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REVIEW ARTICLE

# Ultrasound guided airway access

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**KEYWORDS**
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**Abstract** Ultrasound has increasingly growing applications in anesthesia. This procedure has proven to be a novel, non-invasive and simple technique for the upper airway management, proving to be a useful tool, not only in the operating room but also in the intensive care unit and emergency department. Indeed, over the years mounting evidence has showed an increasing role of ultrasound in airway management. In this review, the authors will discuss the importance of ultrasound in the airway preoperative assessment as a way of detecting signs of difficult intubation or to define the type and/or size of the endotracheal tube as well as to help airway procedures such as endotracheal intubation, cricothyrotomy, percutaneous tracheal intubation, retrograde intubation as well as the criteria for extubation.


**PALAVRAS-CHAVE**
Ultrassom;
Manejo de vias aéreas

**Acesso às vias aéreas guiado por ultrassom**

**Resumo** O uso do ultrassom em anestesia tem aumentado consideravelmente. Esse procedimento provou ser uma técnica nova, não invasiva e simples para o manejo das vias aéreas superiores, mostrou ser uma ferramenta útil não apenas em salas de cirurgia, mas também em unidades de terapia intensiva e prontos-socorros. De fato, ao longo dos anos, evidências crescentes mostraram que o papel do ultrassom no manejo das vias aéreas se destacou. Nesta revisão, discutiremos a importância da ultrassonografia na avaliação pré-operatória das vias aéreas, como forma de detectar sinais de intubação difícil ou definir o tipo e/ou tamanho do tubo endotraqueal, bem como auxiliar nos procedimentos de abordagem das vias aéreas, como

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intubação endotraqueal, cricotireotomia, intubação traqueal percutânea, intubação retrógrada e critérios de extubação.


## Introduction

Ultrasound (US) has increasingly growing applications in anesthesia. In addition to its common use in peripheral nerve blockades, central blocks, chronic pain or vascular accesses, the role of ultrasonography in airway management has gained significance, although still ill defined.[1] Lately, this procedure has proven to be a novel, non-invasive and simple technique for the upper airway management, proving to be a useful tool, not only in the operating room but also in the intensive care unit and emergency department.[1]

US equipments are widely available in anesthetizing departments and the accurate interpretation of US images requires a basic understanding of the physical principles involved in image generation. Knowledge about transducer selection, probe orientation and airway anatomy is also crucial to increase the accuracy of US interpretation.[2] To attain competence in airway ultrasonography, some authors recommend the following approach: as when using US for central venous access or to perform a peripheral nerve blockade, the probe should be slide over the thoracic wall to look for lung sliding and practice localizing each tracheal ring and the cricothyroid membrane.[3]

In this review, the authors will discuss the importance of US in the airway preoperative assessment as a way of detecting signs of difficult intubation or to define the type and/or size of the endotracheal tube as well as to help airway procedures such as endotracheal intubation, cricothyrotomy, percutaneous tracheal intubation, retrograde intubation as well as the criteria for extubation.

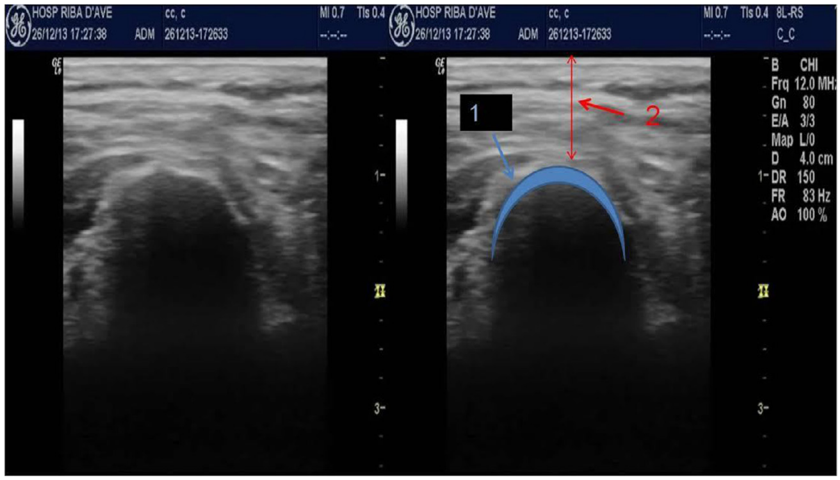
## Preoperative assessment and prediction of difficult intubation

