Review Article

# Ultrasonographic assessment of airway

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## Abstract

Ultrasound is gaining increasing popularity among anesthesiologists as it is readily available and provides real-time imaging for various procedures. It is considered as a “visual stethoscope” of the anesthesiologist. After establishing its use in regional blocks and central venous catheter insertion, it is now finding increasing use in anticipation of difficult airway and securing and maintaining it. It has challenged the classical approach of clinical assessment of airway and allows more dynamic bedside assessment. This article attempts to briefly outline the role of ultrasound and its applications for airway management in patients.

**Keywords:** Airway, anesthesia, clinical, sonographic, ultrasound

## Introduction

Ultrasound, since its first reported medical use in era of 1940, has come a long way. From huge machine to compact handheld devices, from detection of big lesions to characterization of tiny lesions, this painless, noninvasive, relatively inexpensive, repeatable, real-time, radiation-free technique is continuing to attain gargantuan stature in the field of medicine. So how can anesthesiologists be left aside! Ultrasound is gaining increasing utility in the hands of an anesthesiologist – from elective use in operating room (pain management procedures, airway management, etc.), critical care procedures, to use in even emergency situations.

Airway management is of paramount importance to an anesthesiologist. Be it predicting, encountering, and managing difficult airway, managing airway using different modalities, or even ensuring safe extubation, dynamic and real-time visualization and assessment of airway structures would provide an edge. This is where ultrasound scores over other radiological modalities.

This article aims to highlight the use of ultrasound in airway management.

## The Basics

Let us start with the basic physics related to ultrasound.

The mechanical waves above 20 kHz are called “ultrasound” – the waves which the human ear cannot hear normally. These are produced by lead-zirconate-titanate-based small piezo-crystals. The frequency of the transducer is determined by the thickness of the piezoelectric ceramic plates. These ceramic plates work as both transmitters and receivers. In receiver function, the reflected ultrasound from the investigated area causes vibrations in piezoelectric crystal, from which electrical impulses can be collected. The ultrasound images are high-performance computer-assembled echo-images.

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The choice of the appropriate ultrasound transducer is the basic prerequisite for proper visualization of the airway structures. A linear, high-frequency (5–14 MHz) transducer is used for visualization of the relatively superficial anatomical structures, such as the cricoid cartilage, cricothyroid membrane, epiglottis, vocal cords, arytenoid cartilages, or trachea. For the location of more deeply located anatomical structures, such as the base of the tongue, microconvex ultrasound probes with a working frequency of 4–10 MHz or convex (curvilinear) probes with a frequency of between 3 and 8 MHz are most frequently used [Figure 1]. The lower the frequency, the higher is the penetrance of tissues but lower is the potential image resolution. So, high-frequency probe gives richer resolution but lacks depth, whereas low-frequency probe provides advantage of greater depth evaluation at the cost of lesser resolution. Reflection, refraction, scatter, absorption, and transmission of sound occur as it passes through soft tissue structures, allowing characterization of the shape and internal architecture of that structure in addition to those behind it.

The amount of echo returned after hitting a tissue interface is determined by a tissue property called acoustic impedance. Bone is represented as a very bright structure and appears "hyperechoic." It creates a significant acoustic impedance mismatch and therefore is very reflective and shows as bright white (hyperechoic) on the image. Cartilaginous structures (e.g., thyroid and cricoid cartilages) are homogeneously hypoechoic. Muscle presents as hypoechoic, with some internal signals as a result of collagen fibers. Nerves appear as "honeycomb" or "pepper pot"-like structures composed of hypoechoic spots embedded in a hyperechoic background. Glandular structures such as the submandibular and thyroid glands are homogeneous and mildly to strongly hyperechoic in comparison to adjacent soft tissues. Fluid presents as an anechoic appearance on ultrasound. Air has the lowest acoustic impedance ($0.0004 \times 10^6$ kg/(m$^2$ s)). Air is said to be the "enemy" of ultrasound as ultrasound waves tend to reflect strongly at air–tissue interface, resulting in very poor image. Intraluminal air produces both comet tail and reverberation artefacts. Hence, this is the most important problem while trying to image air-containing structures, that is, lungs and trachea.

