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Ultrasonographic identification of the cricothyroid membrane: best evidence, techniques, and clinical impact

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Abstract

Inability to identify the cricothyroid membrane by inspection and palpation contributes substantially to the high failure rate of cricothyrotomy. This narrative review summarizes the current evidence for application of airway ultrasonography for identification of the cricothyroid membrane compared with the clinical techniques. We identified the best-documented techniques for bedside use, their success rates, and the necessary training for airway-ultrasound-naïve clinicians. After a short but structured training, the cricothyroid membrane can be identified using ultrasound in difficult patients by previously airway-ultrasound naïve anaesthetists with double the success rate of palpation. Based on the literature, we recommend identifying the cricothyroid membrane before induction of anaesthesia in all patients. Although inspection and palpation may suffice in most patients, the remaining patients will need ultrasonographic identification; a service that we should aim at making available in all locations where anaesthesia is undertaken and where patients with difficult airways could be encountered.

Key words: airway, anatomy; airway, complications; airway, obstruction; airway, patency; cricothyrotomy; tracheostomy; ultrasonography

Access via the anterior neck, preferably via the cricothyroid membrane, is recommended as a last resort by all major guidelines for difficult airway management in the event of oxygenation failure where the airway cannot be managed successfully with tracheal intubation, face mask ventilation, or supraglottic airway insertion.[1–6] Additionally, the cricothyroid membrane may serve as a route for application of local anaesthetics before awake intubation, retrograde awake intubation, awake placement of a cannula cricothyrotomy, and awake surgical cricothyrotomy. The success rate of real emergency airway access performed by anaesthetists is low, with only 9 of 25 (36%) attempts being successful.[7] An inability to identify the cricothyroid membrane is an important contributor to this high failure rate,[8] because misplacement is the most common complication when attempting cricothyrotomy.[9] Despite its key role in airway management, the success rate for anaesthetists in identifying the cricothyroid membrane with traditional modalities of inspection and palpation is notoriously low, especially in obese patients, for whom reported success rates vary between 0 and 39%.[10–13]

The aim of this narrative review is four-fold: first, to summarize the current evidence for identification of the cricothyroid membrane using ultrasound and the clinical application of these techniques; second, to compare success rates of the individual clinical methods of identification of the cricothyroid membrane with the rates obtainable by ultrasonography; third, to identify the most well-proved techniques and to provide detailed

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descriptions of these techniques in sufficient detail with complimentary video links to allow clinicians to practice for clinical use; and fourth, to provide clinical recommendations based on the above findings.

The PubMed database was searched for relevant articles using the search strategy '[(ultrasound OR ultrasonography OR sonography) AND (trachea OR cricothyroid membrane OR tracheostomy OR cricothyrotomy)]', and major textbooks of airway management and of ultrasonography were also searched. Subsequently, we scrutinized reference lists of the included studies and retrieved the papers that were cited. The publications in languages other than English (German, Japanese, and French) were translated into English. We scrutinized these resulting papers, and subsequently, we used the Web of Science™ to see whether these papers had themselves been cited, subsequently retrieving the papers in which they were cited.

We included publications that described the ultrasonographic appearance of the cricothyroid membrane, the technique for identification of the cricothyroid membrane, and publications that described clinical use of ultrasound-guided identification of the cricothyroid membrane in comparison to traditional modalities. We excluded publications describing the use of ultrasonography for tracheostomy (whether it was surgical or a percutaneous dilatational technique) in instances where a tracheal tube was already in place.

Results of the literature search are summarized in Table 1.

Identification of the cricothyroid membrane with clinical techniques only

Three different clinical techniques (palpation, visual inspection, and the 'four finger widths technique') for identifying the cricothyroid membrane were documented (Table 1).

