displacing tracheostomy device. This surgical emergency must be recognized by radiologist.

Clinical indications for gastroenteric feeding tube placement and enteral nutrition include prolonged anorexia, severe protein-calorie undernutrition, comatose states or depressed sensorium, liver failure, head or neck trauma precluding oral feeding, and critical illnesses inducing high metabolic stress (e.g., in individuals with burns) [22, 24, 25]. Currently recommended guidelines indicate that the optimal timing for enteric tube placement is when a patient shows an inability to achieve full oral dietary intake needs within 3 days of hospitalization [3]. Absolute contraindications for gastroenteric feeding tube placement and enteral nutrition include ileus, intestinal obstruction, active gastrointestinal bleeding, and hemodynamic instability, as enteral nutrition in the setting of an ischemic small bowel can exacerbate ischemia, leading to necrosis and bacterial overgrowth [3].

On imaging, gastroenteric feeding tubes appear as thin-walled, relatively radiolucent catheters compared with NGTs, and they often have a weighted radiopaque tip. This weighted tip ideally should lie within the third to fourth portion of the duodenum at the ligament of Treitz [22, 24, 25], although there is some controversy regarding the benefit of postpyloric placement that is beyond the scope of this chapter. The most common complications associated with gastroenteric feeding tube placement are like those encountered with NGT placement, including incomplete insertion, coiling within the hypopharynx or esophagus, and inadvertent malpositioning in the airway [18, 22, 24] (Fig. 3C). Rarely, more ominous complications may occur, including pharyngeal, esophageal, pleural, and bronchial perforation. Imaging findings of such potential complications, beyond the device following an anomalous or untoward course, may include new or rapidly evolving pleural effusion, pneumo- or hydropneumothorax, pneumomediastinum, mediastinal air-fluid levels, or a combination of these complications [18, 22, 24] (Fig. 3D). Caution is advised against ever placing a NGT or nasal gastroenteric feeding tube in trauma victims with suspected or known basilar skull fractures or maxillofacial trauma. Doing so may result in the tube piercing the cribriform plate of the ethmoid and entering the cranial vault, resulting in devastating consequences [26, 27].

Thoracostomy Tubes

The primary clinical indications for TT placement in the ICU are evacuation of pleural air (e.g., pneumothorax) or abnormal transudative or exudative pleural fluid collections (e.g., hydrothorax, hemothorax, pyothorax, chylothorax, bilothorax, and other collections). In the absence of pleural adhesions, intrapleural air will rise to the most nondependent space, whereas intrapleural fluid will gravitate to the most dependent portions of the pleural cavity. Therefore, appropriate evacuation of uncomplicated pneumothorax requires that the tube be directed anteriorly and apically. Alternatively, evacuation of pleural fluid collections requires the tube be directed posteriorly and inferiorly [15, 28, 29]. Appropriate deployment also requires that the proximal-most tube side port be positioned medial to the inner margin of the thoracic cavity. Loculated intrapleural air and or fluid collections often necessitate image-guided placement (e.g., fluoroscopy, ultrasound, CT) to direct placement of the distal tip and side ports of the TT into the anomalous collection for evacuation [15, 28, 29].

Malpositioning or ectopic deployment is the most common complication associated with TT placement [30]. Curtin et al. [31] showed TT malpositioning confirmed by CT in 26% of cases in their series. Not all malpositioned TTs are clinically significant, but others are indeed. Other complications associated with TT placement include infection (e.g., empyema, mediastinitis) and organ injury [30, 31].

Approximately 15–20% of ectopic TT placements are subcutaneous. That is, the tube fails to penetrate the parietal pleura and access the pleural cavity. Such tubes fail to function immediately or shortly after placement. A clinical clue is that the collection system fluid chamber will not show respiratory variation. A radiologic clue is ineffective drainage of the targeted pleural fluid or air collection [32]. Contributing factors to ectopic subcutaneous tube deployment may include operator experience, obesity, and various chest wall deformities (e.g., severe scoliosis, flail chest, and burns with or without associated eschar).