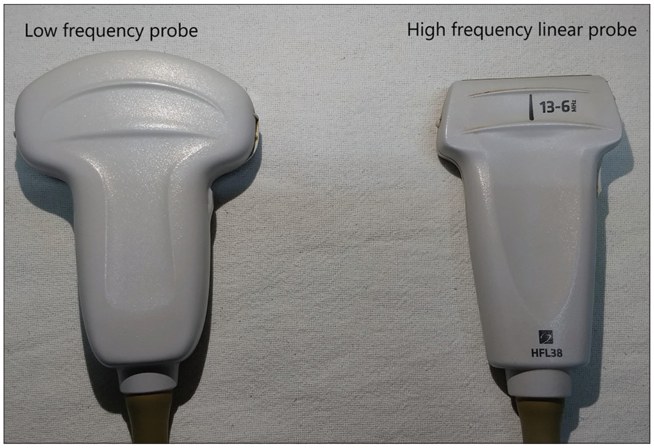

**Figure 1:** Ultrasound probes commonly used for airway management

Now, having done with the basics, we move to imaging the airway using ultrasound.

## Structures Visualized

The airway structures of importance to an anesthesiologist that can be visualized using ultrasound are tongue, epiglottis, hyoid bone, larynx, vocal cords, cricothyroid membrane, cricoid cartilage, thyroid cartilage, trachea, and esophagus.[1-5]

## Different Approaches

Airway ultrasound can be done through two approaches:

### Transcutaneous approach

This can be used for examination of the upper airway from the floor of the mouth to the suprasternal notch, and even paratracheal structures using either a linear or curved transducer oriented in one of these planes: sagittal, parasagittal, transverse, or oblique planes.

### Transoral or sublingual approach

Excellent probe–tissue contact without inciting gag reflex thereby producing clear images forms the points in favor of this technique. Whereas uneasiness of probe underneath one's tongue, inability to use in children and uncooperative patients, inability to visualize trachea, requirement of a small footprint probe, and steeper learning curve make it a relatively difficult approach to gain favor among and master by anesthesiologists.[6,7] Nevertheless, it has been used in one study to predict difficult intubation.[8]

## Sonographic Appearance of Various Airway Structures

Airway examination is usually done with the patient in supine position and neck extended.

*Tongue* is best visualized using a low-frequency curvilinear probe. It appears as a hyperechoic structure. A patient is usually asked to appose the tongue to the palate to facilitate visualization of the palate and the anterior part of the tongue. Mid-sagittal section reveals fan-shaped or striated appearance of the tongue and is used for determination of its cross-sectional area [Figure 2a]. Axial section is used to view floor of the mouth and tongue [Figure 2b].

*Epiglottis* is seen as hypoechoic structure with curvilinear structure in the parasagittal section and as an inverted C on transverse view. Anterior to the epiglottis lies the pre-epiglottic space which appears hyperechoic due to presence of fat [Figure 2c].

Even though *larynx and trachea* are filled with air, they have good inherent soft tissue contrast which makes these structures suitable for visualization with ultrasound. The larynx lies between the hyoid bone superiorly and cricoid cartilage inferiorly. The thyroid, cricoid, and arytenoid cartilages are more echogenic than the intrinsic muscles of the larynx. Variable ossification of the laryngeal cartilages, thyroid, and cricoid cartilages causes significant difference in appearance of these structures between different patients. Tracheal rings appear as hypoechoic structures on sonography. On transverse view, it appears as an inverted U-shaped hypoechoic structure, delineated posteriorly by a linear hyperechoic air–mucosal interface and reverberation artefact, whereas in parasagittal view, it appears as "string of beads" [Figure 3].