The importance of preoperative airway evaluation before planning an intubation is widely known. Mallampati classification depends on patient's collaboration and cannot be used in sedated and trauma patients. Alternatively, the Cormack Lehane (CL) classification for airway assessment depends on invasive direct laryngoscopy and hence it is inapplicable for pre-anesthetic assessment in patients without prior history of tracheal intubation.[4]

Previous studies showed some controversy in the use of US as a method of predicting a difficult airway. Adhikari et al.[5] reported that measurements of anterior soft neck tissue thickness at the level of the hyoid bone and thyrohyoid membrane can be used to predict difficult airway (Fig. 1). Ezri et al.[6] stated that an increased pre-tracheal soft tissue at the level of the vocal cords could be a predictor of difficult laryngoscopy, which could be a much better indicator than body mass index per se. These authors concluded that patients who had greater pre-tracheal soft tissue (28 mm) and a higher circumference (50 cm) at the level of the vocal cords had difficulty in laryngoscopy.[6] On the other hand, Komatsu et al.[7] measured the distance from the skin to the anterior aspect of the airway at the level of the vocal cords and failed to show a prediction of difficult laryngoscopy in obese patients. Tsui and Hui[8] found that sublingual ultrasound imaging fails to capture the epiglottis due to the presence of air (a poor ultrasound medium), although in a different study they noticed that this imaging may have merit for predicting airway difficulties using the identification of the hyoid as a landmark.[9] The authors evaluated 100 elective patients and found that failure to identify the hyoid bone predicts a difficult laryngoscopy view.[9] These findings show an advantage of US over other tests like the Mallampati classification, thyromental distance and neck extension.

Gupta et al.[10] analyzed the correlation between the ultrasound view of the airway and the CL classification of the direct laryngoscopy. The authors found a negative correlation of the distance between the epiglottis and the vocal cords (E-VC) with the CL classification. On the other hand, they established a positive correlation between the pre-epiglottis space (Pre-E) and the CL grading and also stated that the ratio of Pre-E and E-VC distances with the CL grading had a strong positive correlation. The authors concluded that a prediction of the CL grading can be adequately made through the ratio of Pre-E and E-VC distances (Pre-E/E-VC): $0 < [\text{Pre-E/E-VC}] < 1 \approx$ CL Grade 1; $1 < [\text{Pre-E/E-VC}] < 2 \approx$ CL Grade 2; and $2 < [\text{Pre-E/E-VC}] < 3 \approx$ CL Grade 3. The average time for a complete ultrasound examination in this study was $31.7 \pm 12.4$ s showing that the non-invasive ultrasonographic modification of the invasive CL classification for pre-anesthetic airway assessment can supplement the presently available modalities like the Mallampati classification.

In anesthesia and intensive care, assessment of the upper airway's narrowest diameter may be helpful to select the endotracheal tube (ETT) size and also to assess laryngeal stenosis after prolonged tracheal intubation. It is well known that formulas based on age and height often fail to reliably predict the proper ETT size in pediatric patients and especially in adults,[11] making ultrasonography an appealing noninvasive technique for this purpose. Lakhal et al.[12] evaluated the subglottic upper airway diameter (transverse diameter of the trachea) measured by US which corresponds to the width of the air column at the level of the




1—hyoid bone
2—skin / hyoid bone distance

**Figure 1** Measurement of anterior soft neck tissue thickness at the level of hyoid bone and thyrohyoid membrane.

cricoid cartilage. They verified a strong correlation between ultrasonography and MRI measurements and concluded the feasibility of US as a good predictor of correct cuffed and uncuffed ETT sizes.[12] The easiness of the US technique is reinforced by the need for only 15 raining examinations for nonskilled physicians to adequately perform these measurements.[12]

Shibasaki et al.[13] studied 192 children aged one month to 6 years proposed for surgery under general anesthesia. The authors concluded that measuring subglottic airway diameter with ultrasonography helps the selection of appropriately sized endotracheal cuffed and uncuffed tubes in pediatric patients.[13] This selection method better predicted optimal outer ETT diameter when compared to standard methods.[13]

