The Ultrasound Probe in the Hands of the Anesthesiologist:
A Powerful New Tool for Airway Management

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Ultrasonography has become an inherent part of the anesthesiologist's armamentarium, a natural tool for vascular access and for locoregional anesthesia. Therefore, as ultrasound machines are widely available in anesthetizing locations, anesthesiologists should become familiar with their use—including for managing airways. Optimal airway management typically is the anesthesiologist's most important task before and during surgery, and it is the area in which the specialty has the ultimate knowledge and final responsibility.

Ultrasound (US) can help anesthesiologists locate the cricothyroid membrane before managing a difficult airway, rule out an intraoperative pneumothorax, locate the optimal level for elective dilatational tracheostomy, distinguish between tracheal and esophageal intubation before initiation of ventilation, and help clinicians overcome many other challenges related to the upper and lower airways. Indeed, the availability of easily transportable US machines, combined with increasing familiarity with the use of this technology, now makes ultrasonography a fundamental tool in airway management. Moreover, because ultrasonography can be performed at the point of care by the anesthesiologist, it is not merely another procedure to be ordered from another specialty. Ultrasonography offers anesthesiologists a means of further distinguishing what they can provide from what can be provided from nurse anesthetists, for example.

This article updates the status and perspectives of ultrasonography and airway management in the hands of the anesthesiologist,[1,2] supplemented with practical guides to implementing the technique.

Airway Anatomy: What Does Ultrasound Reveal?

Ultrasound does not penetrate air, so which structures relevant for airway management can it help clinicians to visualize? As soon as the US beam reaches air, a strong echo appears in the form of a bright white line. This line delineates the border between tissue and air; everything beyond it is artifact (Figure 1). The result is that tissue appears distinct from skin until the anterior part of the airway, as for example the posterior surface of the tongue, the mucosal lining of the anterior trachea, and the pleura. Intraluminal air thus will prevent visualization of structures such as the posterior pharynx, posterior commissure and posterior wall of the trachea.

Different tissues have different acoustic impedance, and sound reflection occurs at interfaces between different types of tissues. Impedance differs most when soft tissue is next to bone or air. Some tissues, such as fat and bone, produce a strong echo; these structures are called *hyperechoic* and appear white on US. Other tissues—fluid collections or blood in vessels—have little resistance to the US beam and thus generate little echo; they are called *hypoechoic* and appear black on the screen.

When the US beam reaches the surface of a bone, a strong echo appears. Absorption of US energy results in the depiction on the screen of bony tissue of limited depth. Acoustic shadowing obscures nearly everything beyond the bone. Cartilaginous structures, such as the thyroid, the cricoid, and the trachea, appear homogeneously hypoechoic but tend to calcify with age. Muscles and connective tissue membranes are hypoechoic but appear more heterogeneously striated than cartilage. Glandular structures, such as the submandibular and

Table 1. Important Airway Structures Visible on Ultrasound[3-10]

Mouth	Epiglottis	Trachea
Tongue	Larynx	Esophagus
Oropharynx	Vocal cords	Stomach
Hypopharynx	Cricothyroid membrane	Lungs
Hyoid bone	Cricoid cartilage	Pleurae