Success rates of identification by palpation varied with sex, patient positioning, and body habitus. In males, it was reported to be successful in 72% of non-obese[12] and in 39% of obese subjects.[12] In females, success rates were 24,[12] 25 (neutral position),[10] 29 (hyperextended neck),[10] and 71% in the non-obese,[13] whereas they were found to be 0 (neutral position),[10] 6 (hyperextended neck),[10] 35,[12] 37,[11] and 39%[32] in obese females. In heterogeneous populations including a mixed population of both sexes and with various BMI, a wide range of success rates was found, as follows: 19,[29] 30,[16] 39 (cadaver),[32] 46,[21] 62,[33] 66.7,[34] and 70%.[29]

Identification of the cricothyroid membrane by visual inspection of the overlying skin creases was successful in 50%.[33] The 'four finger widths technique' was successful in 46% of patients in a mixed population.[33]

Identification of the cricothyroid membrane with ultrasonography

In a high fraction of studies (Table 1), the ultrasound examinations were performed by one or two clinicians only, and ultrasonography was often applied purely as a descriptive technique[17 31] or as a reference method[10 12 13 16 29 33] in studies that investigated success with clinical methods. In the latter studies, the success rate is invariably 100%.

Two additional studies described ultrasound examinations performed by only two clinicians: Curtis and colleagues[24] described 95% success rate in 21 cadavers in a mean of 3.6 s and Nicholls and colleagues[15] obtained 100% success in 50 clinical examinations in a mean of 24 s. All case reports described 100% success in finding the cricothyroid membrane using ultrasound.[14 23 30]

Studies comparing palpation and ultrasonography in manikins, cadavers, and humans

In a non-anatomical manikin, when 25 clinicians used palpation to identify the cricothyroid membrane, cannulation of the airway was successful in only 44%, compared with 83% when ultrasonography was used.[22]

A cadaveric[32] study randomizing 23 anaesthetists showed that palpation and trocar cricothyrotomy was successful in 39%, compared with 63% when using ultrasonography, albeit longer [mean (SD) 111 (47) *vs* 196 (61) s, respectively]. Ultrasonography training here comprised a 10 min lecture on cricothyrotomy, 3 min video, and five hands-on attempts on the cadaver.

Three clinical studies investigated the success of palpation *vs* ultrasonography in a larger heterogeneous group of clinicians.[11 21 34] Successful identification of the cricothyroid membrane with palpation alone was reportedly 67% in lean subjects,[34] 46% in a mixed BMI cohort,[21] and 37% in the morbidly obese.[11] With ultrasonography, this improved to 69% in lean subjects,[34] 100% in mixed BMI subjects,[21] and 83% in morbidly obese subjects.[11] Ultrasonography 'training' *per se* was varied, and ranged from a 'brief surgical airway anatomy and ultrasonography training'[34] and a 'theoretical airway ultrasonography and 15 min hands-on training'[21] to 'a structured teaching program consisting of e-learning, a 20-minute lecture on airway ultrasonography and 20 min of hands-on training'.[11] Six months after the original ultrasonography training, the clinicians still had higher success in finding the cricothyroid membrane using ultrasound than with clinical examination (78 *vs* 33%, $P<0.05$).[21]

Positioning and types of ultrasonographic techniques

Mallin and colleagues[27] reported a 100% success rate with ultrasonography when performed by 23 physicians acting as both models and investigators. The time to successful identification of the cricothyroid membrane was not reported. They found that ultrasound-guided marking of the cricothyroid membrane of healthy volunteers before simulated intubation accurately identified the cricothyroid membrane also after the simulated intubation, even after the head and neck were brought back into the initial extended-neck position. Their training consisted of watching a short video of unspecified duration.[27] When a cohort of 42 anaesthetists compared two ultrasonography techniques (transverse and longitudinal) to best identify the cricothyroid membrane in a randomized sequence on morbidly obese females, success rates of 90% were achieved with each technique in a mean of 24 (transverse technique) and 37 s (longitudinal technique), respectively.[37] One hundred per cent of the anaesthetists were able to identify the cricothyroid membrane with at least one of the techniques. The ultrasonography education consited of a 1 h structured training programme that included e-learning, a lecture, and hands-on training.[37]