When Double-Lumen Tubes (DLT) are used to selectively isolate or collapse lungs during thoracic procedures, there should be a particular concern about the selection of the proper size of the DLTs.[14] Inappropriate sized DLT can cause airway trauma and interfere with oxygenation and lung separation during one lung ventilation.[14] Several methods have been proposed to determine DLT size.[14] Brodsky's rules for determining the proper left sided DLT were as follows: a tracheal width (measured by computed tomography) of ≥18 mm, ≥16 mm, ≥15 mm, ≥14 mm, ≥12.5 mm predicted a DLT of 41, 39, 37, 35 and 32 Fr, respectively.[14] Alternatively, Sustic et al.[14] found a statistically significant correlation between US measurements of the outer tracheal width and the inner tracheal and bronchial width measured by a multislice computed tomography scan, showing that US is a valid alternative for the same purpose. The authors proposed a guideline to determine proper DLT based on tracheal width measured by US: a tracheal width of ≥21.2 mm, ≥19.3 mm, ≥18.3 mm, ≥17.4 mm, ≥15.9 mm predicted a DLT of 41, 39, 37, 35 and 32 Fr, respectively. Both methods seem to be reliable on measuring tracheal diameter (14). However, there are certain circumstances, as in an emergence situation, where US may have advantage when compared to CT.[14]

The use of US is also helpful in assessing airway diseases such as tumors,[15] Zenker's diverticulum,[16] maxillary sinusitis,[17] goiter[18] and epiglottitis[19,20] which may lead to plan modification. Siegel et al.[21] pointed upper airway ultrasonography to be a reliable method for identifying the mechanism of airway obstruction. Furthermore, the width of the tongue base (the distance between the lingual arteries) and the thickness of the lateral pharyngeal wall measured by US were found to correlate with sleep related breathing disorders.[22,23]

Finally, in all algorithms of difficult airway management the final step is oxygenation through the Cricothyroid Membrane (CM).[24] Location of the CM is often difficult and, as a result, emergency oxygenation through the CM has a low rate of success.[25] For that reason, Kristensen et al.[3] recommend that, in the case of a predictably difficult airway, the CM must be located in advance and marked with a pen in order to eventually use that route for oxygenation (Fig. 2).

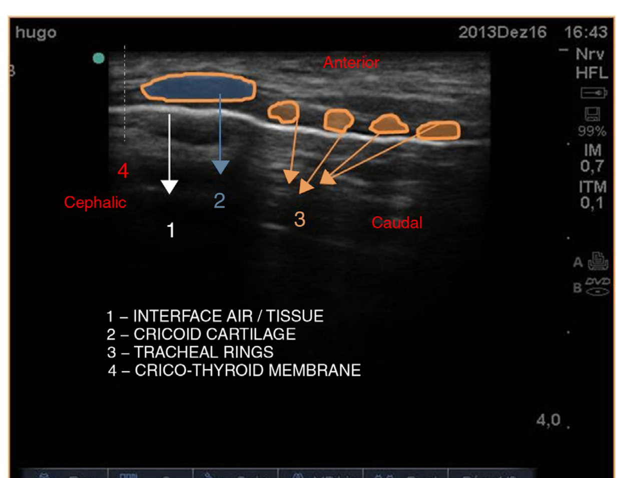



**Figure 2** Identification of cricothyroid membrane.

## Ultrasound to guide tracheal intubation

There are few studies in real time ultrasound guided tracheal intubation. Marciniak et al. investigated the characteristic real-time ultrasonographic findings of the normal pediatric airway during tracheal intubation and its suitability for clinical use.[26] Successful tracheal intubation was verified using the following criteria: identification of the trachea and tracheal rings, visualization of vocal cords, widening of glottis as the tracheal tube passes through, tracheal tube positioning above carina and demonstration of movement of the chest wall visceroparietal pleural interface after manual ventilation of the lungs.[26] Esophageal intubation was readily recognized by visualization of the tube in the left paratracheal space. Fiadjoe et al. described for the first time a real-time ultrasonography to direct the insertion of the endotracheal tube during intubation without performing laryngoscopy in a patient of 14 months old who failed traditional laryngoscopy.[27] They located the tube in the pharynx by ultrasound and assessed its relationship to the glottis opening. They modified the trajectory of insertion of the tube to place it through the glottis opening. The authors recommended this approach in patients in whom secretions or blood obscures visualization of the airway, or patients with limitations in mouth opening precluding the use of laryngoscopy.[27]

