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Original Article

A randomised cross-over comparison of the transverse and longitudinal techniques for ultrasound-guided identification of the cricothyroid membrane in morbidly obese subjects

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Summary

We compared the transverse and longitudinal approaches to ultrasound-guided identification of the cricothyroid membrane, to determine which was faster and more successful. Forty-two anaesthetists received a one-hour structured training programme consisting of e-learning, a lecture and hands-on training, and then applied both techniques in a randomised, cross-over sequence to obese females with body mass index 39.0 – 43.9 $kg.m^{-2}$. The mean (SD) time to identify the cricothyroid membrane was 24.0 (12.4) s using the transverse technique compared with 37.6 (17.9) s for the longitudinal technique ($p = 0.0003$). Successful identification of the cricothyroid membrane was achieved by 38 (90%) anaesthetists using either technique. All anaesthetists were successful in identifying the cricothyroid membrane with at least one of the techniques. We advocate the learning and application of these two techniques for identification of the cricothyroid membrane before starting anaesthesia in difficult patients, especially when anatomical landmarks are impalpable. Further use in emergency situations is feasible, if clinicians have experience and the ultrasound machine is readily available.

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Introduction

The cricothyroid membrane is the final route of access to the airway in case of failure of other airway management methods. Despite its key role in airway management, the success rate for anaesthetists in identifying the cricothyroid membrane with standard inspection and palpation is notoriously low, especially in obese patients, where success rates are reported between 0 and 39% [1–4]. The success rate of emergency airway access via the cricothyroid membrane by anaesthetists is also very poor [5], and the failure of identification of the cricothyroid membrane is likely to be an important contributor to this [6].

Several studies have described the use of ultrasonography for identification of the cricothyroid membrane with different techniques [1–4, 7–13]. However, in the majority of these studies, ultrasonography was performed exclusively by one or two practitioners [1, 3, 4, 9, 10, 13]. Two different techniques for ultrasound-guided identification of the cricothyroid membrane have been described in sufficient detail to allow for reproduction; these are the transverse and the longitudinal methods.

The transverse technique was described by De Oliveira et al. [14] and was compared with palpation by Barbe et al. [8]. It involves placing the ultrasound transducer transversely on the anterior neck followed by identification of the thyroid cartilage, with its characteristic 'inverted-V'-shape [8, 14], and then inferiorly the cricoid cartilage with a hypo-echoic (dark), 'arch-like'- [14] or 'horseshoe-like' appearance. In between these cartilages, the cricothyroid membrane is identified as a hyperechoic (white) line resulting from the air-tissue border on the luminal side of the cricothyroid membrane.

The longitudinal technique was described by Kristensen et al. [11, 15] and has subsequently been applied in two controlled studies that compared the ultrasound-guided technique with palpation in humans [2] and cadavers [12], and in one study as a reference/gold-standard method [4]. It relies on the systematic step-wise identification of the anterior parts of the tracheal rings and of the cricoid and thyroid cartilages in the longitudinal mid-sagittal plane, preceded by identification of the centre of the trachea by placing the transducer transversely on the neck just cephalad to the sternum [11, 15].

Both techniques significantly increase the success rate of identifying the cricothyroid membrane as compared with palpation. With the longitudinal technique, it took a median 48 s in morbidly obese individuals to correctly identify the cricothyroid membrane [2]. For this reason, the technique is mainly recommended to identify the cricothyroid membrane before initiation of airway management [16]. Due to large differences between the studies regarding the subjects, the participants and their training, no valid comparison between these two methods can be performed regarding success rate or time to identification of the cricothyroid membrane. It would be attractive to have a technique that allows identification of the cricothyroid membrane that is fast enough to be applied in the emergency situation, and that can be learnt by ultrasound-naïve anaesthetists following a brief structured training programme. Furthermore, not all patients have necks amenable to longitudinal placement of the ultrasound transducer, for example those with severe neck flexion deformity from ankylosing spondylitis or radiation fibrosis, and a different but complementary approach is needed.