*Esophagus* is difficult to visualize as it is mostly collapsed. Asking the patient to swallow eases identification.

## Major Clinical Applications

### Identification or prediction of difficult airway

Adhikari *et al.*,[9] in their pilot study of 51 patients, measured thickness of tongue and anterior neck soft tissue at the level of hyoid bone and thyrohyoid membrane using ultrasound and found soft tissue thickness at the level of hyoid bone and thyrohyoid membrane to be significant predictor in differentiating difficult from easy intubation. Ezri *et al.*[10] quantified anterior neck soft tissue thickness at the level of vocal cords and suprasternal notch in obese patients. They found difficult laryngoscopy to be associated with more soft tissue at the level of vocal cords. Many other ultrasonographic parameters have been studied, namely, anterior neck soft tissue thickness at various levels[11] and various derived ratios, but none of these parameters has attained unequivocal acceptance for this purpose.

### Identification of cricothyroid membrane

This is very useful in cases of difficult airway anatomy, emergency settings, retrograde intubation, cricothyoidotomy, percutaneous tracheotomy, and so on.[12] Apart from facilitating identification of cricothyroid membrane, it also guides in finding correct tracheal ring interspace, avoids bleeders through identification of blood vessels in proximity, and also in determination of depth from skin to target site, especially in obese patients [Figure 4].

### Prediction of appropriate endotracheal tube size

Subglottic area is the area with smallest upper airway diameter. The measurement of subglottic airway diameter enables determination of appropriate size endotracheal tube (ETT) and postintubation laryngeal stenosis[13,14] [Figure 5]. This is especially relevant in pediatric settings where an oversize tube may lead to dangerous airway edema, whereas an undersized tube would lead to airway leaks. Ultrasound of subglottic airway has proven superior to other conventionally used formulae for ETT size prediction and prevention of multiple intubation attempts in pediatric population.[15]

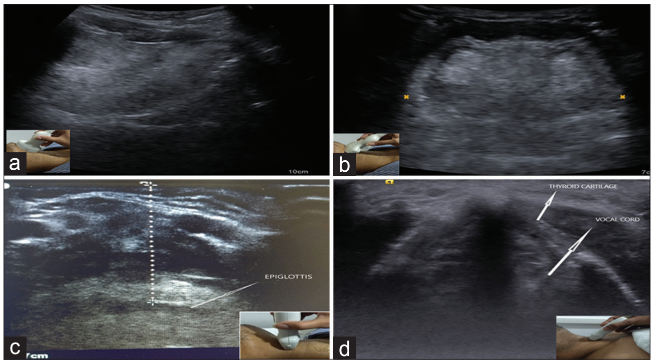

**Figure 2:** (a) Tongue (longitudinal view). (b) Floor of mouth and tongue (axial view). (c) Epiglottis (axial section). (d) Vocal cords (axial section)