## Ultrasound to confirm tracheal intubation

The classical methods for detecting endotracheal intubation are based on ventilation. Direct observation of the ETT passing through the glottis may not be possible especially when laryngoscopy is difficult.[28] Pulmonary auscultation, chest movement check and the observation of condensation in the ETT are alternative methods to confirm a successful intubation, although not completely reliable.[26] End-Tidal Carbon Dioxide ($ETCO_2$) is considered the gold standard in the identification of an esophageal intubation.[28]

Ultrasound can be used to confirm airway device placement indirectly by visualization of diaphragmatic and pleural movements which are qualitative and quantitative indicators of lung expansion.[29] Firstly, if the ETT is in the correct position, a bilateral equal motion of the diaphragm toward the abdomen synchronized with ventilation can be observed.[29] Secondly, the so called lung sliding sign (which is best seen dynamically in real time) at the lung chest wall interface is seen, by positioning the probe in the intercostal space. In M Mode (M = motion), the typical ''sand and sea'' image can be observed (Fig. 3). If the tube is endobronchial the movement of the diaphragm is present. Additionally, there should be a lung-sliding sign on the ventilated lung and absence or restricted movement of the diaphragm and absence of the lung-sliding sign on the contralateral side (non-ventilated lung).[30] On the other side, if the tube is in the esophagus, there is no expansion of the lungs or active motion of the diaphragm.[30] Remarkably, a paradoxical motion of the diaphragm may be present in this condition, where 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.[30] Also, instead of observing the lung sliding sign there can be a lung pulse which results from the vibrations of the pleura in rhythm with the heartbeat.[30–32]

In a pediatric intensive care, Hsieh et al.[29] used the motion of the diaphragm to determine the position of the ETT and recommended it for the secondary confirmation of the tube position. Hosseini et al.[33] suggested that diaphragm motion in the right subcostal ultrasound view is a sensitive and specific secondary confirmatory method for diagnosing ETT placement in apneic or paralyzed patients undergoing intubation.

US can be used as a direct method of endotracheal intubation confirmation by the visualization of the tube in the