The aim of this study was to compare the transverse and longitudinal techniques in a group of anaesthetists who had followed a brief structured training programme. The hypothesis was that the transverse technique is faster than the longitudinal technique. The primary outcome was the time to identification of the cricothyroid membrane, with a secondary outcome of success rate for identification. We also wished to determine whether some subjects were not amenable to identification of the cricothyroid membrane using either technique.

Methods

This study was approved by the Ethics Committee for the Capital region of Denmark. All participating anaesthetists and subjects gave their written informed consent. The study population consisted of clinically active medically-qualified anaesthetists, either certified or in training (Table 1). The study was conducted at the Department of Anaesthesia, Centre of Head and Orthopaedics, Rigshospitalet, University Hospital of Copenhagen, Denmark between 26 November 2015 and 26 December 2015.

Both techniques were performed with the anaesthetist standing on the right-hand side of the subject, who was positioned supine with the neck extended.

The transverse-'TACA' technique involves placing the ultrasound transducer transversely on the anterior neck followed by identification of the following structures:

- 'T': thyroid cartilage, with a characteristic triangular shape.
- 'A': 'airline' at the cricothyroid membrane, recognisable by a hyperechoic white line resulting from reflection at the air-tissue border of the mucosal

Table 1 Characteristics of 42 anaesthetists who performed ultrasound investigations. Values are mean (SD) or number (proportion).

Personal and educational characteristics		95% CI
Age; years	38.7 (6.8)	
Years since graduation as a physician	12.3 (6.1)	
Years working in clinical anaesthesia	9.5 (5.5)	
Educational background		
Certified	32 (76%)	61–88
In training	10 (24%)	12–39
Prior experience with ultrasonography		
Uses ultrasonography every day	14 (33%)	20–50
Uses ultrasonography every week	23 (55%)	39–70
Uses ultrasonography every month	4 (9.5%)	2.7–23
Uses ultrasonography less than every month	1 (2.4%)	0.1–13
Has used ultrasonography for airway management before the study	2 (5%)	1–16
Has never used ultrasonography for airway management before the study	40 (95%)	84–99
Availability of an ultrasound machine in daily practice		
Yes, always	36 (86%)	71–95
Yes, but limited	6 (14%)	5–29
No	0	0.0–8.4

lining on the inside of the cricothyroid membrane, often with deeper parallel white lines from reverberation artefact.

- 'C': cricoid cartilage, resembling a black horseshoe with a white lining.

The technique is performed as follows (Fig. 1):

1) The transducer is placed transversely on the anterior neck where the thyroid cartilage is thought to be, and the transducer is moved until the thyroid cartilage is identified.
2) The transducer is slid caudally until the cricothyroid membrane is identified.
3) The transducer is slid further caudally until the cricoid cartilage is identified.
4) The transducer is moved back cranially until the centre of the cricothyroid membrane is located; this is marked on the skin with a pen.

The technique is demonstrated on video at http://airwaymanagement.dk/taca [17].

We call the longitudinal technique the 'string of pearls' technique because it relies on the recognition of the sagittal midline of the anterior part of the tracheal rings and the cricoid cartilage as a row of hypo-echoic (dark) rings, resembling pearls, that will be seen superficial to the white, hyper-echoic, air-tissue border.

The technique is performed as follows (Fig. 2):

1) The transducer is placed transversely on the neck, cranial to the suprasternal notch, to view a tracheal ring recognised as a horseshoe-shaped dark structure with a posterior white line.
2) The transducer is slid towards the operator until the edge of the transducer is at the midline of the trachea.
3) The free end of the transducer is rotated 90° degrees and slid cephalad until the cricoid and thyroid cartilages come into view.
4) The left hand is used to slide a needle horizontally *between* the transducer and the skin until its shadow is seen midway between the caudal border of the thyroid cartilage and the cephalad border of the cricoid cartilage. The centre of the cricothyroid membrane is identified; in the clinical setting this can be marked on the skin with a pen.