Gleaning the results from the published literature, we can draw the following conclusions: (i) the identification of the cricothyroid membrane by clinical measures (inspection and palpation) alone is insufficient in a high fraction of patients, especially the obese; (ii) ultrasonography improves the accuracy of identification of the cricothyroid membrane, with a success rate very close to 100% once the clinicians have gained some experience; (iii) after a structured training programme lasting ~1 h, it is possible to attain a clinically useful skill level; (iv) the ultrasound-

Table 1 Publications describing the ultrasonic appearance of the cricothyroid membrane or the technique for ultrasound-guided identification of the cricothyroid membrane or presenting data on the ultrasound-guided or clinical (visual or palpation-guided) identification of the cricothyroid membrane. CTM, cricothyroid membrane; 3D, three-dimensional; MRI, magnetic resonance imaging; n.a., not assessed; US, ultrasonography

Publication	Study design	Subjects (human, cadaver, or manikin); *n*; characteristics	Physicians identifying the CTM (*n*)	Physicians who performed the US (*n*); US training for the study	Description of the US appearance of CTM	Identification of CTM by palpation (success rate; duration)	Identification of CTM with US (success rate; duration)	US technique for identification of the CTM	Technique described in detail for replication and applicable without palpable landmarks (yes/no)	Comments
Orr and colleagues[14]	Case report, CTM identified before awake intubation	Human; 1; difficult airway	1	1; n.a.	n.a.	0/1=0%; n.a.	1 of 1=100%; n.a.	n.a.	No	
Nicholls and colleagues[15]	Identification of the CTM with US	Humans; 50 patients; mean BMI 26 kg m^{-2}	2	2; cadavers	Bordered by the very echogenic thyroid and cricoid cartilages	n.a.	Success in all 50 patients; time to viewing 24.3 s	Longitudinal initially, then transversely on the CTM	No	Palpation before ultrasound
Elliott and colleagues[16]	Palpation study, with US as reference	Humans; 2 male and 4 female subjects; BMI 24–53 kg m^{-2}	18	2; n.a.	n.a.	30%; n.a.	100%	n.a.	No	
Singh and colleagues[17]	Descriptive	Humans; 24 volunteers; mean BMI 24 kg m^{-2}	1	1; n.a.	Hyperechoic band	n.a.	n.a.	n.a.	No	
Kristensen[18]	Descriptive	Humans	n.a.	n.a.; n.a.	Hyperechoic band	n.a.	n.a.	Stepwise. Trachea in transverse, transducer then rotated to sagittal plane.	Yes	
Kundra and colleagues[19]	Descriptive	Human; n.a.	n.a.	n.a.; n.a.	Hyperechoic band	n.a.	n.a.	Sagittal, parasagittal, and transverse	No	
De Oliveira and colleagues[20]	Case report. US-guided identification after failed palpation	Human; 1; BMI 57 kg m^{-2}	1	1; n.a.	n.a.	0 of 1=0%; n.a.	1 of 1=100%; n.a.	CTM between inverse V-shaped thyroid cartilage and arch-like cricoid, as in Barbe and colleagues[21]	Yes	