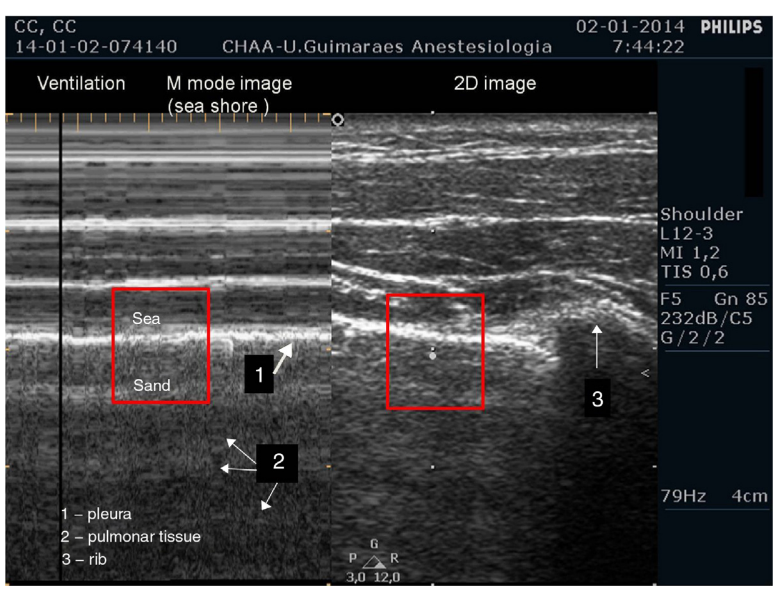



**Figure 3** Sand and sea image in M mode of the ultrasound.

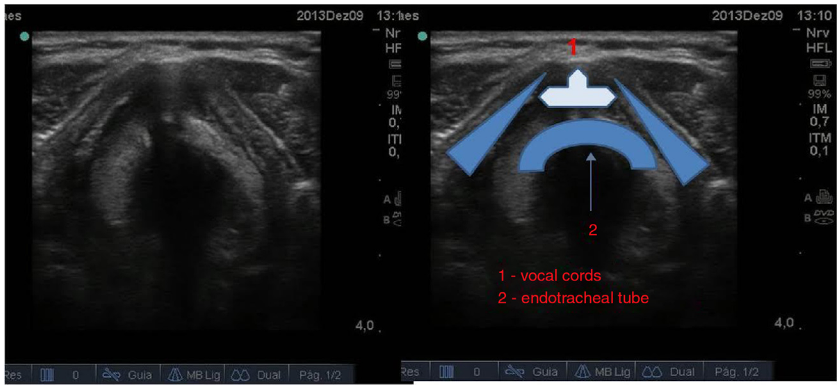



**Figure 4** Visualization of the tube in the trachea in a static manner with the probe oriented horizontally.

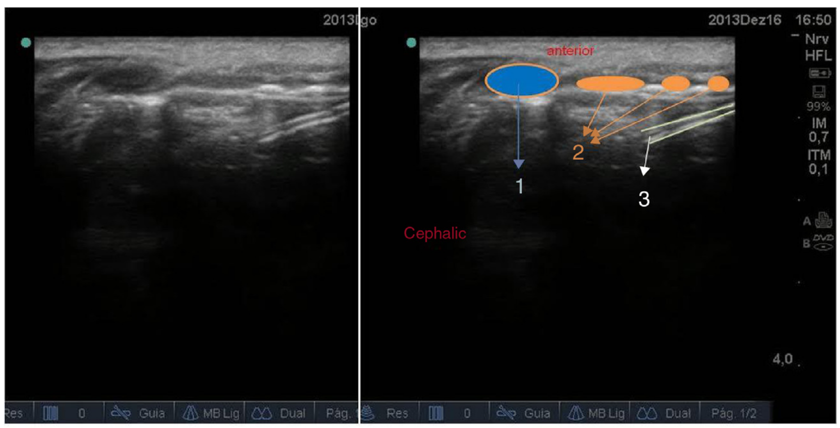



Image of endotracheal tube in trachea
1 – cricoid
2 – tracheal rings
3 – lines of tracheal tube

**Figure 5** Visualization of the tube in the trachea in a static manner with the probe oriented vertically.

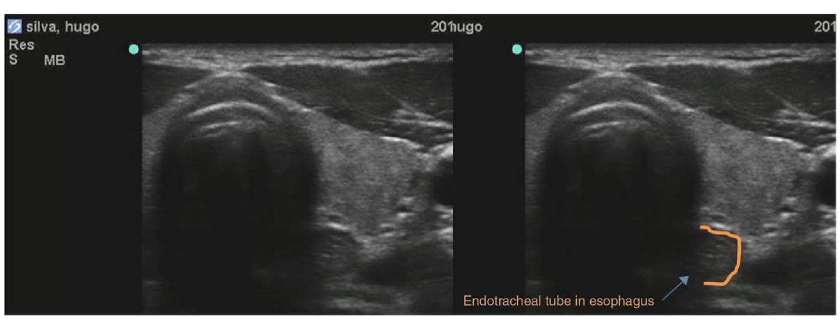



**Figure 6** Esophageal intubation.

trachea in a static or a dynamic manner. In the static manner, if the probe is oriented horizontally (Fig. 4) or vertically (Fig. 5) and the tube is inside the trachea, two hyper-echoic parallel lines are seen; in the presence of esophageal intubation, the trachea is empty with a distended esophagus (Fig. 6), which is normally hard to see, and the hyper-echoic parallel lines of the tube are seen inside this structure. In a dynamic manner, the confirmation of the positioning of the endobronchial tube is made in real time by observing the advancing of the tube through the trachea as well as the widening of the vocal cords. In a previous study, a cadaver model was used by residents to train the correct identification of a tracheal and esophageal intubation after a 5 min explanation of the correct technique.[34] There was a significantly higher sensitivity (97%) using the dynamic method in comparison with the static method, showing a lack of interest in clinical use of the later.[34]

Some authors used stylets inside the tubes or cuffs filled with fluid, air bubbles or a mixture of gelatin and air to enhance the tubes echogenicity[35–37] while others suggested a combination of a longitudinal view with a slight to-and-from motion to improve the ETT visualization.[38]