The technique is demonstrated on video at http://airwaymanagement.dk/pearls [18].

Before the study, the anaesthetists were given training in the two methods as follows:

(i) A 20-min online e-learning programme consisting of demonstrations of ultrasonographic anatomy of the larynx and trachea, and the identification of the cricothyroid membrane with the transverse and the longitudinal techniques.
(ii) A didactic 30-min lecture (including videos) on ultrasonography in airway management, with special emphasis on the identification of the cricothyroid membrane using both techniques.

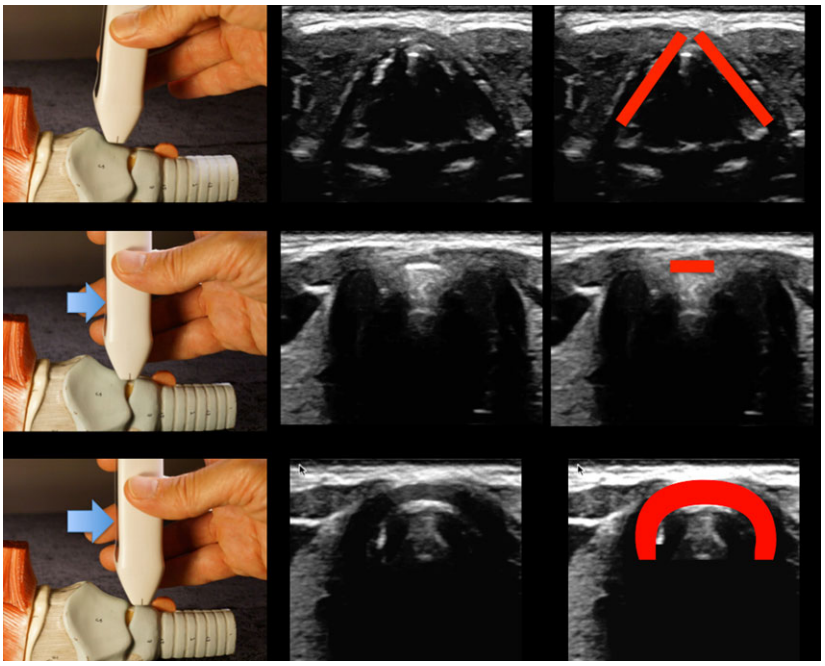

Figure 1 The transverse ('TACA') technique for identification of the cricothyroid membrane. Top row: the transducer is placed transversely on the upper neck until the triangular shape of the thyroid cartilage ('T') is seen (highlighted in red on the right). Middle row: the transducer is slid caudally until the airline ('A') is seen, which is the air/tissue border of the mucosal lining on the luminal side of the cricothyroid membrane. Bottom row: the transducer is slid caudally until the cricoid cartilage ('C') is seen as a black horseshoe with a posterior white lining, arising from the air/tissue border on the luminal side of the cricoid cartilage.

(iii) Hands-on training for 10 min, where the anaesthetists trained and practiced both techniques in slender and obese females, guided and supervised by an airway ultrasound specialist.

Each anaesthetist performed the ultrasonic identification of the cricothyroid membrane on one of two obese female subjects, who did not have any other neck pathology (subject A: 48 years, 188 cm, 138 kg, body mass index (BMI) 39.0 $kg.m^{-2}$; subject B: 57 years, 166 cm, 121 kg, BMI 43.9 $kg.m^{-2}$).

The ultrasound machines used for the training and testing were LOGIQ P9 (General Electrics; GE Medical Systems Information Technologies GmbH, Freiburg, Germany) with a 12L-RS high-frequency linear transducer, put on 'thyroid' setting. The participating anaesthetists all performed ultrasound-guided identification of the cricothyroid membrane with both methods. The sequence of methods was randomly assigned according to a computer-generated random number sequence; the allocated group was placed in an opaque envelope by a secretary who was not otherwise involved in the study. The randomisation envelope was opened immediately before the test, and the anaesthetist started with the allocated technique and subsequently switched to the other technique.