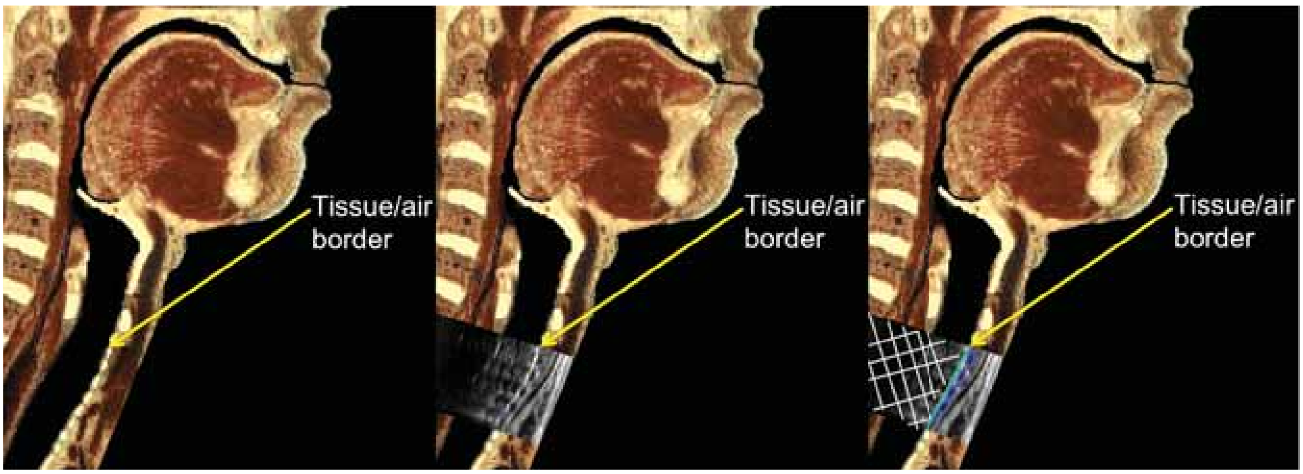

Figure 1. **The tissue/air border. Left: A cadaveric slice of the upper airway. The arrow indicates the tissue/air border. Middle: The ultrasonographic image. Right: Explanation of the ultrasonographic image. Blue rings indicate the anterior part of the tracheal rings; the green line is the tissue/air border between the mucosal lining of the anterior trachea and air. The image area covered by the white grid is entirely made up of artifacts.**

thyroid glands, are homogeneous and mildly to strongly hyperechoic compared with nearby soft tissues.[1]

We have previously described, in easy-to-follow steps, how to visualize the airway from the tip of the chin until the mid-trachea with ultrasonography.[1] Table 1 lists airway structures of special interest that can be visualized on US (Figures 1-5). Because of the superficial location of the larynx, US offers images of higher resolution then computed tomography (CT) or magnetic resonance imaging.[7]

Studies comparing different modes of depiction of the airway have found an overall very good concordance between ultrasonography and CT, and between ultrasonography and direct cadaveric dissection.[11]

Clinical Applications

Table 2 lists the major clinical applications of airway ultrasonography. The following are particularly useful applications: the localization of the cricothyroid membrane and the diagnosis of pneumothorax.

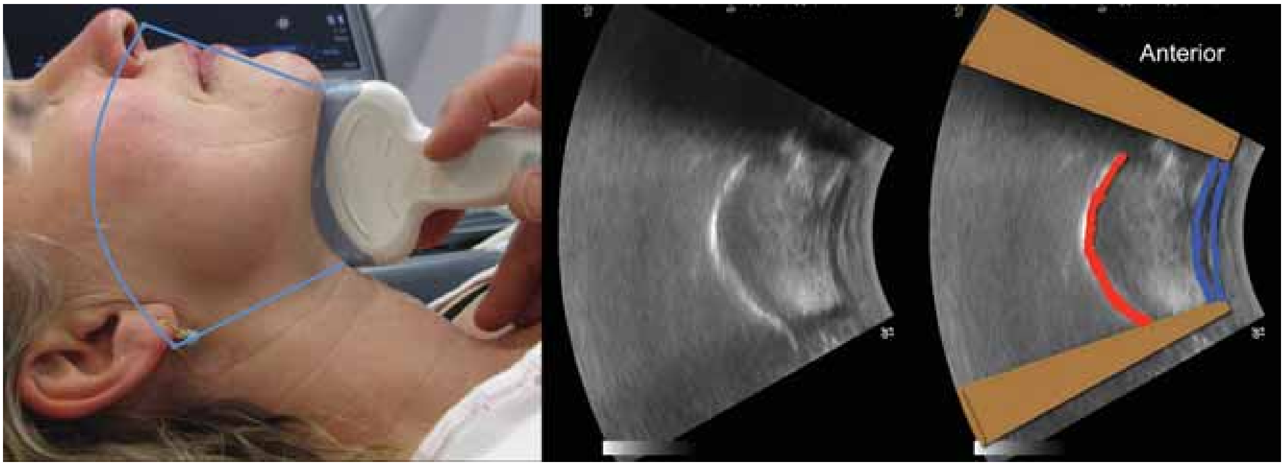

Figure 2. From the tip of the tongue to the hyoid bone. **Left:** The light blue marking indicates the scanning area. **Middle:** Ultrasonographic image. **Right:** Brown indicates the shadow from the mandible anteriorly and from the hyoid bone posteriorly; the red line indicates the surface of the tongue; blue is the base of the floor of the mouth.