Furthermore, ultrasound is becoming very important in emergency care settings because is easy to carry, safe, non-invasive, reproducible and freely available, and it can be a good alternative to capnography, when this is not available. Chou et al.[39] demonstrated that the use of Tracheal Rapid Ultrasound Exam (TRUE) to determine ETT location during emergency intubation is feasible and can be rapidly performed (16 s). Adi et al.[40] also showed that ultrasonography is a quick method in detecting endotracheal intubation (median operating time of TRUE was 9.0 s) and can replace waveform capnography in centers without capnography. It can also contribute to reducing the incidence of unrecognized esophageal intubation and prevent morbidity and mortality.[40]

## Ultrasound to guide percutaneous tracheostomy, cricothyroidotomy and retrograde intubation

Percutaneous tracheostomy is frequently performed in ICUs worldwide and is associated with an average mortality of one in every six hundred procedures.[41] Autopsy in cases of fatal bleeding after percutaneous dilatation tracheostomy revealed that the tracheostomy level was more caudal than intended and that the innominate vein and the arch of the aorta had been eroded.[41] There is great promise in using ultrasonography to aid safe placement of percutaneous tracheostomy and avoid complications.

The accurate identification of anterior neck structures (Fig. 7) (tracheal cartilages, tracheal midline thyroid isthmus and the surrounding vessels) during percutaneous tracheostomy can eliminate potential dreaded complications like hemorrhage, laryngotracheal stenosis caused by high placement of the tracheostomy, erosion into high mediastinal vessels and injury of the thyroid isthmus. In one observational study, ultrasound images of the anterior neck were obtained from 50 patients.[42] The distance between the caudal border of the cricoid cartilage and the second tracheal ring was found to be variable across subjects: 19.7 ± 10 mm.[42]

Sustic et al.[43] compared the tracheas of 26 consecutive ICU patients who had undergone percutaneous dilatational tracheostomy but who later died. The tracheas were removed en bloc at autopsy, and the condition of tracheal rings and the site of tracheostomy were macroscopically evaluated. The patients were divided in two groups: Group A with 15 patients who underwent a blind percutaneous dilatational tracheostomy and Group B with 11 patients who underwent ultrasound-guided percutaneous dilatational tracheostomy. In 33% of the patients from the blind group the tracheostomy tube was not found to be placed between the cricoid and the first tracheal ring. In the ultrasound group, cranial displacement did not occur, indicating that the ultrasound evaluation of the tracheal area allows the identification of the second and third cervical level for tracheostomy and avoids a tracheostomy placement which is neither too high nor too low.[43] This is especially important in cases where localizing the trachea is difficult due to neck mass, edema or other pathologies like Ludwig's angina. Hatfiel et al. used ultrasound scans to identify relevant anatomical structures in the neck of 30 patients before a percutaneous tracheostomy.[44] Anterior jugular veins were seen in eight patients near the midline which were considered vulnerable and three were more than 4 mm diameter. Also four patients had arteries which were vulnerable for damage.[44]

They concluded that ultrasound was crucial as a method of screening for vulnerable blood vessels in the neck and for locating the midline for tracheostomy.[44]

Muhammad et al. also pointed out that the diagnostic ultrasound permits careful evaluation of patients for whom percutaneous dilatation tracheostomy is being considered, prevents the puncture of aberrant vessels and estimates the distance from the surface of the skin to the trachea while ensuring the accurate placement of the needle in the trachea.[45] As important as to perform the tracheostomy is predicting the size and shape of a potential

