# Role of ultrasound in the airway management of critically ill patients

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**Ultrasound imaging of the upper airway in critically ill patients offers a number of attractive advantages compared with competitive imaging techniques or endoscopy. It is widely available, portable, repeatable, relatively inexpensive, pain-free, and safe. In this review article, I describe ultrasonographic anatomy of the upper respiratory organs and present the main potential applications of ultrasonography in airway management. The role of ultrasound in endotracheal tube placement, including preintubation assessment, verification of tube position, double-lumen intubation, and extubation outcome, are explained. Also, ultrasound-guided percutaneous tracheostomy, the role of ultrasound in using the laryngeal mask airway, and upper airway anesthesia are described. (Crit Care Med 2007; 35[Suppl.]:S173–S177)**

**Key Words: ultrasonography; airway management; endotracheal tube; double-lumen tube; percutaneous tracheostomy; intensive care unit**

Ultrasound (US) offers a number of attractive advantages compared with competitive imaging techniques or endoscopy for imaging critically ill patients. It is widely available, portable, repeatable, relatively inexpensive, pain-free, and safe. Although the earliest reports dealing with US applications in clinical medicine include the description of soft-tissue imaging of the pretracheal structures and anterior tracheal wall (1), the first detailed reports of using US to assist in various applications in airway management date from only a few years ago. The use of US for assisting with airway management in anesthesia and in the intensive care unit is directly related to the availability of low-cost and portable US capabilities. Clinicians initially described US-guided central venous and arterial catheterization, followed by US-guided regional anesthesia techniques. Subsequently, an increasing experience with the application of US toward airway management has been published. In this review article, I will describe the sonographic anatomy of the upper respiratory organs and outline the main potential applications of ultrasonography in the airway management of the critically ill.

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## Ultrasound Anatomy of the Upper Airway

For US analysis of the upper airway, the most suitable probes are those with a small physical footprint (typically vascular types) with higher frequency (>7.5 MHz) and high resolution. The upper airway consists of the oral and nasal cavities, pharynx, larynx, and trachea, all of which are nearly completely filled with air. Due to the very high acoustic impedence of air, US cannot directly depict the inside of air-filled organs. Fortunately, due to their superficial position, the frontal and lateral walls of nearly all upper airway segments are visible by US examination either partially or completely. US can image the floor of the oral cavity and its lateral wall. The lateral wall, the so-called buccae, appears as a thin hyperechogenic line with a thin muscular layer underneath. We usually image only the second and third part of the tongue and the base, whereas the anterior (frontal) third is examined only if the lingua is attached to the floor of the mouth (2). For US imaging of the tongue and oral floor, we use diagonal and vertical sections from the top of the mandible to the hyoid bone. US shows the tongue as a muscular organ with a typical hypo(-iso)echoic ultrasonographic structure; on both sides of the base, the valleculae are clearly visualized (palatopharyngeal fold), indicating the transition to the hypopharynx (Fig. 1). In a lateral section, the hypoechoic tonsils are visualized, which, especially in childhood, appear as lymphatic tissue with visible lateral walls of hypopharynx below. The lateral walls of the nasal cavity are only rarely visible if the maxillary sinuses are filled with liquid (3). The larynx is an musculocartilaginous structure situated below the hyoid bone (Fig. 2), formed by nine cartilages, the most important being the thyroid and cricoid. Both are very clearly visible by US as hyperechoic structures reciprocally connected by isoechoic membranaceous ligaments with visible air below. The ring-shaped trachea, located inferior to the cricoid cartilage, is easily visible by US in vertical (Fig. 3) or transversal (Fig. 4) section together with the pretracheal tissue (4).

## Intubation

*Preintubation Assessment.* The inability to successfully intubate a pharmacologically paralyzed patient can be a disastrous situation. Although patients who are potentially difficult to intubate can often be predicted clinically, this method does not provide complete assurance, providing a requirement to consider other methods. Obesity is a well-known independent predictor of difficult intubation, but increased body mass index poorly predicts difficult laryngoscopy (5). In the last few years, there have been interesting studies using US to assess the upper airways and to predict difficult intubation, especially in obese patients or those with obstructive sleep apnea. In a select group of obese patients, Ezri et al. (6) found that an abundance of fat tissue at the anterior neck region, as measured by US, was a very good independent predictor of difficult laryngoscopy, being a much better predictor than body mass index, *per se*. In patients with sleep apnea, Siegel et al. (7) found that upper airway ultrasonography was a reliable, simple, and comfortable method for precisely identifying the mechanism of airway obstruction. There has also been further interest in the role of a preintubation US assessment elsewhere in upper airway. Pharyngeal or laryngeal pathology with a significant effect on airway management, such as tumors, abscesses, or epiglottitis, could be detected by ultrasonography (8, 9).