The timing of each procedure was started when the ultrasound transducer touched the skin and stopped when the anaesthetist stated "here", indicating that the cricothyroid membrane had been identified. At this point, one of two experts in airway ultrasonography who had been observing the procedure examined the ultrasound image, and judged whether this was accurate or not. An attempt was also considered to have failed if it lasted for > 120 s.

All tests were recorded on a high-definition video capture system. The video files were later examined by an expert in airway ultrasonography, and the exact result and timing of all attempts were thus verified from the videos. In case of disagreement between the initial judgement and the result obtained from the video recording, the latter was used. The video recordings were preserved for future documentation.

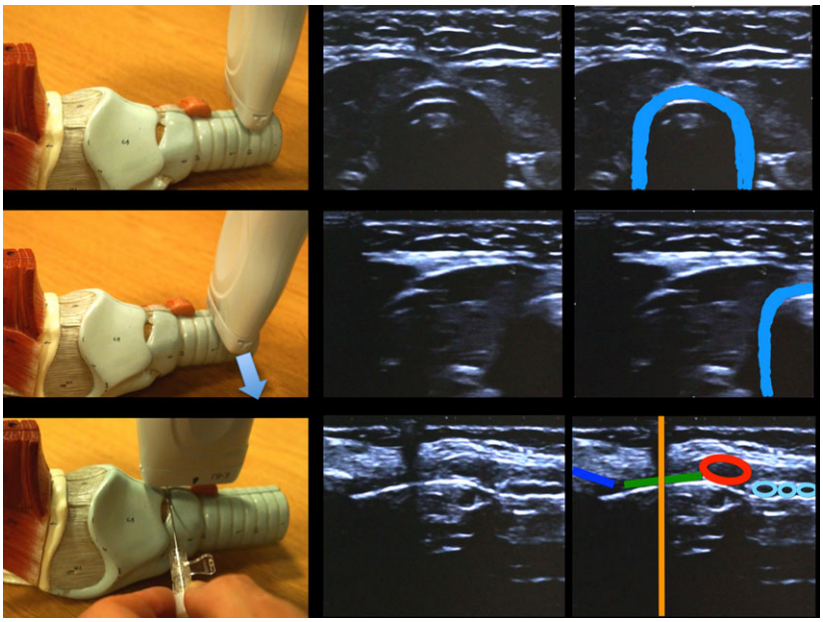

Figure 2 The longitudinal ('string of pearls') technique for identification of the cricothyroid membrane. Top row: The ultrasound transducer is placed transversely on the anterior neck cephalad to the suprasternal notch; a tracheal ring is recognised as a horseshoe-shaped dark structure with a posterior white line (highlighted in blue horseshoe on the right). Middle row: the transducer is slid to the patient's right side towards the operator until the ultrasound image of the tracheal ring is truncated in half on the screen; at this point the border of the transducer is at the midline of the trachea. Bottom row: the free end of the transducer is rotated 90° degrees into the sagittal plane and the transducer is slid cephalad. A series of hypo-echoic rings ('string of pearls') are seen superficial to the hyper-echoic air-tissue border. On the right-hand side image, the anterior part of the cricoid cartilage appears as an elongated ring (red) that is significantly larger and more anterior than the tracheal rings (light blue); the cricothyroid membrane is green and the thyroid cartilage is dark blue. The acoustic shadow from a needle placed on the skin is seen as an orange line.

On the basis of a mean (SD) 55.4 (24.1) s to locate the cricothyroid membrane [2], we calculated that 40 anaesthetists were needed to detect a one-third difference in time to identification of the cricothyroid membrane, with a power of 90% and a significance level of $p < 0.05$ [19]. We decided to include 45 anaesthetists in case of drop-outs. The time it took to perform the procedures was compared using the unpaired Student's t-test. The success rates between the subjects were compared using the two-tailed Fisher's exact test.

