Airway Ultrasound

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Contents

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Imaging of the airway is amenable to probes with linear or curvilinear faces to provide detailed imaging near the skin surface. Since the region of ultrasound interrogation is relatively superficial, high-frequency probes including linear or micro-convex curvilinear probes are preferred for this purpose. Musculoskeletal or small parts imaging settings with higher frequency presets permit high-resolution imaging of small throat structures and appropriate frame averaging smooths images and reduces noise. Given the importance of airway diagnosis, recording of imaging as a part of the medical record is highly recommended.

Applications

Evaluation of Intubation

Measurement of Tracheal Diameter

In older pediatric populations through adulthood, direct visualization of the endotracheal tube has been described with the probe held transversely over the trachea inferior to the cricothyroid membrane [1–11]. In a study of 50 children with congenital scoliosis undergoing surgery [3], an ultrasound-based protocol demonstrated a strong correlation between predicted and required endotracheal tube (ETT) size confirmed by the presence of an appropriate leak. In patients with cervical scoliosis there was a moderate correlation, with ultrasound frequently overestimating tube size. The authors suggest this overestima-

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tion occurs because the trachea appears ellipsoid in this view and measurements did not capture the smallest diameter of the trachea. A study of 152 children receiving adenotonsillar surgery demonstrated that airway ultrasound accurately determined ideal ETT size in 88% of patients, with 15 patients requiring larger and 3 requiring smaller tube diameters [1]. Evidence suggests practice is needed to develop a reliable technique of measurement as only 10 of 16 (62.5%) anesthesiology residents performing airway ultrasound were proficient in appropriately measuring tracheal diameter appropriately after 30 examinations [12]. With focused attention to training and skill development, this technique may benefit children with normal airway anatomy. In the setting of airway pathology such as subglottic stenosis, cephalad to caudal sweep of the airway is likely necessary to attain a complete assessment. However, there is limited data of the efficacy of this metric in patients with subglottic stenosis or other airway irregularities therefore no recommendation can be made for standardized evaluation.

To assess the airway, in a transverse view:

1. Visualize the trachea: normally the air artifact within the cylindrical trachea only permits a semicircular view of its anterior surface bounded by air behind it. The homogenous thyroid gland is visible surrounding the trachea, and the great vessels of the neck may also be seen (Fig. 1).
2. Angle the probe such that it is held slightly left of midline. This permits views of the esophagus, which appears as a collapsed ellipsoid in profile. Because the esophagus can be visualized in this profile, this view has been proposed as a method of assessing adequacy of cricoid pressure though further studies are necessary to demonstrate efficacy in children [13, 14].
3. From this view, it is potentially possible to monitor intubation. Changes during intubation can be subtle as the endotracheal tube, similar to the trachea, is an air-filled cylinder. Therefore, most authors who endorse this technique suggest that one visualizes the trachea during the intubation process for confirming that the endotracheal tube is passing into the airway [15, 16]. A probe placed on the neck for monitoring during intubation can obviously confound applying and/or maintaining cricoid pressure during intubation.

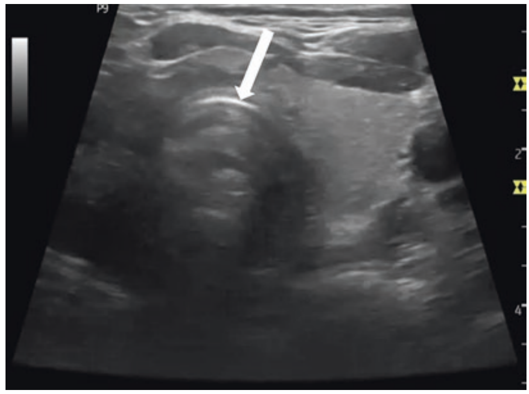

Fig. 1 Transverse trachea (arrow)

Direct Visualization of Endotracheal Tube Cuff

After intubation, confirmation of tube placement depth has also been described where ultrasound imaging of the endotracheal tube cuff is confirmed at the suprasternal notch. This technique was first described by Tessaro et al. (compared to fiberoptic bronchoscope) and Uya et al. (compared to fluoroscopy) [17, 18]. To date, a study comparing ultrasound assessment of cuff position to chest radiography remains lacking and complications including malpositioned ETTs remaining above the glottis cannot be assessed using ultrasound. Identification of the ETT cuff in the suprasternal notch can be particularly challenging with air-filled cuffs due to obscuring effects of air, and therefore both studies cited used a saline-filled cuff in a perioperative setting. It is unclear whether longer dwelling endotracheal tube cuffs in the ICU require different considerations regarding saline injection.