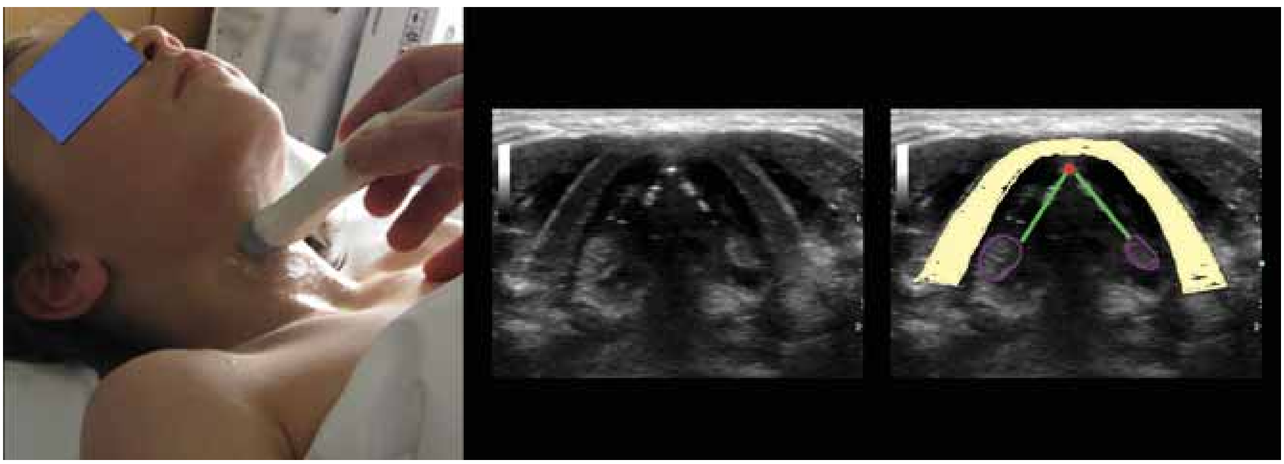

Figure 3. Larynx with vocal cords. **Left:** The linear transducer is placed transversely over the thyroid cartilage at the level of the vocal cords. **Middle:** The ultrasound image. **Right:** The thyroid cartilage (light yellow); the free edge of the vocal cords (green); the anterior commissure (red dot); the arytenoid cartilages (purple).

Figure 4. Trachea and esophagus. The transducer is placed transversely over trachea just cranially to the suprasternal notch. The purple lines indicate the anterior part of the tracheal cartilage behind which artifacts are seen (turquoise). Esophagus is visible posteriorly and laterally to the trachea as a multilayered structure (various orange tones). Red is the lumen of the common carotid artery.