Results

Forty-two anaesthetists participated in the study. The characteristics of the participating anaesthetists are described in Table 1. Figure 3 shows the CONSORT diagram of study recruitment. One anaesthetist erroneously started with the longitudinal technique first, despite being allocated to start with the transverse technique, but was kept in the transverse-first group for further analysis. In 81 (96%) of the examinations, there was agreement between the initial judgement by the observer and the expert review of the video recording. In the three cases where there was disagreement, the decision of the expert reviewer was used.

The transverse technique was faster than the longitudinal technique in identifying the cricothyroid membrane, with a mean (SD) of 24.0 (12.4) s vs 37.6 (17.9) s, respectively ($p = 0.0003$). Successful identification of the cricothyroid membrane with the transverse and the longitudinal method was achieved by 38 (90%) of anaesthetists using each technique. All anaesthetists were successful in identifying the cricothyroid membrane with at least one of the techniques.

Twenty anaesthetists performed the examinations on subject A and 22 on subject B.

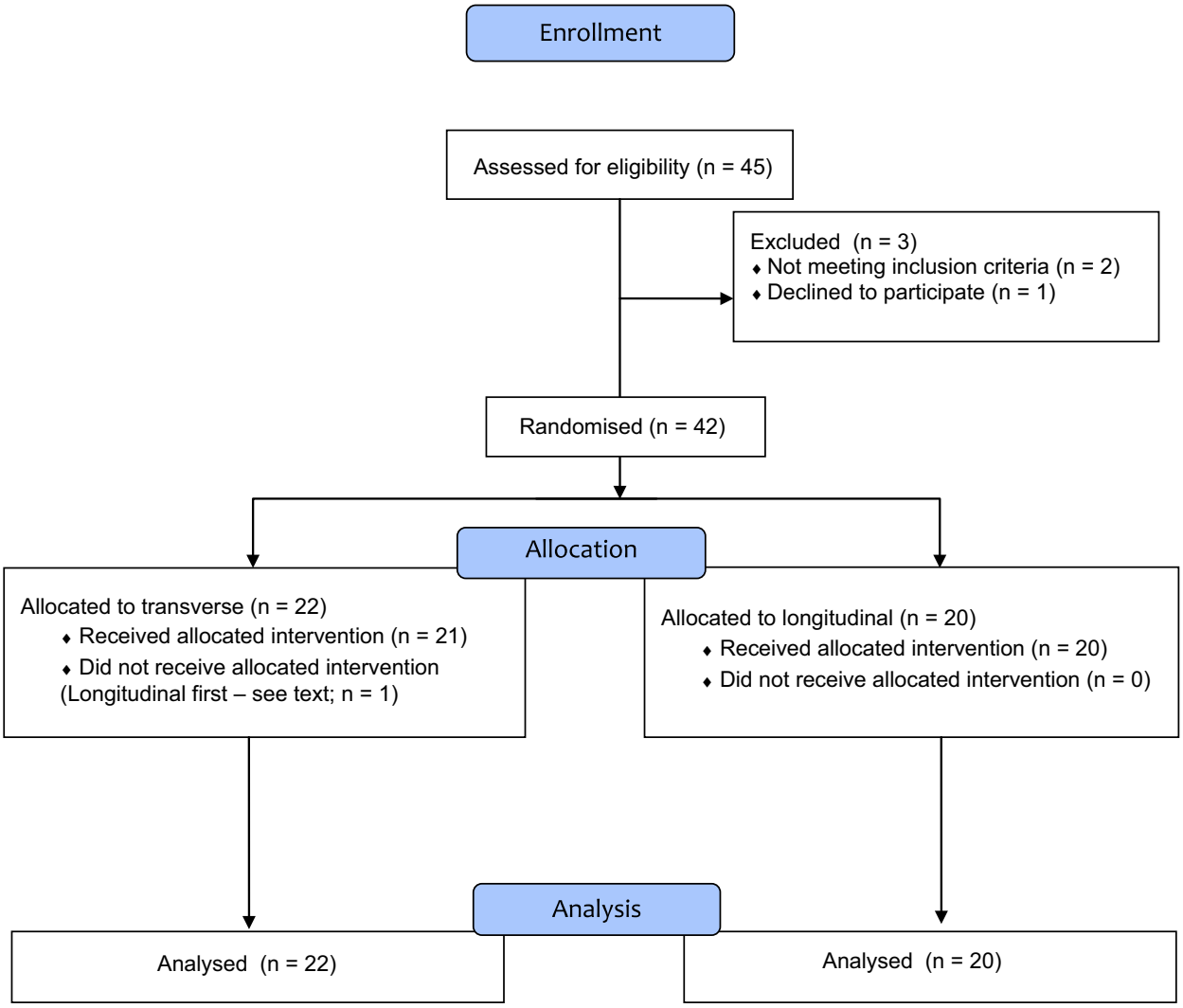

Figure 3 CONSORT diagram of recruitment.

Successful identification was obtained with the transverse technique in 16 (80%) and in 22 (100%) in subject A and B, respectively (p = 0.04). Success with the longitudinal technique was obtained in 19 (95%) and 19 (86%) attempts in subject A and B, respectively (p = 0.61). Time to successful identification with the transverse technique was 19.7 (11.2) s and 27.1 (12.1) s in subject A and B respectively (p = 0.07) and with the longitudinal technique it was 32.9 (16.0) s and 42.2 (17.9) s, respectively (p = 0.11).

The four failures with the transverse technique were all due to incorrect identification, whereas three of the four failed attempts with the longitudinal technique were due to the 120-s time limit being exceeded, and one was due to incorrect identification.

Almost all anaesthetists had never used ultrasonography for airway management before the study; the remaining two had used it sporadically but had had no formal education in, or clinical experience with, any of the two techniques studied (Table 1).

Discussion

The main findings of this study are that both transverse and longitudinal techniques identified the cricothyroid membrane with high accuracy, and that each anaesthetist was successful with at least one of the techniques. Although both techniques were equally accurate, the transverse technique was significantly faster than the longitudinal technique.