Continued

Table 1 *Continued*

Publication	Study design	Subjects (human, cadaver, or manikin); *n*; characteristics	Physicians identifying the CTM (*n*)	Physicians who performed the US (*n*); US training for the study	Description of the US appearance of CTM	Identification of CTM by palpation (success rate; duration)	Identification of CTM with US (success rate; duration)	US technique for identification of the CTM	Technique described in detail for replication and applicable without palpable landmarks (yes/no)	Comments
Dinsmore and colleagues[22]	Palpation *vs* US for cannulation	Manikin, non-anatomical	50	25; 6 min education	n.a.	Cannulation 44%; median 110 s	Cannulation success 83%	Transverse on the simulated trachea; CTM		
Aslani and colleagues[10]	Palpation study, with US as reference	Humans; 56 female subjects, 41 non-obese and 15 obese; BMI 40.5 kg m^{-2}	24	2	n.a.	Neutral: obese 0%, non-obese 25%; Extended: obese (6%), non-obese (29%)	100% success by the two ultrasound examiners; n.a.	Transducer transversely, moving, vocal cords appeared. The probe was moved to see the CTM as in Barbe and colleagues[21]	No	
Suzuki and colleagues[23]	Case report. US-guided localization before awake intubation	Human; 1; cervical spine disease	n.a.	1; n.a.	n.a.	n.a.	1 of 1=100%	Transverse approach	No	
Curtis and colleagues[24]	US-guided cricothyrotomy	Cadavers; 12 female and 9 male cadavers; mean BMI 21.9 kg m^{-2}	2	2	n.a.	n.a.	95%; 3.6 s (cricothyrotomy median 26.2 s)	Sagittal orientation placed just lateral to the midline of trachea	No	
Tsui and colleagues[25]	Comparing US in humans and cadavers	Humans and cadavers; n.a.	n.a.	n.a.; n.a.	n.a.	n.a.; n.a.	n.a.; n.a.	Gradual change of the CTM to the cricoid arch	No	
Or and colleagues[26]	Comparing 3D US and MRI	Humans; 11 volunteers; BMI<35 kg m^{-2}	n.a.	1	A hyperechoic band between the cartilages	n.a.; n.a.	n.a.; n.a.	n.a.	No	3D US images correlate well with MRI
Mallin and colleagues[27]	Identified CTM. Changed position of subjects. Subsequently, rescanned	Humans; 23; healthy volunteers	23	23	n.a.	n.a.; n.a.	23 of 23=100%; n.a.	Longitudinal lateral to midline, followed by 90° rotation and marking	No	Marking of the CTM consistent after attempted intubation

Barbe and colleagues[21]	Compared palpation with US	Humans; 2, female and male; BMI 35.4 and 29.8 kg m^{-2}	12	12 (+2 instructors); theoretical airway US training plus 15 min hands on	Hyperechoic line with a posterior artefact	46% (of 24 examinations); 15 and 24 s, respectively	100% (of 24 examinations); 21 and 28 s, respectively	Transversely, thyroid cartilage 'V', then CTM delimited caudally by arch-like cricoid cartilage	Yes	Significant skills retention was found after 6 months. No randomization of sequence
Kristensen and colleagues[28]	Descriptive	Humans	n.a.	n.a.				Method as for Kristensen[18]	Yes	
Campbell and colleagues[29]	Palpation study, with US as reference method	Human; 44 patients and staff, 24 females	23	2; n.a.	n.a.	Male 70% Female 19%	100% (by the two observers); n.a.	n.a.	No	
Owada and colleagues[30]	Case report. Pre-induction US of CTM for cricothyrotomy	Human; 1; patient with tracheal displacement	n.a.	1; n.a.	n.a.	n.a.; n.a.	1 of 1=100%; n.a.	n.a.	No	
Parmar and colleagues[31]	Descriptive	Human; 100 volunteers, 52 male and 48 female; mean BMI 23 kg m^{-2}		1; n.a.; n.a.	Hyperechoic band	n.a.; n.a.	n.a.; n.a.	Longitudinal and parasagittal	No	
Lamb and colleagues[12]	Palpation study, with US as reference	Human; 12 subjects, 6 men and 6 women; 3 obese in each group, with BMI 30.1–38 kg m^{-2}	41	1; n.a.		Men: non-obese 72%, obese 39%; women: non-obese 24%, obese 35%		Longitudinal, guidewire slid between transducer and skin to identify upper and lower border of CTM	No	
Kristensen and colleagues[11]	Palpation *vs* US, randomized crossover	Human; 1 female; BMI 45.3 kg m^{-2}	35	35; e-learning, 20 min lecture, 20 min hands on	n.a.	37%; 18 s, median	83%; 48 s, median	Same longitudinal approach as described by Kristensen[18]	Yes	
Siddiqui and colleagues[32]	Randomized to palpation or US for percutaneous cricothyrotomy with trocar device	Cadaver; 47; 28 female and 19 male	47	24; 10 min lecture, 3 min video, and 5 times hands on	n.a.	Identification and trocar cricothyrotomy: 39.1%; mean 110.5 s	Identification and trocar cricothyrotomy: 62.5%; mean 196.1 s,	Same longitudinal approach as described by Kristensen[18]	Yes	injury to larynx reduced from 73.9 to 25% in the US group