The lung is the most injured organ during TT placement. Contributing factors enhancing the risk of inadvertent intraparenchymal deployment include decreased lung compliance (e.g., pulmonary fibrosis, acute respiratory distress syndrome, consolidation) and preexisting significant pleural adhesions [32]. Clinical and/or radiologic recognition of this complication is often difficult and delayed. Potential clinical and/or radiologic clues include persistent pneumothorax or pleural effusion despite the new tube placement and/or new airspace disease about the chest tube indicating lung injury and potential intraparenchymal hemorrhage [32] (Figs. 4A and 4B). Confirmation with CT is needed in most cases. Of interest, Landay et al. [33] reported that 26% of patients with intraparenchymal TT placement improve clinically and/or radiographically, as the chest tube must first cross the pleural cavity before inadvertently penetrating the lung. Fortunately, up to 42% of these patients have no adverse sequelae develop [33]. However, other patients are at risk for serious complications, including lung laceration with or without parenchymal hemorrhage or hemothorax, abscess formation, air leaks, bronchopleural fistula, vascular injuries, and pseudoaneurysms [32, 34].

The probability of ectopic interlobar fissure placement is significantly higher with TT insertions performed using a lateral approach as opposed to an anterior approach. Although not optimally positioned, such intrafissural TTs may still effectively decompress pneumothoraces but may less effectively evacuate complex pleural effusions (e.g., hemothorax, pyothorax). Kim et al. [35] reported that up to 20.7% of patients with intrafissural deployments required an additional chest tube, although others have found that an additional chest tube is less commonly needed. Radiographically, intrafissural placement should be suspected if the tube follows the expected course of the horizontal fissure or has a superior convex orientation when placed