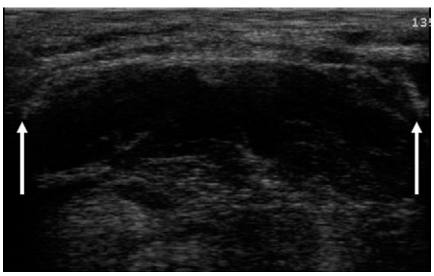

**Figure 1.** Transversal ultrasonographic section of the basis of the tongue. The tongue is presented as a muscular organ with typical hypo(-iso)echogenic ultrasonographic structure; on both sides of the base, palatopharyngeal folds are clearly visualized (*arrows*).

**Figure 2.** Transversal ultrasonographic section across the hyoid bone (*solid arrow*). The membrane between the hyoid bone and thyroid cartilage is presented as an isoechogenic line (with hyperechogenic air below) from both sides of the hyoid bone (*dashed arrows*).

*Verification of Endotracheal Tube Position.* Endotracheal tube (ETT) insertion remains the primary method of definitive airway protection and control in critically ill patients. According to the 2000 Advanced Cardiac Life Support guidelines, after insertion of the ETT, a confirmatory procedure should be done to exclude esophageal or endobronchial intubation (10). Further, it is imperative that the ETT tube position should be continuously monitored during the patient's intensive care unit stay to avoid incidental endobronchial intubation with subsequent atelectasis (11). Although physical examination consisting primarily of auscultation of the left thoracoabdominal area is suggested as the primary and routine method of ETT positioning confirmation, it is burdened by a low accuracy. Thus, a secondary method of confirmation is necessary. Among the suggested methods for secondary confirmation mentioned, end-tidal $CO_2$ detection and the esophageal suction device are the most frequently used methods. Unfortunately, both of these methods have limitations in the detection of endobronchial intubation, and both methods fail to provide direct anatomic evidence of the correct ETT position (12, 13). Conversely, US provides indirect but accurate dynamic anatomic evidence of the correct physiologic function of the ETT in paralyzed or apneic patients during and after resuscitation. US can quickly and efficiently visualize the motion of the diaphragm and pleura, which are indirect quantitative and qualitative indicators of lung expansion (14, 15).

If the ETT is in the correct position (i.e., trachea), bilateral equal motion of the diaphragm toward the abdomen can be seen (16, 17). It represents the equal bilateral expansion of the lungs. Also, with an intercostal ultrasonographic view, it is easy to identify the so-called lung-sliding sign at the lung–chest wall interface, a kind of "to-and-fro" movement of the pleura synchronized with ventilation (18). If this sign is visualized on the left or, especially, on both sides of the chest, it should correlate with regular bilateral lung ventilation and thus correct ETT position (19). On the contrary, if the ETT is in the esophagus, assisted ventilation through the tube will not result in expansion of the lungs, and the diaphragm will show active motion in accordance with the patient's own spontaneous respiration if the patient still retains respiration. If the patient is paralyzed or apneic, the esophageal intubation will result in an immobile or paradoxic state of the diaphragm. In some cases, ventilation through esophageal-positioned ETT results in a paradoxic motion of the diaphragm, in which the diaphragm moves toward the chest due to increased intra-abdominal pressure caused by the positive pressure ventilation being directed into the esophagus and upper gastrointestinal tract (16). An intercostal view in paralyzed or apneic patients with an intraesophageal ETT should not result in any respiratory-type movements of pleura on both sides of the chest (i.e., lung sliding) with assisted ventilation (18–20). The absence of the lung-sliding sign will result in visualization of the vibrations of the pleura in rhythm with the heart beat, a sign known as the *lung pulse* (21). Finally, if the tube is in the right main bronchus, movements of the left diaphragm will not be seen or will be considerably reduced, and the movements of pleura (lung sliding) will be seen only on the right side of the chest (18–20). On the left side of the chest, the lung pulse only should be seen.

In some cases, the ETT can be directly visualized by US to be positioned in the trachea. There have also been limited reports of using US to document ETT position with the echogenicity enhanced by retaining a stylet in the tube or by filling the ETT cuff with fluid and air bubbles (Fig. 5) (9).