Several previous studies had found that identification of the cricothyroid membrane by the traditional palpation method in the obese had an accuracy of < 40% [1–4]. We have previously found that the longitudinal technique, developed as part of a structured step-wise teaching programme, was more accurate than palpation (87% vs 37%) in a randomised controlled study [2]. This present study provides further confirmation that success using ultrasound guidance far exceeds published results using clinical assessment, and reveals that the transverse technique is as accurate as the longitudinal technique. This opens the possibility of using ultrasound-guided identification of the cricothyroid membrane in cases where there is not enough space on the neck for longitudinal placement of the transducer, as in patients with short necks or severe neck flexion deformity. The speed of identification obtained with the transverse technique suggests that it might be useful not only for elective use before starting anaesthesia but also in emergency airway management.

In the majority of studies on cricothyroid membrane identification with ultrasonography, only one or two practitioners performed the scans [1, 3, 4, 9, 10, 13], which might provide bias in favour of the ultrasound technique [4]. These studies reveal close to 100% success with ultrasonography and demonstrate the potential of the technique; however, they leave unanswered questions regarding how it could be expanded to larger groups of anaesthetists, and what kind of structured training is required to attain a clinically useful performance level by all, including ultrasound-naïve anaesthetists.

Although cadaveric ultrasonographic studies [12, 13] reveal useful information on sono-anatomy and performance of invasive procedures, clinicians utilising cadavers alone are still not able to appreciate the real-time challenges of laboured respiratory movements, which makes airway ultrasonography a particular challenge [20] in patients with difficult airways. In addition, cadavers have altered tissue handling characteristics [12].

A group of 23 lean residents and physicians performed ultrasound-guided identification of the cricothyroid membrane on each other followed by manipulation of the head to simulate intubation. When the head was subsequently placed back in the premanipulation position, the marking of the cricothyroid membrane was still where the cricothyroid membrane was actually located [7]. This supports the concept of identifying the cricothyroid membrane before initiating airway management.