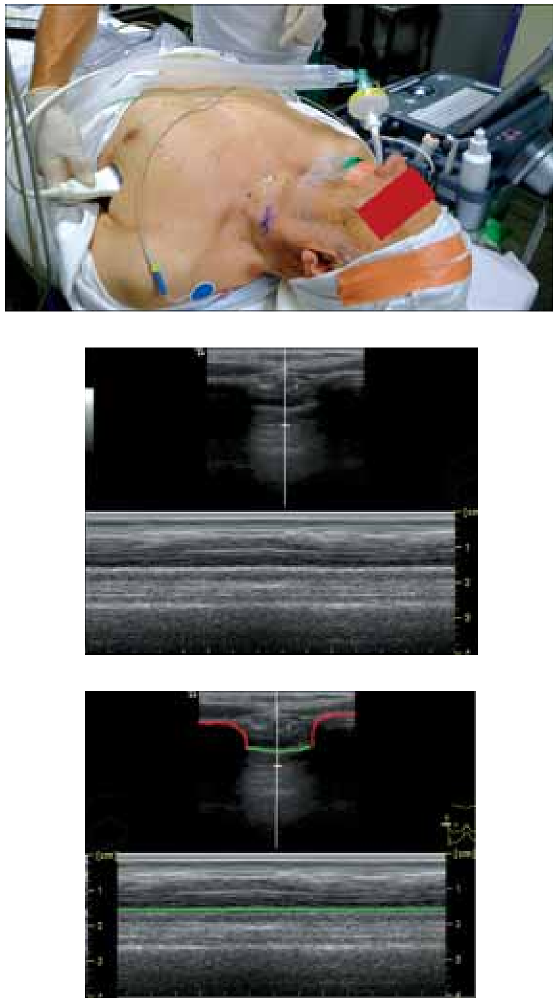

Figure 5. Lung sliding. **Top:** The ultrasound probe is placed transversely in an interspace between 2 ribs during normal ventilation. **Middle:** The scanning image, upper: B-mode scan, lower: M (Motion)-mode. **Bottom:** The green line indicates the pleural line. The red lines indicate the anterior surface of 2 ribs behind which shadowing is seen. Note that the outline of the ribs and the pleural line forms the image of a flying bat—the "bat sign" demonstrating that 2 ribs are involved, which is necessary in order to identify the pleural line among the many white lines. Note that in the M-mode image, it is easy to distinguish the nonmoving tissue above the pleural line from the artifact created from the respiratory movement of the visceral pleura relative to the parietal pleura. This is called the "sea shore sign" or the "sandy beach sign" because the nonmoving part resembles waves and the artifact pattern below resembles a sandy beach.