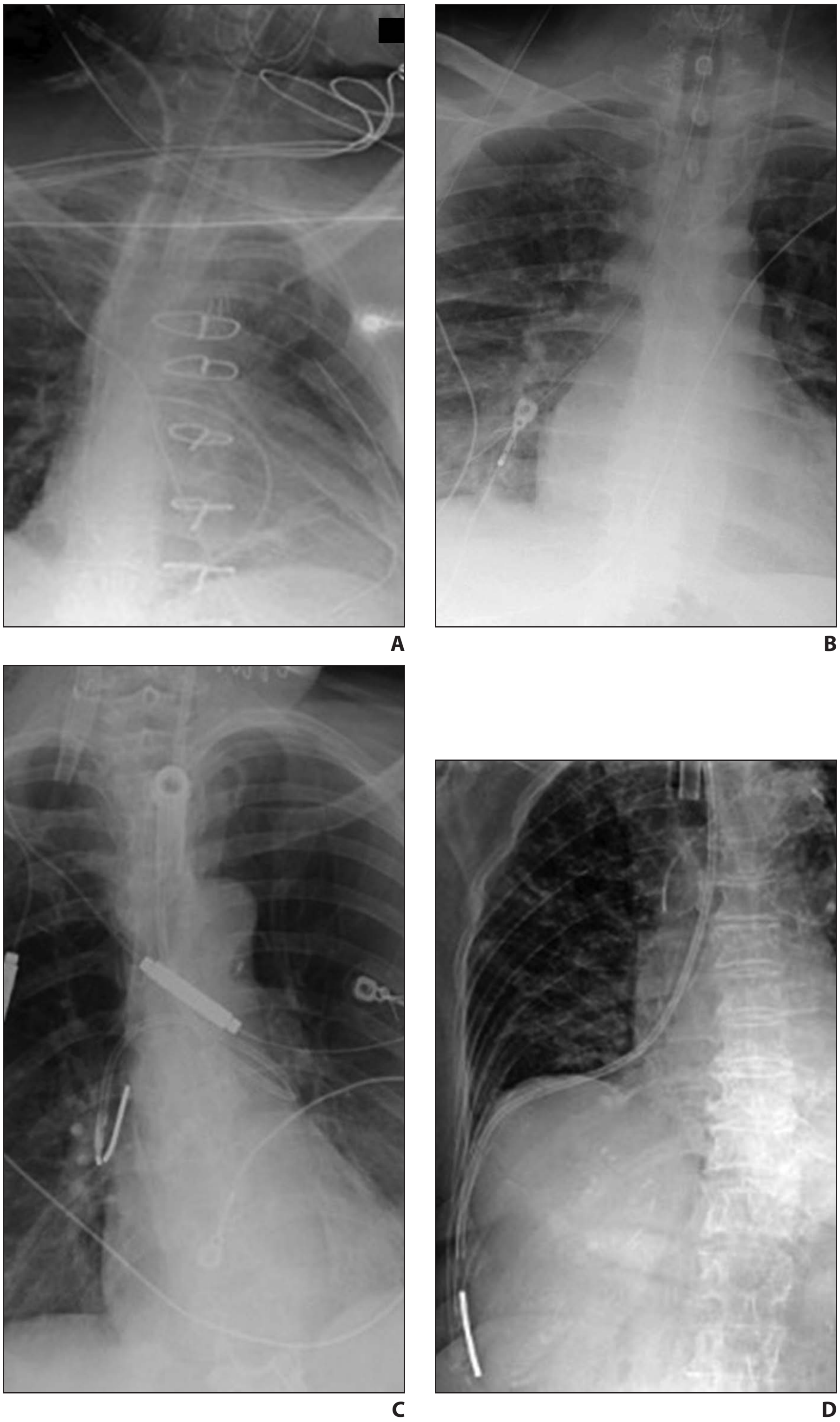

Fig. 3—Malpositioned nasogastric and gastroenteric feeding tube deployments, as seen on coned-down anteroposterior portable chest radiographs of four patients.
A, Radiograph shows malpositioned nasogastric tube (NGT) redundantly looped in hypopharynx.
B, Radiograph reveals malpositioned NGT redundantly looped in distal cervical esophagus and then coursing into trachea and then downward to right lower lobe bronchus.
C, Radiograph shows malpositioned feeding tube coursing down trachea into left mainstem bronchus and then into right mainstem bronchus, terminating in bronchus intermedius.
D, Radiograph shows malpositioned feeding tube coursing down right lower lobe bronchus perforating airway, terminating deep in lateral pleural recess.

in the oblique fissure. Lateral chest radiography and/or CT can confirm suspected ectopic positioning (Fig. 4B).

Ectopic mediastinal TT placement may result in perforation of the heart, which has catastrophic results and/or causes injury to the great vessels, esophagus, and nerves, with the latter resulting in phrenic nerve damage or Horner syndrome. Contributing factors include operator experience, thoracic wall deformities, enlarged cardiac chambers, trauma, pleural adhesions, and entrance into a postpneumonectomy space [36]. Radiographic clues may include a TT approaching or crossing the midline, with or without associated mediastinal contour changes (Fig. 4C). CT may be used to confirm ectopic mediastinal deployment and to assess the nature and degree of potential incurred mediastinal injury. Ectopic mediastinal TT placement requires emergent attention, cardiothoracic surgical consultation, and correction of positioning.

Ectopic subdiaphragmatic intraabdominal TT placement usually occurs when the tube insertion is performed too low, below what is termed the “triangle of safety.” This anatomic triangle is created by the anterior border of the latissimus dorsi muscle, the lateral border of the pectoralis major muscle, a line superior to the horizontal level of the nipple, and an apex below the axilla [37]. Such ectopic deployments may be associated with injuries to the diaphragm, stomach, small and/or large bowel, liver, spleen, kidney, or a combination of these areas. Surgical consultation is always needed in such cases [36]. Potential radiographic clues include a chest tube that is positioned low, a chest tube that courses below the diaphragmatic sulcus, and ineffective drainage of the targeted pleural air or fluid collection (Fig. 4D).