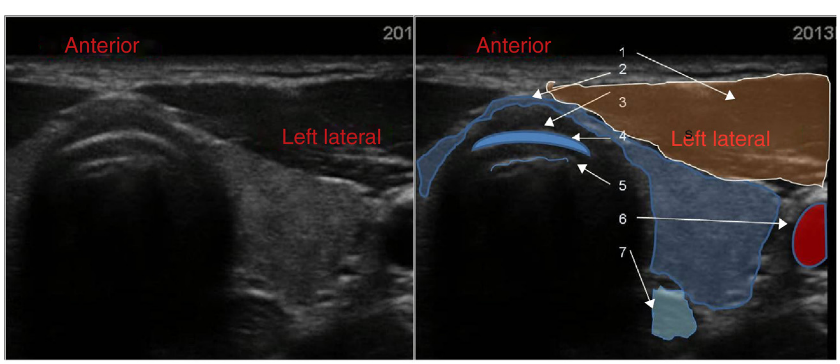



**Figure 7** Identification of anterior neck structures.

replacement tracheostomy tube is important in performing the procedure. Although there are tables of sizes of trachea for different age groups they are estimations of normal and may not be accurate for atypical cases. Hardee et al. scanned four children with various abnormalities who were being considered for replacement tracheostomies.[46] In the four children the US changed the earlier strategy because in three, the scan showed there was no space to allow a larger tube to be placed. In the other children the ultrasound confirmed that a new larger fenestrated tube could be placed which improved vocalization and respiration.[46]

Orr et al. demonstrated the value of ultrasound in identifying the tracheal rings in an obese patient with Ludwig's angina.[47] They could verify with ultrasound that the trachea was 2 cm lateral from the midline and they suggested that US is a useful technique in identifying tracheal prior to both elective transtracheal cannulation and emergency cricothyrotomy.[47]

Dismore et al. found an increase in the success rate during the transtracheal or transcricothyroid placement of a cannula (83% vs. 43%, $p = 0.011$) and a significant decrease in time for successful placement (median time to successful cannulation 57 vs. 110 s, $p = 0.008$) when the procedure is performed using ultrasound guidance compared to unguided cannula placement.[48]

Recently, Vieira et al. commended ultrasound guidance for the use in time critical airway management of patients with potentially hemorrhagic laryngeal tumors, for whom retrograde intubation may be the safest option.[49] Ultrasonography to guide retrograde intubation with the aim of decreasing the likelihood of complications described in the blind technique although further studies are required to confirm these benefits.[49]

As a conclusion, both identification of the trachea, the adequate tracheal ring interspace, the measurement of depth from skin to tracheal lumen and the cricothyroid membrane before or during percutaneous tracheostomy, cricothyroidotomy and retrograde intubation is advisable.

## Ultrasound to predict successful extubation

Extubation failure is one of the most frequently encountered events in the management of patients receiving mechanical ventilation. A failed extubation attempt prolongs the duration of mechanical ventilation and ICU stay, as well as increase the risk of hospital mortality.[50,51] Predicting extubation outcome and preventing extubation failure is therefore an important task.

The cuff-leak test was widely used for the prediction of post-extubation stridor, but controversial results limit its clinical application. Ding et al. studied fifty-one intubated patients and evaluated by US the laryngeal morphology and quantified the laryngeal air column, especially during balloon cuff inflation and deflation.[52] The authors identified that after cuff deflation, an air column width of 4.5 (0.8) mm was associated with post-extubation stridor, while patients who did not develop stridor had an air-column width of 6.4 (2) mm.[52] They concluded that the change in the air column width during balloon deflation may reflect the change of air leak and airflow around the endotracheal tube and has a potential ability to predict post extubation stridor in intubated patients.[52]

Ultrasonography has been shown to be a promising tool in the evaluation of diaphragm function.[53–55] The extent of diaphragm movement influences neighboring organs, such as the liver and spleen.[53] Jian et al. used ultrasound to evaluate the movements of the liver and spleen that may represent the movements of the hemidiaphragms, with the purpose of analyzing their value in predicting successful extubation in 55 patients.[53] The cutoff value of liver and spleen displacement for predicting successful extubation was determined to be 1.1 cm. Using this cutoff value the sensitivity and specificity to predict successful extubation were 84.4% and 82.6% respectively.[53]

## Summary

Ultrasound is available in the operating room, intensive care unit and emergency department and has become part of the anesthesiologist's armamentarium. It has many advantages because it is a safe, quick, non-invasive, portable and repeatable technique, which gives real time dynamic images relevant for airway management.

The review of the literature shows that ultrasonography has the potential to increase safety in the airway management as well as to confirm tracheal intubation.

Further studies should be performed to carry out more comparisons between the established imaging techniques such as X-ray, computed tomography and magnetic resonance imaging.

## Conflicts of interest

The authors declare no conflicts of interest.

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