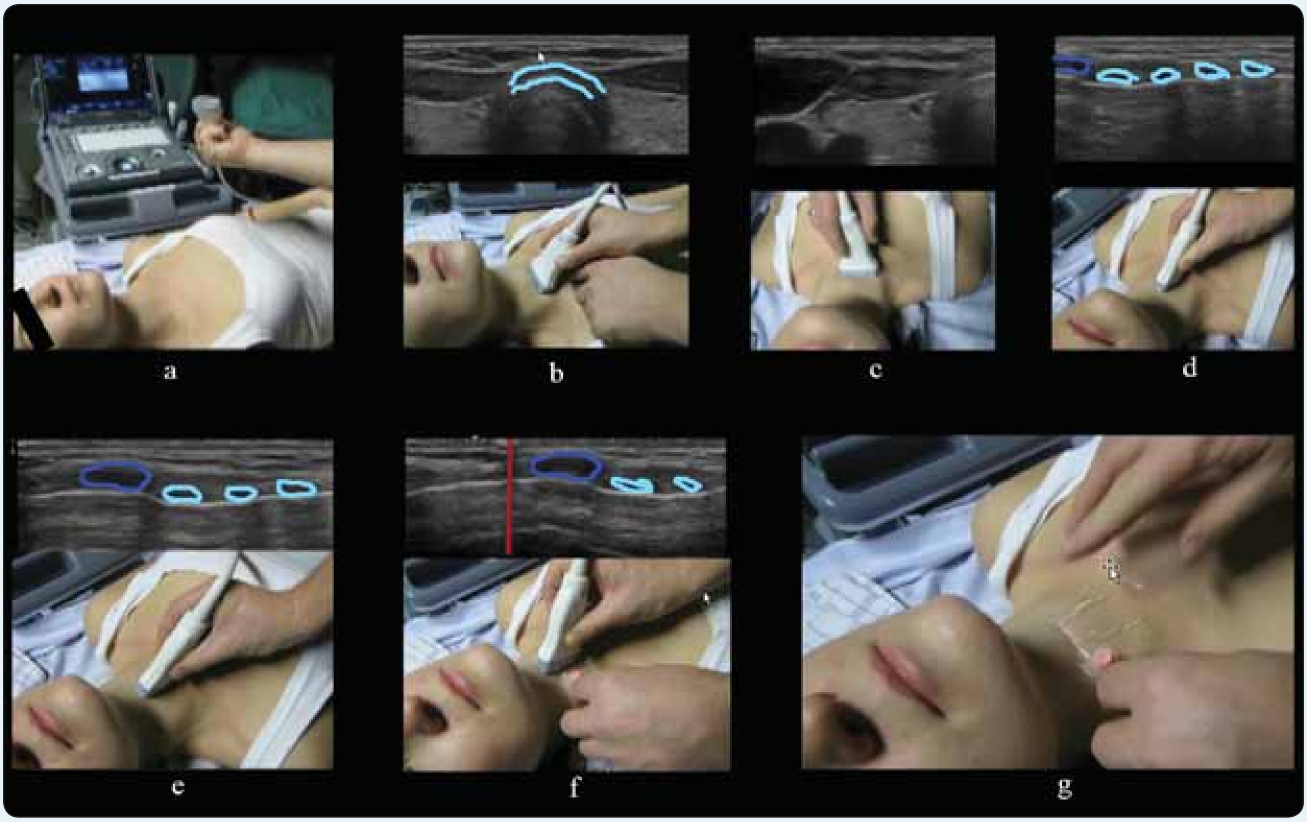

Figure 6. **Localization of the cricothyroid membrane. Light blue is the anterior part of the tracheal rings. Dark blue is the anterior part of the cricoid cartilage. The red line is the shadow from the needle that has been slid underneath the transducer and placed just cranial to the cricoid cartilage, thus indicating the position of the lower part of the cricothyroid membrane, where an emergency airway access should be performed.**

Step 1. Stand on the patient's right side and palpate the sternal bone. The sternal bone can be located even in extremely obese patients and in the vast majority of patients with pathology or post-radiation changes that make direct identification of tracheal and laryngeal structures impossible.

Step 2. From the sternal bone, move fingers cranially and locate the suprasternal notch.

Step 3. Place the linear US transducer transversely on the neck just cranially to the sternal notch and watch for the trachea to appear on the screen (Figure 6b).

Step 4. Slide the transducer laterally toward the patient's right side, until the midline of the trachea is at the right border of the ultrasound image/transducer (Figure 6c).

Step 5. Keep the right border of the transducer over the midline of the trachea and rotate the left edge of the transducer into the sagittal plane to obtain a longitudinal image of the trachea. Adjusting the transducer position with subtle movements from side to side can optimize the image so that "pearls on a string" appear; the pearls represent the cartilages of the anterior part of the tracheal rings (Figure 6d).

Step 6. If the neck is long, the transducer must be slid cranially, staying in the midline, until a more prominent and anterior "pearl" becomes visible. This landmark is the cricoid cartilage. Immediately cranial to the cricoid cartilage is the distal part of the CM (Figure 6e).

Step 7. The CM can be identified by sliding a needle underneath the transducer (avoid hitting the patient with the tip of the needle) until it creates a shadow just cranially to the shadow from the cricoid cartilage (Figure 6f). The transducer now can be removed and the needle indicates the position of the CM. This spot can be marked with a pen so that it is easily located, in case it must be used during subsequent management of the difficult airway (Figure 6g).

Table 2. Major Clinical Applications of Airway Ultrasonography

Clinical Application	Comment
Screening/predicting difficult airway management[12]	Demonstrated to be useful only in smaller series in obese patients
Diagnosing pathology that can affect airway management[13]	Examples: tumors in the neck, tongue, vallecula, pharynx or larynx, or a Zenker diverticulum that can represent an increased risk for aspiration
Identifying the cricothyroid membrane[2]	Should be performed before management of a difficult airway, in case identification by palpation is not straightforward. Allows preparation for emergency cricothyroidotomy, oxygen insufflation, distribution of local anesthetics, or retrograde intubation.
Measuring gastric content before airway management[9]	Best performed in right lateral decubitus position
Airway-related nerve blocks[14]	
Predicting the appropriate diameter of endotracheal,[15] endobronchial, or tracheostomy tubes	
Differentiating between tracheal and esophageal intubation[16]	Allows detection of esophageal intubation before ventilation is initiated and works when there is no circulation (eg, cardiac arrest), as opposed to CO_2 detection
Differentiating between tracheal and endobronchial intubation	Useful in noisy environments where a stethoscope is inadequate
Confirming gastric tube placement[17]	
Diagnosing pneumothorax[18]	By far, the fastest way to rule out a suspicion of intraoperative pneumothorax
Differentiating between different causes of dyspnea/hypoxia and pulmonary edema[19]	Diagnosing pulmonary edema and allowing differentiation between different types of lung and pleura pathology
Predicting successful weaning from ventilator treatment[20]	Obtained by measuring whether the respiratory forces of the patient are sufficient, and/or the width of the airway is large enough, to allow extubation of the trachea
Localizing trachea and tracheal ring interspaces for tracheostomy and percutaneous dilatational tracheostomy[21,22]	