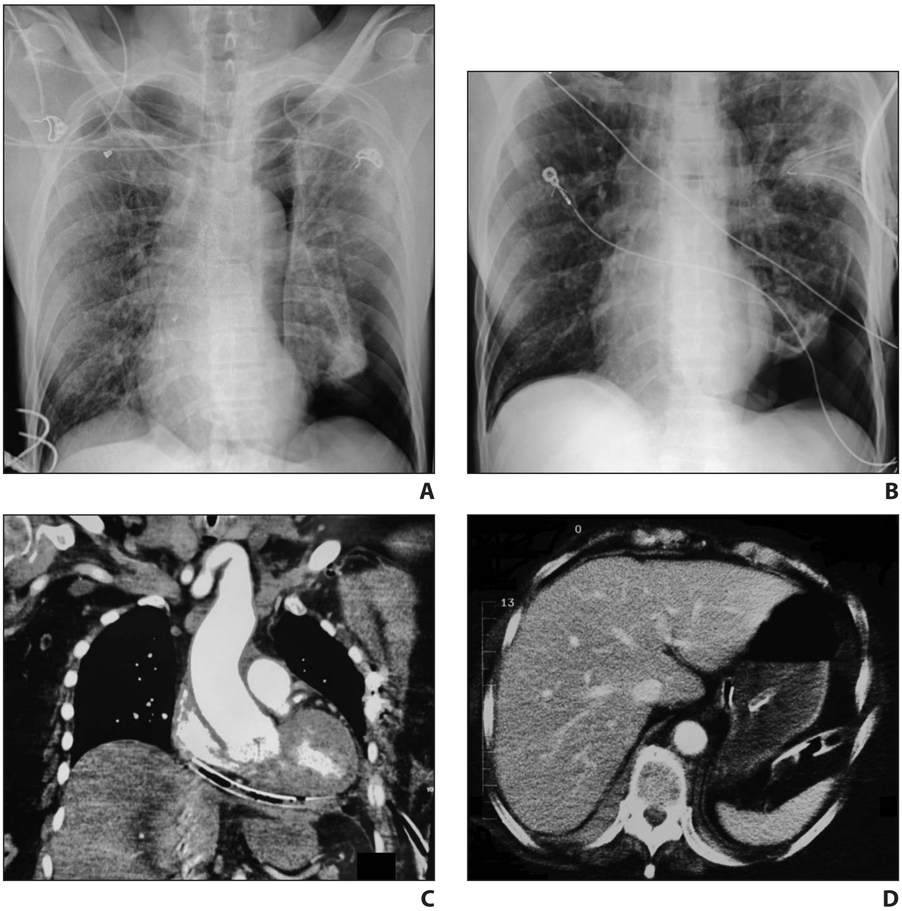

Fig. 4—Ectopic tube thoracostomy tube placement in three patients.
A, Anteroposterior (AP) portable chest radiograph of patient with blunt trauma shows large left pneumothorax with left lower lobe contusion.
B, Subsequent AP portable chest radiograph of same patient shown in **A**, obtained after left chest tube placement, shows failure of left pneumothorax to decompress and new airspace disease around chest tube, suggesting inadvertent intraparenchymal deployment. This was subsequently confirmed on CT (not shown).
C, Coronal multiplanar reformation contrast-enhanced CT (mediastinal window) confirmed radiographic suspicion on ectopic placement of left chest tube attempt into pericardium.
D, Axial contrast-enhanced CT (mediastinal window) through upper abdomen reveals ectopic left chest tube coursing between stomach and spleen.

Central Venous Catheters

Approximately 5 million central venous access lines are placed every year in the United States [38]. The primary clinical indications for CVC placement in the critical care and ICU setting include vascular access needed in patients with otherwise difficult peripheral venous access (e.g., prior cannulation with stenosis and/or occlusion, upper extremity scars, burns, fractures, and body habitus limitations), delivery of specific medications or IV fluids that may damage small peripheral veins (e.g., vasopressors, hypertonic solutions, chemotherapeutic agents), the need for prolonged IV therapy (e.g., total parenteral nutrition, prolonged systemic antibiotics), and various forms of specialized medical therapy or management (e.g., blood transfusions, plasmapheresis, hemodialysis, central venous pressure monitoring–pulmonary artery catheter, temporary transvenous pacing) [39, 40].

Most CVCs used today are triple-lumen catheters. CVCs may be introduced via the internal jugular, subclavian, or femoral vein. The site of insertion depends on several factors, including the indication for venous access, the anticipated duration of use, previous instrumentation at that site, and the presence of relative contraindications (e.g., coagulopathy, thrombocytopenia, ipsilateral hemothorax or pneumothorax, vessel thrombosis or stenosis, infection overlying the insertion site, ipsilateral indwelling central vascular devices, and other contraindications). The internal jugular venous system is easily visualized on bedside imaging ultrasound studies, is relatively easily accessed clinically with fewer potential complications, and is the most frequently selected site for short-term use [39, 40].

Appropriate CVC tip positioning must always be confirmed on chest radiography. As many as 40% of new central line placements are abnormally positioned. Radiologists and treating clinicians both need to be cognizant that suboptimal positioned catheters may not reflect true central venous pressure measurements and may also be associated with an increased risk of mechanical and thrombotic complications. High catheter tip placement in the superior vena cava may be associated with central venous thrombosis. Alternatively, low placement in the right atrium may be complicated by cardiac arrhythmias, myocardial perforation, rupture with complicating tamponade, or a combination of these. Furthermore, patients may experience potential adverse systemic effects caused by the infusion of potentially toxic substances that otherwise would be diluted in the central venous system [41, 42].

Radiographically, the CVC tip should be placed in the mid superior vena cava, well below the first anterior rib and slightly above the right atrium such that it is above the pericardial reflections. The bronchus intermedius is a good anatomic landmark [41, 42]. CVCs may inadvertently gain access to unexpected normal venous structures, including but not limited to the axillary, azygos (Fig. 5A), hemiazygos, interazygos, internal mammary, superior pulmonary, and pericardiophrenic veins. Recognition of anomalous venous positioning by the radiologist and correction of such by the clinician is imperative to avoid potential complications (e.g., venous perforation or rupture, vasovagal reaction, painful infusions and inappropriate delivery of fluids, medications, blood products, or a combination of these).