*Double-Lumen Intubation and One-Lung Ventilation.* Double-lumen tubes (DLTs) are used to isolate or collapse the lungs selectively during thoracic proce-

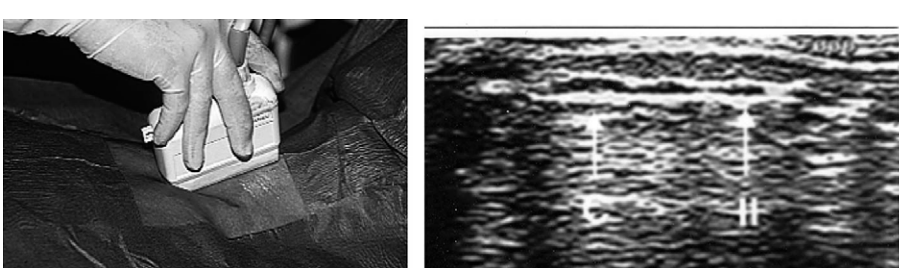

**Figure 3.** *Left*, with a linear ultrasonography transducer (vascular probe), the trachea was presented by vertical medial section. *Right*, after a clear ultrasound verification of cricoid cartilage and tracheal rings, the site of puncture for percutaneous tracheostomy (usually between the second and third tracheal rings) or cricostomy can be determined.

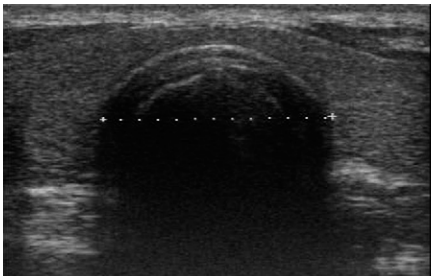

**Figure 4.** Transversal ultrasonographic section of the trachea. Ultrasonographic measurement of outer tracheal width is presented.

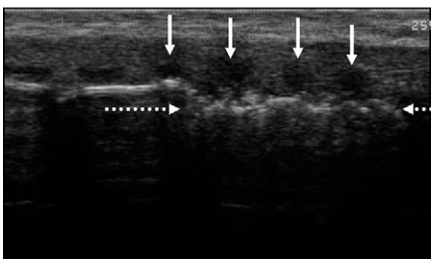

**Figure 5.** Anterior tracheal wall is visualized with cricoid cartilage, tracheal rings (*solid arrows*), and pretracheal tissue. The cuff of the endotracheal tube, filled with fluid and air bubbles, is presented (*dashed arrows*).

dures or one-lung ventilation. It is imperative that a DLT be safely and accurately positioned because a misplaced or improperly used tube can jeopardize any procedure or injure the patient. A left DLT is preferred for both right- and left-sided procedures, and it can be used successfully in >98% of patients (22). Auscultation and fiberoptic bronchoscopy are the current methods of choice used to confirm (left) DLT placement. The evidence strongly suggests that auscultation alone is not reliable for confirmation of proper DLT placement (23). Unfortunately, in clinical practice, fiberoptic bronchoscopy may not always be available, especially for narrow DLT tubes for children or small individuals (24). Further, blood or mucus in the airway and anatomic distortion can make visual confirmation of DLT position difficult or impossible. Fiberoptic bronchoscopy does not guarantee success because positioning problems and serious complications can still occur even when fiberoptic bronchoscopy is used (24). US may then be a new and very useful tool for confirmation of proper (left) DLT placement. The philosophy of using US to confirm proper DLT position is the same as described for the verification of the endotracheal position of ETTs. Therefore, if the left DLT tube is in the correct position (i.e., left main bronchus), movements of the right diaphragm will not be seen or will be considerably reduced, and the pleural movements (lung sliding) will only be seen on the left side of the chest. On the right side of the chest, the lung pulse will be seen. If the DLT is in the trachea, bilateral equal motion of the diaphragm toward the abdomen and bilateral lung sliding should be seen.