Using this method:

1. Place the probe again transversely but at the level of the suprasternal notch.

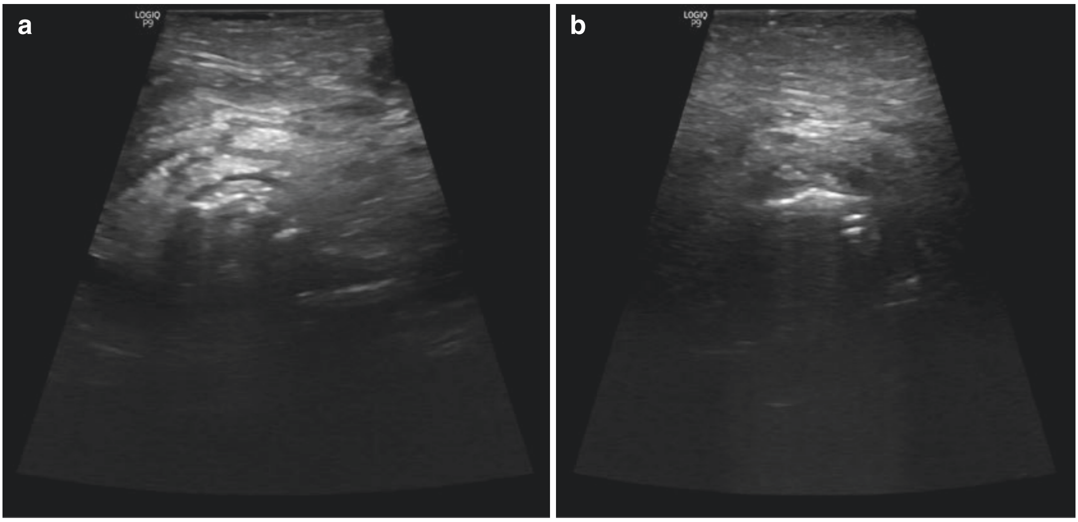

Fig. 2 (**a**) Transverse trachea, cuff up; note the rounded form of the anterior tracheal wall. (**b**) Transverse trachea, cuff down

2. Inflation of the cuff is performed, and pre- and post-inflation images demonstrate a change in the diameter of the air shadow caused by the cuff. A common strategy to improve visualization of the cuff profile is to inflate the cuff with saline. Protocols regarding routine use of saline inflation in the ICU have not been described. Confirmation of cuff location at the notch is considered an appropriate position of the ETT (Fig. 2a and b).

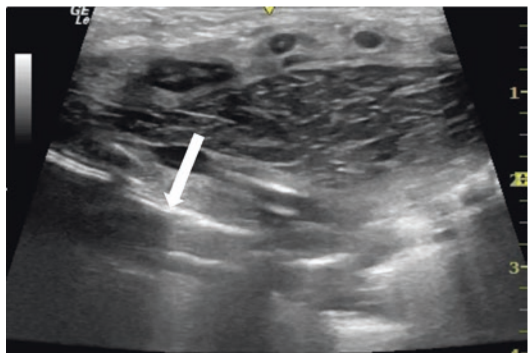

Fig. 3 Longitudinal view of endotracheal tube in a neonate; the tip of the tube is indicated by the arrow and can be identified by the shadowing artifact distal to the tube (right brace)

Direct Visualization of Endotracheal Tube Tip

To varying degrees, endotracheal tubes can be visualized within the airway as they displace normal anatomy. In the neonatal population, visualization of the endotracheal tube has been described in a longitudinal orientation by placing a linear array probe over the length of the sternum and aligning it with the trachea. Slovis and colleagues described this in a series of 16 newborns where the endotracheal tube was identified in all patients with a good correlation between chest X-ray and ultrasound [19]. This method has been replicated by other authors [20–25].