CO_2, carbon dioxide

Identifying the Cricothyroid Membrane Before Management of the Difficult Airway

In all airway algorithms, the final escape if everything else fails is always oxygenation through the cricothyroid membrane (CM), either as a small-bore jet-insufflation catheter, a larger-bore needle technique, or as a surgical emergency cricothyroidotomy.

Localization of the CM often is difficult or impossible, and even when anesthesiologists think that they have found it, they may be mistaken. As a result, emergency oxygenation through the CM has a disappointingly low rate of success.

It therefore is warranted for all airway patients whom an anesthesiologist must manage that he or she identify the CM before proceeding with the delivery of anesthesia. In patients with slender necks and no history of radiation or pathology, inspection alone or inspection combined with palpation may be sufficient. However, for patients whose CM is not easily visible or palpable, ultrasonography is an ideal method for locating the membrane (Figure 6). Once located, the clinician should mark the CM with a pen so that it is easy to access in the rare event that subsequent airway management results in the need for oxygenation via that route.

Diagnosis of Pneumothorax

Ultrasonography is an obvious first choice for diagnosis in cases of suspected intraoperative

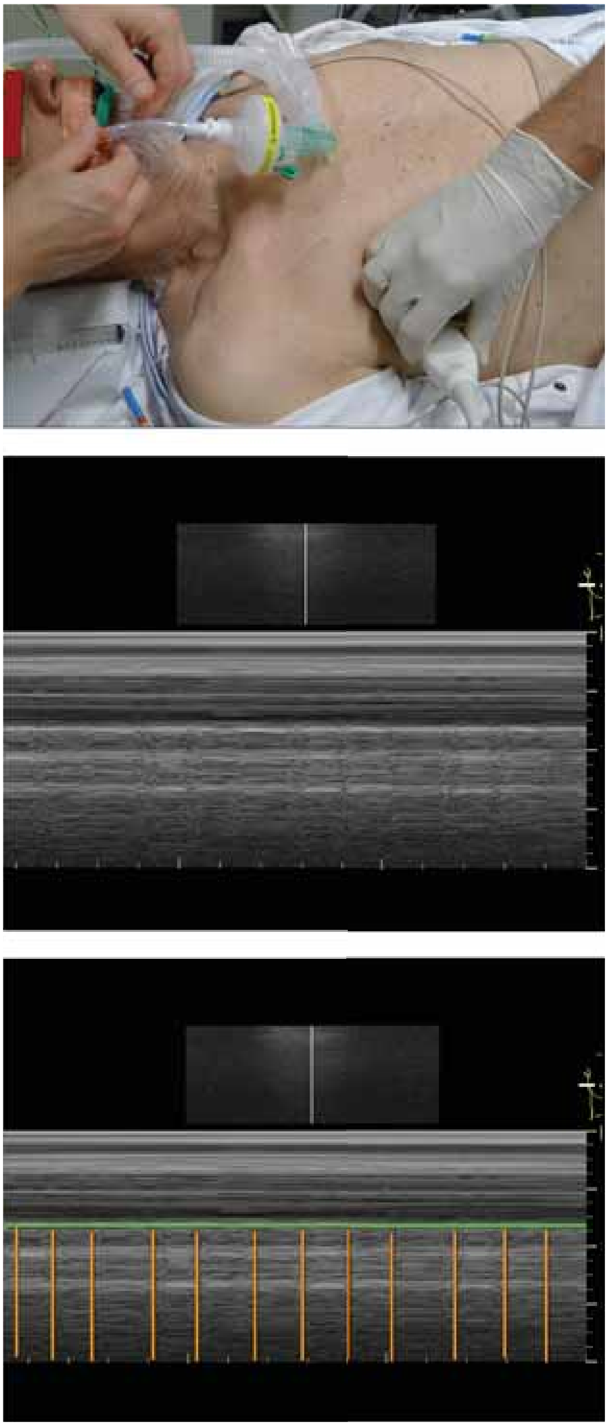

Figure 7. **Lung pulse. Top:** The ultrasound probe is placed transversely in an interspace between 2 ribs during normal ventilation. **Middle:** The scanning image, upper: B-mode scan, lower: M (Motion)-mode. **Bottom:** In the nonventilated but inflated lung, the heart will make the 2 pleural layers (green) move a bit with every heartbeat, creating the artifact known as "lung pulse" (orange).

pneumothorax, or if a pneumothorax is suspected during or after central venous cannulation or nerve blockade. It is particularly helpful if US is already in use for the procedure itself and therefore is immediately available. Lung ultrasonography is better than chest x-ray for ruling out pneumothorax[10]; it has a sensitivity of 91% and specificity of 98% in diagnosing pneumothoraces in supine patients, whereas chest radiography has a sensitivity of 50.2% and a specificity of 99.4%.[18]

The presence of lung sliding (Figure 5) or lung pulse (Figure 7) on ultrasonographic examination indicates that at the position under the transducer, the 2 pleural layers are in direct contact with each other; in other words, no pneumothorax exists in that location. Free air in the part of the pleural cavity beneath the transducer will prevent lung sliding or lung pulse from being visible. In the M-mode, the "stratosphere sign"—parallel lines throughout the entire depth of the image—will appear.