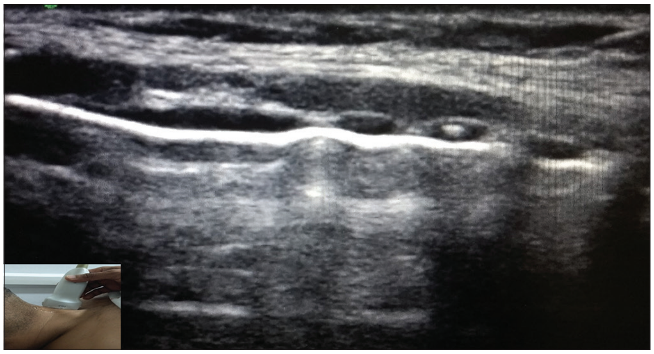

**Figure 3:** "String of beads" appearance of tracheal rings in parasagittal plane

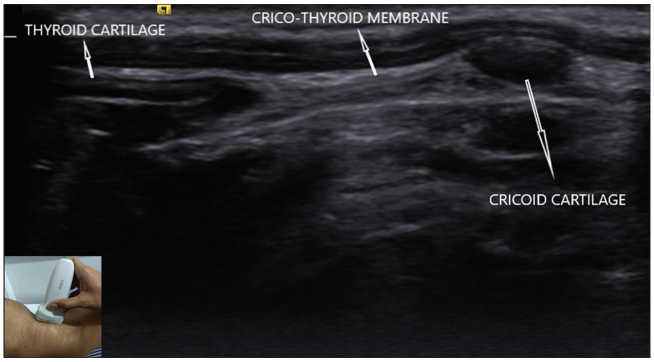

**Figure 4:** Cricothyroid membrane in sagittal plane

## Determination of size of double-lumen tube

For this, the outer tracheal width is measured at the level just above the sternoclavicular joint [Figure 6]. This measurement is used to determine the appropriate size of double-lumen tube.[16,17] This has been found to have good correlation with the widely accepted computed tomography (CT) scan–based evaluation.

## Confirmation of endotracheal intubation

Capnography is considered the gold standard for verification of endotracheal location of the ETT. But there are certain conditions which warrant use of another method for ETT location confirmation, for capnography does not find much use in those situations. Anesthesiologists, being masters in airway management, should thus be familiar with this modality to rise up to the occasion should the need arise. These situations include patients with cardiopulmonary arrest, pulmonary embolism, severe bronchospasm, or technical problems with capnography. Trachea normally appears as a hyperechoic curvilinear structure with comet tail artefact and shadowing. In case of endotracheal intubation, an increase in artefact and shadowing is noted in the region of the trachea only. Esophageal intubation appears as "double tract" sign on ultrasonography[18-20] [Figure 7]. An indirect method of ETT confirmation through ultrasound is by determination of bilateral lung sliding while ventilating a paralyzed patient.

## Confirmation of correct ETT depth

Ultrasound has proven to be beneficial for this, especially in pediatric population and in pregnant patients. For pediatric patients (infants and neonates), the probe is placed mid-sagittally on the sternum and ETT tip confirmation usually between 1 - 1.5 cm above aortic arch or superior portion of right pulmonary artery (surrogate marker for carina).[21-23] Tracheal rapid ultrasound saline test (T.R.U.S.T.) involves inflating the ETT cuffs using saline instead of air to overcome the problem of nonvisualization of air-filled ETT cuff. It determines correct placement of ETT when saline-filled ETT cuff is visualized with the ultrasound probe in transverse orientation at the level of sternal notch.[24,25]

## Detecting endobronchial intubation

Endobronchial intubation can be diagnosed by the movement of the diaphragm and presence of lung-sliding sign on the ventilated lung (endobronchial) and absent or restricted movement of the diaphragm and absence of lung-sliding sign on the contralateral side (nonventilated lung).