In the method described by Dennington et al., a linear array transducer is placed sagittally along the length of the sternum, preferably with the probe indicator towards the patient's head. (Fig. 3; [26]) The beam is aimed to align with the endotracheal tube such that shadowing artifact caused by the tube can be used to determine the tube tip, optimally around 2 cm proximal to the right pulmonary artery seen in cross-section and used as a landmark approximating the level of the carina. Beyond the neonatal period, direct visualization of the endotracheal tube becomes more difficult due to air artifact, sternal ossification, and patient size. Therefore, this technique is practical in few patients and confounded by difficulties in conceptualizing the endotracheal tube only in terms of artifacts.

Diaphragmatic Ultrasound for Confirmation of Intubation

Intubation can also be indirectly assessed using diaphragmatic ultrasound. After intubation, providers can image the diaphragm from a transverse subxiphoid position with sufficient depth to visualize the spine and include interrogation of the anterior sagittal or lateral coronal planes (Fig. 4). Differential or lack of movement of diaphragm leaflets suggests mainstem intubation or failure to intubate the trachea. Ultrasound assessment of diaphragm movement has been explored by multiple authors in the pediatric population [27, 28]. In the PICU setting, efficacy has been demonstrated in a population of 59 children where all intubations were correctly identified as successful or not successful, including failed intubation and right mainstem intubation [27].

To perform this technique after attempted endotracheal intubation:

1. For the anterior subxiphoid approach, place a phased array or curvilinear probe below the xiphoid process and aim it cephalad at an approximately 45° angle to the skin to visualize the bright diaphragm leaflets. Gastric contents may obscure the view of the left hemidiaphragm (Fig. 4).
2. For a lateral coronal approach, the diaphragms can be visualized independently from the flanks of the patient at the level of thoracic ribs 10–12 with the probe oriented coronally and parallel to the spine. The imaging target is the bright arc of the hemidiaphragm on each side of the patient. A limitation to this approach is that both diaphragms cannot be viewed at the same time, though the image of the diaphragm architecture and movement will be clearer compared to the subxiphoid approach.
3. Alternatively, each hemidiaphragm can also be imaged in the anterior sagittal plane at the lower margin of the ribcage in line with the midclavicular line. This may be possible for patients where lateral views can be difficult due to patient habitus but is problematic when the stomach contains air or solids.
4. With manual bagging ventilation of the endotracheal tube, both diaphragm leaflets should move towards the ultrasound probe as the lungs inflate in the subcostal view or past the probe in the lateral or anterior views.
5. Preferential inflation of one side indicates possible mainstem intubation of that respective bronchus.
6. No movement suggests failure to intubate the trachea.

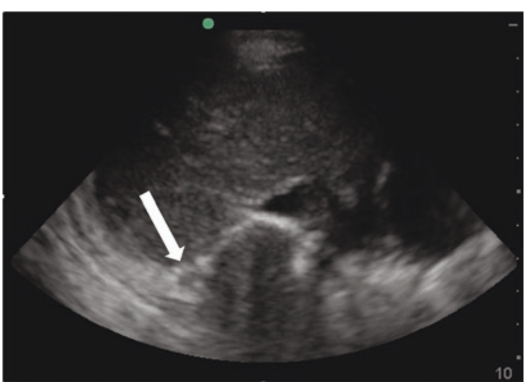

Fig. 4 Subcostal diaphragm view (arrow indicates right hemidiaphragm)

Though this technique cannot detect the position of the endotracheal tube tip, it can identify aeration of the lungs readily while keeping the ultrasound away from the neck in the event of a failed intubation when other manipulations may be required.

An alternative technique has also been described using a linear probe for identifying lung sliding in the aforementioned lateral coronal and anterior sagittal planes but higher in the chest [29]. Using the same manual ventilation technique, differential or absent movement may suggest mainstem or failed intubation, respectively.

Cricothyroid Imaging

In the sagittal plane, a linear ultrasound probe can be placed longitudinally over the larynx and trachea to identify the cricoid membrane for guidance of percutaneous or surgical cricothyroidotomy. This technique has been described by Walsh et al. successfully identifying the membrane on ultrasound in comparison to MRI, though a test of practicality is stymied by the rarity of the procedure and has not been described [30].