If the transducer is placed at the border of the pneumothorax where the visceral pleura intermittently is in contact with the parietal pleura, the "lung point" will be evident. The lung point appears as a sliding lung alternating with the stratosphere sign synchronous with ventilation. The lung point is pathognomonic for pneumothorax. The clinician can systematically "map" the rib interspaces of the thoracic cavity and confirm or rule out a pneumothorax. The lung point is best seen on real-time ultrasonography (http://www.airwaymanagement.dk/ultrasonography-in-airway-management). A systematic approach is recommended when examining the supine patient. The anterior chest wall can be divided in quadrants; the probe is first placed at the most superior aspect of the thorax with respect to gravity—in other words, the caudal part of the anterior chest wall when the patient is supine. The probe is positioned on each of the 4 quadrants of the anterior area followed by the lateral chest wall between the anterior and posterior axillary lines and the rest of the accessible part of the thorax.[23]

Attaining Competence In Airway Ultrasonography

To attain competence in airway ultrasonography, the following stepwise approach is helpful: When using US for central venous access or to administer upper extremity/truncal regional anesthesia, slide the transducer over the thoracic wall to look for lung sliding and to practice localizing each tracheal ring and the cricothyroid membrane.

After having practiced in approximately 20 patients, ask for supervision and feedback: Hands–on courses are available at the annual scientific meeting of the American Society of Anesthesiologists and other venues. The authors can arrange and conduct lectures and hands-on workshops in ultrasonography for airway management by appointment (contact info: michael.seltz.kristensen@regionh.dk and teohwendy@yahoo.com).

Instructive airway ultrasonography videos are available at the not-for-profit Website: http://www.airwaymanagement.dk/ultrasonography-in-airway-management. Online training programs (for example, http://usabcd.org/elearning) covering many aspects of anesthesia-related ultrasonography, including the airway, also are available.

Conclusion

By using ultrasonography before, during, and after anesthesia induction and when suspicion of a pneumothorax arises, the anesthesiologist can locate a variety of anatomic structures and diagnose clinical conditions highly relevant to safe management of the airway.

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