Continued

Table 1 *Continued*

Publication	Study design	Subjects (human, cadaver, or manikin); *n*; characteristics	Physicians identifying the CTM (*n*)	Physicians who performed the US (*n*); US training for the study	Description of the US appearance of CTM	Identification of CTM by palpation (success rate; duration)	Identification of CTM with US (success rate; duration)	US technique for identification of the CTM	Technique described in detail for replication and applicable without palpable landmarks (yes/no)	Comments
You-Ten and colleagues[13]	Palpation study, with US as reference	Human; 56; women in labour, 28 non-obese and 28 obese, mean BMI 39.2 kg m^{-2}	41	1; trained in neck US	n.a.	71% non-obese women, 39% obese women; obese 23 s, non-obese 12 s, median	(100% by the expert sonographer)	Same longitudinal approach as described by Kristensen[18]	Yes	
Bair and colleagues[33]	Comparing three different clinical methods, with US as reference	Human; 50; mean BMI 28 kg m^{-2}	49	1; n.a.	n.a.	Palpation 62%, four finger widths 46%, visually identifying overlying skin crevasses 50%; 5–45 s (range)	1 of 1=100%	Not described	No	
Yildiz and colleagues[34]	Palpation *vs* US	Humans; 24 volunteers; mean BMI 23.8 kg m^{-2}, mean age 24 yr	5	5; brief training to detect the CTM	n.a.	66.7%; 8.3 s (7.3–9.1), mean (95% CI)	69.2%; 17 s (15.3–18.7), mean (95% CI)	Parasagittal and transverse scan. Relies on being able to identify initially with palpation	No	The sequence was not randomized
Kristensen and colleagues[35]	Descriptive	Humans; n.a.; n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Longitudinal as described by Kristensen;[18] transverse as in Barbe and colleagues[21]	Yes	
Votruba and colleagues[36]	Descriptive	Humans	n.a.	n.a.	'A hyperechogenic membrane'	n.a.	n.a.	Median or paramedial sagittal view	No	
Stafrace and colleagues[38]	Descriptive, paediatric airway in US	Humans (children)	n.a.	n.a.	n.a.	n.a.	n.a.	Sagittal midline		

guided marking of the cricothyroid membrane is unaffected by changing neck positions (e.g. markings made in the extended-neck position before head manipulation to intubate the trachea accurately identify the cricothyroid membrane also after the intubation attempt when the head and neck are repositioned in extension); and (v) after learning ultrasound-guided techniques, significant retention of skills exists after 6 months.

The studies also give us insight into what type of training is necessary in order to achieve clinically useful success rates in ultrasound-airway-naïve clinicians. We saw success rates in human subjects ranging from 69.2%[34] after 'brief surgical airway anatomy and ultrasonography training' to 100% after 'theoretical airway ultrasonography and 15 min hands-on training'.[21] A 1 h structured lesson that consisted of e-learning, a lecture, and hands-on training resulted in clinically useful 84–90% success in morbidly obese females[11 37] (100% with at least one of two techniques applied).[37]

For some of the described methods, it was a prerequisite that the laryngeal and tracheal structures be identified first with palpation before placement of the ultrasound transducer, whereas other techniques allowed identification of the necessary structures by ultrasound guidance alone without the need for previous clinical identification of laryngeal and tracheal structures. Some studies described their ultrasound technique for identification of the cricothyroid membrane in sufficient detail to allow the method to be reproduced by clinicians, whereas other studies did not. This is summarized in the second column from the right in Table 1.