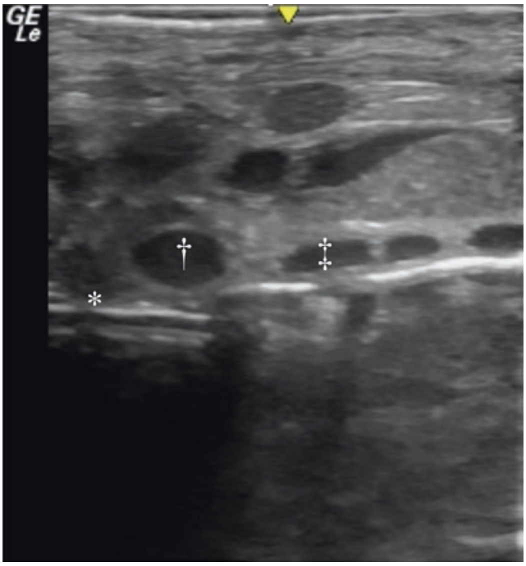

Fig. 5 Sagittal cricothyroid membrane view. * Cricothyroid membrane; † cricoid cartilage; ‡ first tracheal ring

To accomplish this:

1. Place the probe longitudinally over the thyroid cartilage and trachea. By convention the probe indicator goes towards the head. A variety of imaging presets can be used for this modality.
2. Elements of the upper airway can be identified longitudinally including the thyroid cartilage, the cricothyroid membrane, the cricoid cartilage, and the tracheal rings (Fig. 5).

Vocal Cord Imaging

Assessment of the vocal cords can be performed at the level of the cricothyroid membrane tilting the plane of the transducer cephalad for visualization. This technique has been reported by multiple authors as a reliable method of evaluating vocal cord dysfunction. Though primarily described in the patient who has received cardiac surgery in the vicinity of the aortic arch, it has also been mentioned in the evaluation of patients with primary thyroid malignancy as well as

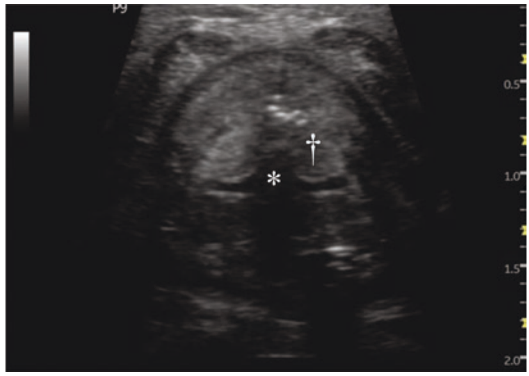

Fig. 6 Vocal fold imaging. * True vocal folds are in this anechoic area; † false focal folds

laryngeal trauma [31–36]. A recently published meta-analysis revealed a pooled sensitivity for laryngeal ultrasound in detecting vocal cord immobility of 91% (95% CI, 83–95%) and specificity of 97% (95% CI, 82–100%) across varied pediatric practice settings [37].

In imaging the vocal cords:

1. The transducer is oriented transversely and angled cephalad to visualize the true and false vocal cords at the level of apposition to minimize air interference.
2. From this vantage, the vocal folds and the arytenoid cartilages can be imaged. (Fig. 6).
3. Note that the angle of the probe to the skin may be shallow.

Evaluating the Difficult Airway

To date, a number of authors have published information on preintubation ultrasound assessments yielding measurements potentially predictive for difficult intubation. None of these have been readily translated to clinical practice in the neonatal and pediatric population. These methods identify a panel of assessments of anterior neck tissue thickness or distances from the chin to neck structures such as the hyoid bone. Further study is necessary to determine a practical set of measurements for ultrasound-based difficult airway assessment in infants and children.

Conclusion

Visualization of the airway is practical in point-of-care ultrasound and ultimately yields useful information for clinical care. It is gaining attention as a modality for evaluating airway procedures as well as airway pathology. As it is a relatively new area of interest in clinical ultrasound, airway ultrasound will continue to evolve with insights from promising emerging research and clinical application.

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