Determining the proper size of (left) DLTs is a very important part of the lung-separation procedure. If the tube is too large, it will cause trauma and cuff overinflation; if the tube is too small, it will be easily dislocated, with subsequent malposition (25). Brodsky et al. (26, 27) found that measurement of the tracheal width from a chest radiograph can be used as a guide to help predict which size of left DLT to select for each patient. We believe that US can also be a very useful method for determining proper left-sided DLT size. In a recently conducted study, we found a statistically significant correlation between US measurement of the outer tracheal width (Fig. 4) vs. the inner tracheal and bronchial width measured by multi-slice computed tomography scan. Brodsky's rules for determining proper left-sided DLT were as follows; a tracheal width of $\geq$18 mm = predicted left DLT of 41 Fr; tracheal width of $\geq$16 mm = predicted left DLT of 39 Fr; tracheal width of $\geq$15 = predicted left DLT of 37 Fr; tracheal width of >14 = predicted left DLT of 35 Fr. If these measurements are validated, US measurement of tracheal width could be a simple noninvasive bedside method for determining the proper left-sided DLT.

*Extubation Failure.* Extubation failure is one of the most frequently encountered serious adverse events in the management of mechanically ventilated patients. Predicting extubation outcome (failure) is, therefore, an important task. Extubation outcome is in direct correlation with respiratory muscle endurance, in which diaphragmatic function plays a pivotal role. The respiratory movements and excursions of the diaphragm, liver, and spleen directly correlate with respiratory muscular strength. Fortunately, these movements can be easily detected by US (28). In a recent study presented by Jung-Rern et al. (29), the authors found significantly larger displacement of the liver and spleen (i.e., diaphragm movement) in those patients with successful extubation than in those who failed. The authors concluded that ultrasonographic measurement of liver and spleen displacement during a spontaneous breathing trial before extubation was a good method for predicting extubation outcome. Therefore, evaluation of diaphragmatic movements by US may become an important tool to evaluate the respiratory muscle endurance in critically ill patients.

## Percutaneous Tracheostomy and Cricothyrostomy

Percutaneous dilatational tracheostomy (PDT) is an established and safe means of gaining tracheal access in intensive care (30–32). However, the blind technique has significant potential complications and relative and absolute contraindications (31–33). To reduce these, bronchoscopic or US-guided PDT is suggested. Although bronchoscopic guidance is more often used and provides the best visualization, it has some disadvantages vs. US. First, bronchoscopy is not without complications of its own, including compromised ventilation and significant hypercarbia with elevation of intracranial pressure, which may be poorly tolerated by those with acute severe head or spinal cord injury (34–37). Second, during bronchoscopy, minute volume is significantly reduced and bronchoscopy, *per se*, can be responsible for pulmonary barotrauma and pneumothorax (35, 38). For this reasons, we and others have recently recommended US-guided puncture of the trachea, a method that can be successfully used even in difficult cases (4, 39–43).

The trachea and paratracheal soft tissues of the neck can be examined at the highest resolution with US probes of high frequency due to their superficial position. The anterior tracheal wall, thyroid and cricoid cartilages, tracheal rings, and pretracheal tissue may all be well visualized (Fig. 3), which allows the clinician to select the optimal intercartilaginous space for tracheostomy tube placement (40). The relationship of the thyroid gland and the vascular structures of the neck to the trachea can also be readily seen on diagnostic US. As a patient safety–related practice, patients with unfavorable anatomy for PDT demonstrated by US can be referred for open tracheostomy (44).

To perform US-guided PDT, we routinely use a guidewire/dilational forceps technique (Portex, Kent, UK). US-guided PDT is performed at the patient's bedside in the intensive care unit using continuous physiologic monitoring. After admin-

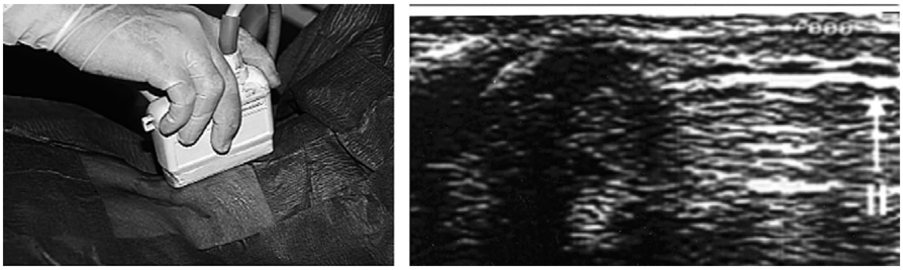

**Figure 6.** The ultrasound transducer is pulled cranially until the lower edge of transducer is placed above the tracheal ring (second ring), below which the puncture of trachea for percutaneous tracheostomy will be performed.

istering analgesia, sedation, and muscle relaxants, the patient is placed on 100% oxygen ($F_{IO_2}$ of 1.0) and is prepared for PDT in a standard manner with or, if it is not possible, without neck hyperextension. With a linear transducer that has been prepared in a sterile sheath (short vascular probe, 5–10 MHz), the trachea is imaged in vertical medial section and the continuous Doppler signal over the trachea on the level of the second ring (or pulsed-Doppler signal with sample volume in trachea) is activated. The ETT is thereafter withdrawn until the cuff is just below the vocal cords. When the tip of the tube reaches the second tracheal ring, the intensity of the Doppler signal increases greatly due to an increased signal from unencumbered, turbulent air, confirming the correct position of the ETT (34).