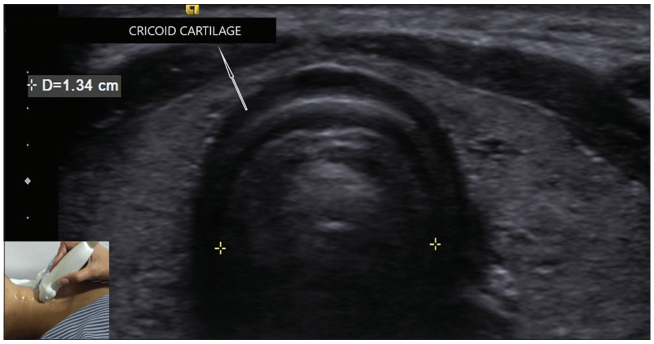

**Figure 5:** Subglottic diameter (air column measurement) for determination of appropriate endotracheal tube size

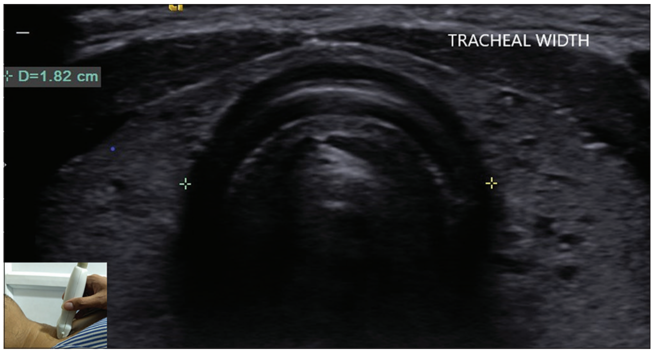

**Figure 6:** Axial view above the level of sternoclavicular joint for measurement of outer tracheal diameter for determination of size of double-lumen tube

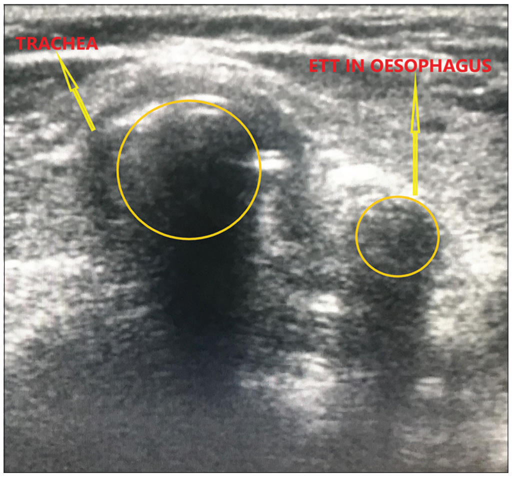

**Figure 7:** "Double tract" sign of esophageal intubation

## Facilitation of percutaneous dilational tracheostomy

Ultrasound is of immense help in improving safety of this procedure. It helps in selection of appropriate site of puncture, avoidance of vessel and surrounding soft tissue injuries and creation of "false passages," determining size of tracheostomy tube, and also confirmation of successful procedure. This comes as a boon in cases of altered airway anatomy as in patients with neck tumors, thyroid pathologies, and so on. The ability to measure distance of skin to trachea finds special implication in obese patients and also guides for appropriate tube length. Even real-time ultrasound-guided tracheostomy is possible and has been proven to have relatively lesser complications in comparison to traditional landmark-based or bronchoscopic guidance. It improved first pass puncture rate and accuracy.[26-29]

## Prediction of postextubation stridor

Laryngeal edema and mucosal ulcerations are common in patients intubated for more than 24 h in intensive care unit settings and in cases of trauma. This may lead to stridor post-extubation. Studies have been conducted to predict this postextubation stridor. Ding *et al.*, in their pilot study, used laryngeal air column width measurement at the level of cricothyroid membrane, post-cuff deflation, to predict this.[30] This was followed by few more studies which, however, produced equivocal results and are limited by their small sample size.[31,32]

## Detection of laryngeal mask airway (LMA) position

Proper ventilation of a patient using laryngeal mask airway (LMA) under anesthesia requires proper placement and seal around the glottis. Due to frequent suboptimal positioning of LMA, prompt recognition and correction is mandatory for safe ventilation. Clinical tests are regularly used for this. But they have limitations. Flexible fiberoptic bronchoscopy (FOB) is stated to have maximum sensitivity and specificity for determination of optimal LMA insertion. Two scoring systems have been devised for the same.[33,34] But FOB-guided confirmation requires discontinuation of ventilation. Studies have been conducted to determine the efficacy of using ultrasound for the same, which ensures uninterrupted ventilation as well [Figure 8]. The results of these studies are encouraging, especially in pediatric population where the risk of mal-rotation is highest.[35-39]