CVCs may inadvertently access preexisting and, in some cases, unknown developmental anomalies, such as patent foramen ovale, atrial septal defect, or a persistent duplicated superior vena cava. Catheters should always be removed from the former two locations. Superior vena cava duplication occurs in 0.3–0.5% of the general population and in up to 4.5% of individuals with congenital heart anomalies [43–45]. The left-sided SVC most often persists along with the physiologic right-sided SVC. Most individuals are asymptomatic unless other developmental cardiac anomalies coexist. Embryologically, both the right and left SVC arise from their respective precardinal and common cardinal veins. These veins compose the primary venous drainage system of the embryologic heart. In utero, an anastomosis usually forms between the left and right venous systems, creating the left brachiocephalic vein and the left precardinal and left common cardinal veins atrophy. Failure of the left anterior cardinal vein, proximal to the brachiocephalic anastomosis, to involute results in a duplicate SVC system [43–45]. Eighty-two percent of patients with a persistent left-sided SVC have a normal right-sided SVC. In 90% of patients, the left SVC drains into the coronary sinus and then the right atrium, and affected patients are asymptomatic. Radiographically, catheters placed in the persistent left SVC fail to cross the midline and follow a left paramediastinal course. Distally, a gentle curve or J-shaped configuration may be observed as the catheter enters the coronary sinus (Figs. 5B and 5C). The placement of central venous lines and pacemakers in a persistent left-sided SVC may potentially irritate the coronary sinus, resulting in symptomatic hypotension, arrhythmia, myocardial ischemia, and cardiac arrest. In approximately 8–10% of patients, the persistent left SVC drains into the left atrium, causing a right-to-left shunt. In these latter cases, air or particulate emboli from such catheters and an increased risk of right-sided heart failure have been reported [38].

Pneumothorax is the second most frequent complication associated with CVCs. Its incidence varies between 1% and 6.6%. Higher incidence rates occur with emergent as opposed to elective placement, large catheter sizes, dialysis catheters, and the number of needle passes made. The

Fig. 5—Ectopic central venous catheter (CVC) positioning.
A, Anteroposterior (AP) portable chest radiograph shows malpositioned CVC placed via left internal approach coursing into azygos vein. Note characteristic curl or J-shaped configuration of ectopic azygos positioning. Correction of positioning is indicated to avoid painful infusion and potential vasovagal reaction and/or central venous thrombosis.
B, AP portable chest examination of patient in ICU who was intubated shows expected course and position of central catheter placed by right internal jugular approach and terminating at atrial-caval confluence. Note that second left internal jugular approach catheter fails to cross midline and follows vertical paramediastinal course, with distal tip projected over left heart.
C, Remote contrast-enhanced coronal multiplanar reformation CT image (mediastinal window) of same patient shown in **B** confirms persistent duplicated left superior vena cava.

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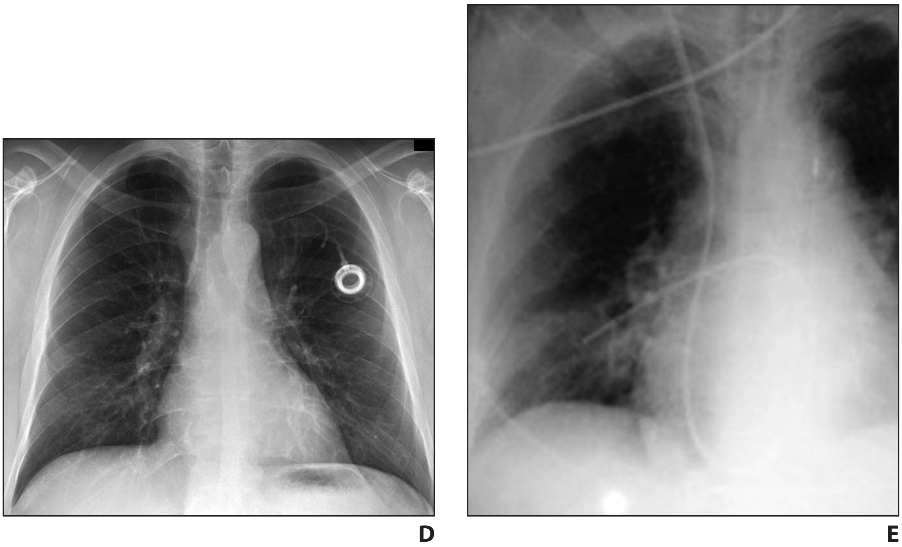