The site of puncture is usually selected between the second and third tracheal rings, after a clear US verification of anatomy of the thyroid and cricoid cartilage and tracheal rings (Fig. 3). If the thyroid isthmus is situated alongside planned puncture canal, we do not try to avoid it because isthmus penetration is relatively frequent in PTD but without serious consequences (45). The US transducer is then pulled cranially until the lower edge of the transducer is placed above the tracheal ring, below which the tracheal puncture will be performed (Fig. 6). After infiltration of anesthesia (local anesthetic with adrenaline), a transverse 1- to 2-cm-long incision into the skin and subcutaneous tissue is made parallel and as close to the lower edge of the transducer as possible. Then, the distance from the probe to the echo of the anterior tracheal wall is measured and marked on the cannula to be used for puncture. To control the depth of the puncture, we have designed a special "stopper," consisting of a metal device, which avoids inadvertent injury to the posterior tracheal wall (46). This stopper is positioned 5 mm distally from the indicated location on the cannula, and the puncture is performed through the incision up to the depth permitted by the stopper. Proper insertion into the trachea is verified by aspiration of air into a syringe attached to the cannula. After placing the guidewire through the cannula into the trachea, the cannula itself is removed. A 14-gauge dilator is then passed over the guidewire to start the stoma formation. Then, the guidewire dilational forceps is advanced along the guidewire and multiple (usually 3 to 4) dilations are performed. After the forceps is removed, the tracheostomy tube is advanced along the guidewire through the stoma into the trachea.

The correct position of the tracheostomy tube is also confirmed at the end of the procedure by means of US (16, 19). If the tracheostomy tube is in the correct position (i.e., in the trachea), bilateral equal motion of the diaphragm toward the abdomen is seen by subxiphoid or subcostal US imaging, representing equal bilateral expansion of the lungs. Conversely, if the tube is out of the trachea, this will result in an immobile state of the diaphragm during the positive pressure ventilation. Further, an intercostal US view can identify lung-sliding signs, a kind of to-and-fro movement of pleura synchronized with ventilation. If this sign is visualized on the left or on both sides of the chest, it correlates with bilateral lung ventilation and with correct tracheostomy tube position (18–20). In our experience, diagnostic ultrasonography is a useful and exact supporting method for PDT, which could be an alternative to endoscopy in avoiding the serious complications of blind PDT.

## Miscellaneous

*Laryngeal Mask Airway.* The laryngeal mask airway (LMA) is an adjunctive airway device composed of a tube with a cuffed mask-like projection of the distal end. The exact position of the cuff, which has to seal the larynx, is crucial for adequate ventilation through the LMA. From the lateral approach, the position of the LMA cuff can be seen by US if the cuff is filled with fluid. If the LMA is not visualized by US equally on both sides of the larynx, it can be subsequently repositioned correctly (9). This application of ultrasonography may be especially useful during clinical training in the use of the LMA. Also, US has been successfully used to determine the optimal puncture site of the right internal jugular vein after LMA placement (47).

*Ultrasound-Guided Upper Airway Anesthesia.* Manipulation of the airway during either laryngoscopy or endotracheal intubation in critically ill but awake patients is often associated with laryngospasm, coughing, and cardiovascular reflexes, which are undesirable. The anesthesiologist or critical care physician can abolish or blunt these reflexes by anesthetizing the upper airway, including the superior laryngeal nerve (48). The exact position of an optimal superior laryngeal nerve block, located between the hyoid bone and thyroid cartilage, can easily be visualized with ultrasonography and a guided block performed (Fig. 2). The clinical promise of this technique requires further investigation.

## Conclusion

There is growing body of literature demonstrating the value of ultrasonography in the care of critically ill patients, including airway management (49). The increasing availability of small, competitively priced, US devices providing high resolution has led to an increased use of US in the critical care setting. The current devices are particularly useful for the examination of the superficial structures such as the upper airway. It is likely that in the future, such techniques will become routine in airway management, particularly in teaching and in the management of difficult cases.


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