## Assessment of vocal cords/determination of recurrent laryngeal nerve palsy

Vocal cords are easily visualized on ultrasonography [Figure 2d]. This finds various uses in clinical practice. This can be beneficial in ascertaining recurrent laryngeal nerve involvement preoperatively in cases of thyroid cancer. With increasing use of ultrasound to characterize thyroid nodules preoperatively, this can be achieved easily in the same setting especially in patients uncooperative for laryngoscopy or FOB. This superficial, noninvasive modality has good correlation with fiberoptic laryngoscopic findings.[40,41] It can also be used for ensuring integrity of superior and recurrent laryngeal nerves by real-time analysis of vocal cords post-thyroidectomy.[42]

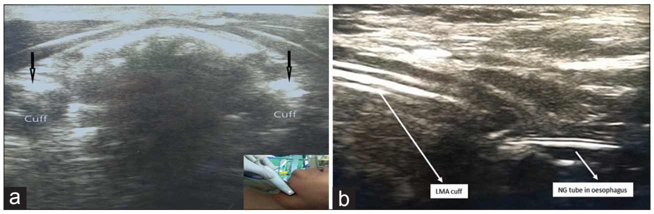

**Figure 8:** (a) LMA cuffs visualized in transverse plane. Arrows indicate cuff edges. (b) Nasogastric (NG) tube through LMA seen in parasagittal view

## Detection of tracheal stenosis

Tracheal stenosis can be due to a variety of reasons – post-intubation, post-infections, trauma, edema, and so on. Extrathoracic trachea can be easily scanned for any irregularities in contour or reduction in its diameter.

## Determination of tracheal wall thickening

Normal tracheal wall thickness, as measured on ultrasound, is around 1.5 ± 0.2 mm in males and 1.2 ± 0.2 mm in females.[43] Tracheal wall thickness is increased in conditions such as infections, mucosal edema, sarcoidosis, and Wegener's disease. Kameda and Fujita used this parameter to detect airway involvement due to smoke inhalation.[44]

## Tracheal invasion due to thyroid cancer

Sonography has been shown to satisfactorily identify tracheal invasion due to thyroid carcinoma. However, it has certain limitations owing to tumor calcifications, infraclavicular tumor extension, and so on.[45,46]

## Identification of intrathoracic extent of goitre

A simple, accurate, bedside method of diagnosing intrathoracic extent of goitre is through use of ultrasound. A low-frequency probe is used for supraclavicular, suprasternal, or a parasternal approach to sonography. It reveals mediastinal mass as a continuum of cervical thyroid.[47]

## Diagnosing epiglottitis

Epiglottitis used to be common mostly in pediatric population. But advent of vaccines has reduced the incidence in this population and the balance has shifted toward the adults. Nevertheless, epiglottitis, when present, demands emergency treatment and watchful guard for airway. Ultrasound finds use in quick diagnosis of this condition even in emergency settings. It is mostly recognized by "P-sign" of swollen epiglottis in mid-sagittal view of neck. Epiglottitis results in significant increase in anteroposterior diameter of epiglottis as determined in transverse view of the neck.[48,49] Its diagnosis finds special importance in oncology patients who develop epiglottitis after radiotherapy to head and neck, for prevention of airway complications and for prediction of difficult airway.

## Detection of maxillary sinusitis

Ultrasound was first used for this purpose in early 1970s, in A-mode. "Sinusogram," the ultrasonography of sinuses, presently performed in B-mode, has been found to be useful for detection of maxillary sinusitis. Clinical examination alone does not suffice as a reliable method for diagnosis of maxillary sinusitis and sinusogram has been found to be comparable to X-ray and CT scans, especially in cases of acute sinusitis. Sinusogram is said to be "complete" on visualization of internal, external, and posterior walls of the sinus and "incomplete" on partial visualization of these walls. The sinus is usually scanned in transverse view, with the probe placed under the orbit and lateral to the nose. The sensitivity and specificity of ultrasound for this have been found to be 70%–100% and 84%–97%, respectively. It has been found to be a suitable modality and proposed as first line of investigation for diagnosing maxillary sinusitis in intubated patients.[50,51] The limitation is high error rate in identification of mucosal thickening.[50-55]