In order to advocate a clinically useful approach, we reviewed each publication to ascertain whether the ultrasonographic technique described fit the following criteria: (i) could be applied even when tracheal or laryngeal landmarks could not be identified by inspection or palpation alone; (ii) the technique was described in sufficient detail to allow reproduction by other clinicians; (iii) demonstrated a higher success rate than palpation in at least one comparative study; and (iv) published in more than one peer-reviewed indexed publication. Only two techniques fitted the criteria, namely the 'transverse'[20 21 37] and the 'longitudinal'[11 13 18 28 32 37] techniques, and they are outlined in further detail below.

What equipment does one need? Airway ultrasonography can be performed with a standard laptop-sized ultrasound machine. A standard linear high-frequency probe, such as the one most often used for regional anaesthesia and vascular access, will be sufficient.[28]

Performing the transverse technique (for mnemotechnical reasons, we name this the 'TACA' technique ('Thyroid cartilage–Airline–Cricoid cartilage–Airline'))

(i) The transducer is placed transversely on the anterior neck at the estimated level of the thyroid cartilage, and the transducer is moved until the thyroid cartilage is identified as a hyperechoic triangular structure (Fig. 1).

(ii) The transducer is then moved caudally until the cricothyroid membrane is identified; this is recognizable as a hyperechoic white line resulting from the echo of the air–tissue border of the mucosal lining on the inside of the cricothyroid membrane, often with parallel white lines (reverberation artefacts) below.

(iii) The transducer is then moved further caudally until the cricoid cartilage is identified (a 'black lying C' with a white lining).

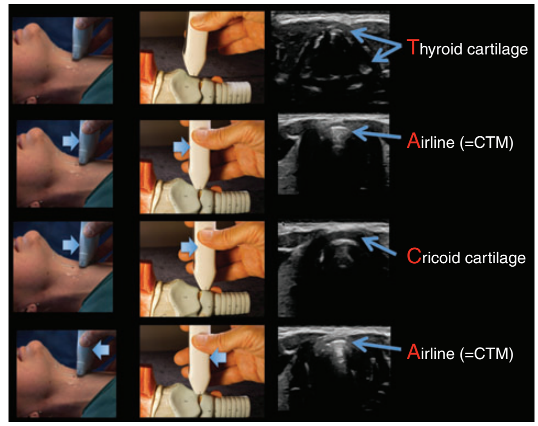

Fig 1 The transverse ('Thyroid cartilage–Airline–Cricoid cartilage–Airline=TACA') method for identification of the cricothyroid membrane. First row: the transducer is placed transversely on the neck where the thyroid cartilage is thought to be until the triangular shape of the thyroid cartilage (=the 'T') is identified. Second row: the transducer is moved caudally until the 'Airline' (=the 'A') is seen; this is the hyperechoic (white) line from the tissue–air border on the luminal side of the cricothyroid membrane. The white line has similar echo lines deep to it; those are reverberation artefacts. Third row: the transducer is moved further caudally until the cricoid cartilage (=the 'C') is seen as a black lying 'C' with a posterior white lining. The white lining represents the tissue–air border on the luminal side of the anterior part of the cricoid cartilage. Forth row: subsequently, the transducer is moved a few millimetres back in the cephalad direction, and the approximate centre of the 'Airline' (=the 'A'=the cricothyroid membrane) is thus identified and can be marked with a pen.

(iv) Finally, the transducer is moved slightly back cephalad until the centre of the cricothyroid membrane is identified.

(v) The location of the cricothyroid membrane can be marked both transversely and sagittally on the skin with a pen. By identifying the highly characteristic shapes of both the thyroid and the cricoid cartilages, both the cephalad and caudal borders of the cricothyroid membrane can be identified.

The technique is demonstrated in this video: http://airwaymanagement.dk/taca.[39]

Performing the longitudinal technique (for mnemotechnical reasons, we name this the 'string of pearls' technique)

(i) The sternal bone is palpated, and the ultrasound transducer is placed transversely on the patient's anterior neck cephalad to the suprasternal notch to see the trachea (horseshoe-shaped dark structure with a posterior white line; Fig. 2).