There is one paper in the non-English literature that reports a transverse ultrasonographic approach in a small series with 12 participants. They found ultrasonography more successful than palpation for identification of the cricothyroid membrane, and found the average time to identification to be 21 – 28 s [8]. The subjects examined were only moderately overweight with a mean BMI of 32.6 $kg.m^{-2}$, and the sequence of palpation and ultrasonography was not randomised [8].

We believe that the present study design have some strengths compared with previous studies.

We used direct observation of the ultrasound image, both real time and on the high-definition video recording, to observe if the anaesthetist had correctly identified the cricothyroid membrane. The alternative approach would have been to mark the borders of the cricothyroid membrane with invisible ink before the identification attempts, but this would have carried the inherent risk that the models could have altered their neck extension between the time of marking and performance of the test. The sequence of testing was randomised so that a learning effect, if present, would not favour either of the techniques. Finally, ultrasound identification was performed by a large group of anaesthetists, and not just by one or a few experts. By giving the anaesthetists a structured and standardised training programme, followed by testing, we obtained an indication of the generalisable skill of ultrasound-guided techniques.

The longitudinal technique reveals additional information compared with the transverse technique, i.e. the localisation of the midline of the trachea, the cricotracheal interspace and the tracheal interspaces. This is useful in airway rescue situations where emergency access via the trachea would be needed, instead of access via the cricothyroid membrane (for example in smaller children [21, 22], patients with tumours overlying the cricothyroid membrane and cases of subglottic obstruction), and for elective tracheostomy or retrograde intubation [23].

As preparation for airway management, we must evaluate the potential ease or difficulty in performing tracheostomy [24] and/or cricothyroidotomy [25], and we should preferably identify the cricothyroid membrane before initiation of airway management [16, 26, 27]; if this is not possible by inspection and palpation alone, then ultrasonography is a useful [25, 27] or even essential [26] adjunct. The concept of pre-induction ultrasonographic identification of the trachea [28] or cricothyroid membrane [29], in cases where these structures could not be identified due to obesity or focal pathology, has shown its usefulness in clinical practice.

Furthermore, a pre-induction attempt to identify the cricothyroid membrane has an advantage even if it fails; the knowledge that cricothyroidotomy is likely to be difficult or even impossible may direct subsequent airway management in a more conservative direction, for example towards awake intubation or awake elective tracheostomy under local anaesthesia.

In elective cases, the time difference between the transverse and the longitudinal methods is less relevant, and the individual anaesthetist can apply his or her preferred technique at will. However, even in elective cases, it is important to have knowledge of both approaches to assure the highest chance of success. In the emergency situation, it seems justified to use the transverse technique as an initial step before attempting cricothyroidotomy in cases where no anatomical landmarks are palpable, and an ultrasound machine is already turned on and immediately available.

When the anatomical landmarks are difficult to palpate, there is the possibility of making a vertical incision down to the level of the cartilages, and from there on identify the cricothyroid membrane with palpation, before accessing the cricothyroid membrane [16, 27]. However, this approach also demands some degree of identification of the airway to know where to place the initial incision, and in a model simulating a patient with unidentifiable anterior neck anatomy, ultrasonography was more successful than palpation [30].

In conclusion, the cricothyroid membrane could be identified with at least one of the two techniques by all anaesthetists in our study. We recommend that these techniques be mastered by anaesthetists and put into clinical use before initiation of anaesthesia and airway management, in elective cases, where the cricothyroid membrane cannot be identified with inspection and palpation alone. Furthermore, we found the transverse technique to be sufficiently fast at a mean of 24 s, and reliable with 90% successes, to justify its use when the need for airway access via the front-of-neck is already established and landmarks cannot be identified with inspection or palpation, provided that the physician is experienced in its use and an ultrasound machine is readily available.

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Competing interest

No external funding and no competing interests declared.

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