Fig. 5 (continued)—Ectopic central venous catheter (CVC) positioning.
D, Posteroanterior upright chest radiograph shows pinched-off syndrome with fragmentation of Port-a-Cath placed via left subclavian approach at first rib and clavicle and catheter embolization to left lobar pulmonary artery. Fragment was successfully retrieved by interventional radiology (not shown).
E, Coned-down AP portable chest examination over right thorax in patient in ICU with hemoptysis shows pulmonary artery catheter coursing too far into right lower lobe. Airspace disease around catheter tip represents hemorrhage from arterial perforation. Associated nodular opacity is from iatrogenic middle lobe artery pseudoaneurysm that required embolization by interventional radiology (not shown) to stop hemoptysis.

subclavian venous approach is also associated with a higher rate of pneumothorax compared with the internal jugular approach. Chest radiographs should always be acquired after any successful or unsuccessful line placement attempt, to confirm catheter location and to exclude a potential postprocedural pneumothorax [46].

Vascular perforation is a potentially life-threatening CVC complication. Suspect radiographic findings suggesting vascular injury include an unusual catheter course, an apical cap of extrapleural hematoma, new postprocedural pleural effusion, and changes in mediastinal contour. Further investigation with CT and potential surgical consultation may be indicated in such cases. Extravascular CVC deployment may result in the delivery of fluids or blood products to an extravascular compartment (e.g., mediastinum, pleural space), resulting in an infusothorax that necessitates surgical drainage [41].

Knotting, looping, and kinking of newly placed and preexisting CVCs may occur and may be associated with an increased risk of vascular injury, thrombosis, and catheter embolization. Catheter fragmentation complicates approximately 1% of CVC placements [41]. CVC fragmentation with catheter embolization may result from compression of the CVC between the first rib and clavicle (e.g., pinch-off syndrome) (Fig. 5D). The embolized catheter fragment(s) may cause arrhythmia, vascular injury, and pulmonary embolism. Consultation with the interventional radiology department is advised in such cases given that minimally invasive endovascular retrieval techniques can be used to mitigate these complications [41].

The pulmonary artery (i.e., Swan-Ganz) catheter is a flow-directed balloon-tipped catheter that is usually introduced via the internal jugular or subclavian vein. The balloon is temporarily inflated to measure the capillary wedge pressure. The primary clinical indications are differentiating the causes of shock (e.g., cardiogenic, hypovolemic, septic, obstructive), differentiating the cause of edema (e.g., cardiogenic, noncardiogenic), evaluating pulmonary hypertension, diagnosing left-to-right intracardiac shunt, assisting in the management of unstable perioperative cardiac patients, managing complicated myocardial infarction, guiding pharmacologic therapy (e.g., vasopressors, inotropes, vasodilators), and fluid management (e.g., for trauma, burns, decompensated cirrhosis, renal failure sepsis, and other conditions.) [47]. The tip of the pulmonary artery catheter should ideally be positioned in the right or left main pulmonary artery and should reside within 2.0 cm of the respective hilum. It should not extend beyond the proximal interlobar pulmonary artery. Potential complications include those associated with any CVC placement, pulmonary artery branch occlusion sequelae of persistent balloon inflation or too distal deployment with resultant pulmonary infarction, and vascular injury with pericatheter tip hemorrhage and pulmonary artery branch pseudoaneurysm. In such cases, chest radiography may reveal new airspace opacity around the catheter tip (e.g., hemorrhage), a peripheral wedge-shaped opacity downstream from the catheter tip (e.g., pulmonary infarction), and a new nodular opacity related to a vessel branch injury (e.g., pseudoaneurysm) (Fig. 5E). An interventional radiology consultation for potential vessel embolization may be needed to treat active bleeding or pseudoaneurysm.

Conclusion

Critical care patients and patients in the ICU setting often require one or more of a variety of noncardiac devices and CVCs to manage their illness until their condition stabilizes. Although noncardiac devices and CVCs are necessary for the appropriate care and management of these patients, their use may have its own potential complications that may impact patient care and even survival if these complications are not recognized and emergently treated. Radiologists interpretating imaging studies for critically ill patients and patients in the ICU setting need to know the clinical indications for these devices and should be able to confidently recognize the appropriate and, more importantly, inappropriate placement of these invasive devices to expedite necessary management.

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