(ii) The transducer is slid towards the patient's right side (towards the operator), so that the right border of the transducer is positioned over the midline of the trachea, and the ultrasound image of the tracheal ring is thus truncated into half on the screen.

(iii) The right end of the transducer is kept in the midline of the trachea, whilst the left end of the transducer is rotated 90 degrees into the sagittal plane, resulting in a longitudinal scan of the midline of the trachea. A number of dark (hypoechoic) rings will be seen anterior to the white hyperechoic line

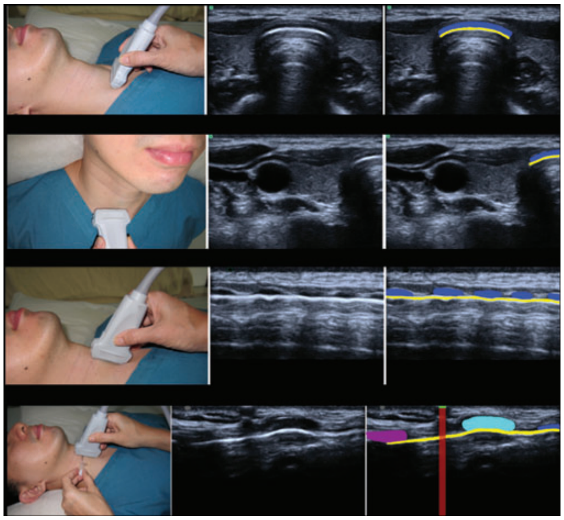

Fig 2 Upper row: step (i) The patient is lying supine, and the operator stands on the patient's right side facing the patient. The sternal bone and the suprasternal notch are palpated, which can be done in even the morbidly obese patient. The linear high-frequency transducer is placed transversely over the neck just cranial to the suprasternal notch, and the trachea is seen in the midline. The middle and the right photographs show the ultrasound image, and the relevant structures are highlighted on the photograph to the right. Blue is the anterior part of a tracheal ring. Yellow indicates the tissue–air boundary inside the trachea. Everything below the tissue–air boundary is artefact. Second row: step (ii) The transducer is slid laterally towards the patient's right side, until the midline of the trachea is at the right border of the transducer, and the corresponding ultrasound image of the trachea (in the right photograph) is truncated into half. Blue is the anterior part of a tracheal ring. Yellows indicate the tissue–air boundary inside the trachea. Third row: step (iii) Staying midline with the right edge of the transducer, the left edge of the transducer is rotated into the sagittal plane to obtain a longitudinal image of the trachea. The anterior parts of the tracheal rings appear as black hypoechoic round structures (like pearls) lying on a strong hyperechoic white line, which is the tissue–air boundary (that looks like a string). Hence, the image is akin to a 'string of pearls'. The blue markings represent the anterior parts of the tracheal rings. Yellow indicates the tissue–air boundary inside the trachea. Fourth row: step (iv) The transducer is slid cephalad, and the anterior part of the cricoid cartilage (turquoise) is seen as a slightly elongated structure that is significantly larger and more anterior than the tracheal rings (blue). Yellow indicates the tissue–air boundary inside the trachea. Immediately cephalad to the cricoid cartilage is the cricothyroid membrane. The distal part of the thyroid cartilage (purple) is seen. Step (v) The cricothyroid membrane can be pointed out by sliding a needle (used only as a marker) underneath the ultrasonography transducer from the cranial end until it casts a shadow (red line) between the cricoid cartilage (turquoise) and the thyroid cartilage. The green spot represents the reflection from the needle. Care is taken not to touch the patient with the sharp tip of the needle. Step (vi) After this, the transducer is removed, and the needle indicates the mid-level of the cricothyroid membrane. This spot can be marked with a pen so that it remains easily identified should it be needed for subsequent difficult airway management. (The figure in the last row is from Kristensen and colleagues).[11]

(air–tissue border), akin to a 'string of pearls'. The dark hypoechoic 'pearls' are the anterior part of the tracheal rings.