### Diagnosis of obstructive sleep apnea

Polysomnography is considered as the gold standard for diagnosis of obstructive sleep apnea. But this modality is expensive and time-consuming. Imaging techniques, which include CT scans and MRI, are also either expensive or pose radiation exposure to the patient. Here also, ultrasound is carving its own niche by being inexpensive, noninvasive, not much time-consuming, and without danger of radiation exposure. Submental ultrasound is used for this purpose. Several studies have been conducted which use various parameters for its diagnosis, namely, tongue base thickness, distance between two lingual arteries, diameter of the retropalatal space, lateral pharyngeal wall thickness, and so on. These studies have presented promising data in favor of ultrasonography.[56-59]

### Assessment for risk of aspiration

Gastric ultrasound is used for assessing the nature and volume of gastric contents. The most commonly used positions are supine and right lateral decubitus (RLD). Semi-recumbent position is used in situations where RLD is not feasible. The region scanned is the antrum of stomach which gives a "bull's eye" appearance when empty, hypo- or anechoeic area when filled with clear fluid, "starry night" with air in clear liquid contents, and hyperechoic or mixed echogenecity and "frosted glass" image with solid contents [Figure 9]. It finds use in patients with delayed gastric emptying, emergency procedures, and situations where prandial history cannot be obtained (e.g., cognition dysfunction, reduced level of consciousness, trauma victims, and language barrier). For calculation of gastric volume (in RLD, at the level of aorta), the formula proposed is gastric volume (mL) $= 27.0 + 14.6 \times$ cross-sectional area $- 1.28 \times$ age. The volume of clear fluids $>1.5$ mL/kg or solid contents imply inadequate fasting and thus increased risk for aspiration. The limitations of assessment are that it is applicable only for clear liquids and validated in nonpregnant subjects with body mass index $<40$ kg/m$^2$.[60,61]

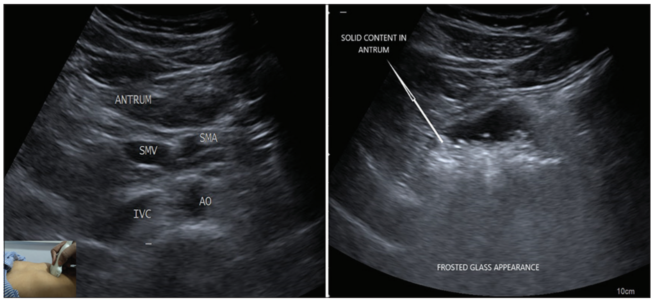

**Figure 9:** Gastric ultrasound to assess prandial status. AO: Aorta, SMA: Superior mesenteric artery, SMV: Superior mesenteric vein, IVC: Inferior vena cava

## Limitations of Using Ultrasound

As would be clear by now, ultrasound has immense applications in the field of airway management. However, it certainly has some limitations too.[62]

- The operator of ultrasound machine is required to have a sound knowledge of sonographic anatomy to delineate acoustic artefacts from that of the structure of interest
- Image acquisition is dependent on the equipment and the operator
- Interpretation is operator-dependent
- It takes time to master the technique.

## Summary

In spite of all its limitations, ultrasound is a rapidly evolving modality in the field of anesthesiology, finding applications in almost every role. As discussed above, it is being increasingly used for cricothyroidotomy, facilitation of percutaneous dilational tracheostomy, confirmation of endotracheal intubation, detection of endobronchial intubation, and assessing vocal cord palsy and goitre. Its role for other purposes is evolving rapidly with increasing awareness, knowledge, skill, and acceptance of this real-time, dynamic assessment modality.

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### Conflicts of interest

There are no conflicts of interest.

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