(iv) The transducer is kept longitudinally in the midline and slid cephalad until the cricoid cartilage comes into view (seen as a larger, more elongated and anteriorly placed dark 'pearl' compared with the tracheal rings). Further cephalad, the distal part of the thyroid cartilage can also be seen.

(v) Whilst still holding the ultrasound transducer with the right hand, the left hand is used to slide a needle (as a marker, for its ability to cast a shadow in the ultrasound image) between the transducer and the patient's skin until the needle's shadow is seen midway between the caudal border of the thyroid cartilage and the cephalad border of the cricoid cartilage.

(vi) Now the transducer is removed; the needle marks the centre of the cricothyroid membrane in the transverse plane, and this can be marked on the skin with a pen.

The technique is demonstrated on this video: http://airwaymanagement.dk/pearls.[40]

Each of these two techniques functions well individually and has its own advantages.[21 37] For example, not all patients have enough space in the neck to apply the ultrasound transducer in a longitudinal mid-sagittal position (e.g. short neck or severe neck flexion deformity). Here, the transverse technique will be the saviour of the day, and it is the faster of the two techniques. The longitudinal technique, in contrast, can reveal additional information compared with the transverse technique (i.e. the localization of the cricotracheal interspace and of the tracheal interspaces). Apart from the ability to identify overlying blood vessels and direct the clinician to choose another tracheal interspace for elective tracheostomy or retrograde intubation,[41] the longitudinal technique is useful in airway rescue situations where emergency access via the trachea would be needed instead of access via the cricothyroid membrane (e.g. in smaller children,[42 43] in patients with tumours overlying the cricothyroid membrane, and if subglottic obstruction occurs). We recommend that clinicians learn and be proficient in both the transverse and longitudinal techniques because each ultrasound technique can address the other's shortcomings and supplement each other synergistically when used in tandem to be a powerful bedside point-of-care tool.

Clinical impact

Before initiating airway management, the potential ease or difficulty of performing cricothyrotomy[5] and tracheostomy[2] should be evaluated, and an attempt should be made to identify the cricothyroid membrane.[3 44 45] The pre-anaesthetic identification of potentially difficult or even impossible cricothyroid membrane access may direct the clinician towards a more conservative approach, such as awake intubation or awake elective tracheostomy under local anaesthesia. Ultrasound-guided cricothyrotomy may result in significantly less tracheal damage[32] and higher success rates, and ultrasonography should preferably be used to identify the cricothyroid membrane before commencing any airway management, instead of waiting until an emergency airway crisis situation arises.[32]

Based on the recommendations above and the findings discussed in this paper, we recommend the following approach. The cricothyroid membrane should be identified in all patients before induction of anaesthesia and in all patients with airway compromise if time allows. The initial approach is inspection. Just by looking for the creases on the anterior neck, the cricothyroid membrane can be identified rapidly in approximately half of patients.[33] If inspection fails, then palpation should be performed, and if this also fails or any doubt exists, then ultrasonographic identification should be performed. All anaesthesia departments or anaesthesia services should aim at being able to deliver this service. The cricothyroid membrane should also be identified before extubation of a difficult airway so that it is available for emergency airway access in case of a failed extubation with subsequent difficult reintubation.

In emergency airway management, time is of utmost importance. However, urgency is relative, and in an impending (incomplete or partial) or progressive airway obstruction, there is a time window for meaningful interventions, such as optimized pre-oxygenation, collation of equipment, and formulation of a plan for airway management, including a plan for failure. In the NAP4[7] study, in at least 18 of 58 patients where a surgical airway was attempted after failed intubation, it was still possible to ventilate by face mask or by a supraglottic airway device, and in such patients there will be sufficient time for performing ultrasonography for identification of the cricothyroid membrane, in tandem with other preparations and attempts at maximizing pre-oxygenation, provided that the clinician is proficient in its use and that an ultrasound machine is readily available.

Authors' contributions

Study design, protocol conceptualization and literature selection: M.S.K., W.H.T.
Literature search: M.S.K.
Writing of the manuscript: M.S.K., W.H.T., S.S.R.

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