this approach has brought. However, what is lacking so far in the videolaryngoscope industry is the ability of the device itself to capture and analyse key data on laryngoscopy and intubation, and to incorporate this into the electronic health record. Such a development would transform the laryngoscope from a device into a service and provide a vast wealth of information on intubation performance. If robotic or robotically assisted tracheal intubation becomes a reality, validation of its performance will rely on automated collection of such data.[15]

Meanwhile, the construction of databases such as the PeDI-R requires considerable collaboration and effort to develop and maintain, and it is often some time before the rewards may be seen. The authors and colleagues in Peyton's group deserve our recognition and thanks for their work to date and in future.

Authors' contributions

Review of literature: AN
Writing, editing, and submission of manuscript: AN
Review, drafting, revision of the manuscript: JA

Declarations of interest

The authors declare that they have no conflict of interests.

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British Journal of Anaesthesia, 126 (1): 22–27 (2021)
doi: 10.1016/j.bja.2020.10.004
Advance Access Publication Date: 31 October 2020

Ultrasound identification of the cricothyroid membrane: the new standard in preparing for front-of-neck airway access

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DOI of original article: 10.1016/j.bja.2020.08.012.

This editorial accompanies: Comparison between ultrasound-guided and digital palpation techniques for identification of the cricothyroid membrane: a meta-analysis by Hung et al., *Br J Anaesth* 2021:126:e9–e11, doi: 10.1016/j.bja.2020.08.012

Keywords: airway management; cricothyrotomy; emergency front-of-neck airway access; palpation; ultrasonography

Cricothyrotomy is an essential procedure that is rarely used. It has a reported 64% failure rate by anaesthesiologists,[1] frequently associated with tube/device misplacement[1,2] or failure to identify the cricothyroid membrane.[3] In this issue of the *British Journal of Anaesthesia*, Hung and colleagues[4] present a new meta-analysis confirming that palpation alone is associated with an unacceptably high failure rate and that ultrasonography is more successful than palpation in leading the clinician to identification of the cricothyroid membrane, and thus the position of the midline of the airway in the neck. In all studies in the meta-analysis involving adults, ultrasonography had a higher success rate of correct identification of the cricothyroid membrane, and the pooled relative risk of failure was 0.50 (95% confidence interval [CI]: 0.33–0.76; P=0.001), indicating an overall important and significant superiority of ultrasound guidance over that of digital palpation techniques. When we combine these results with those of a previous review of ultrasonographic identification of the cricothyroid membrane,[5] which showed that in studies where one investigator performed all the scans, the success rate invariably reached 100%, we can conclude that ultrasonographic identification is superior to palpation and that, with sufficient training and practice, failure is rare. Although it did not reach statistical significance, the time taken with ultrasonography was longer in all but one of the studies, with a pooled weighted difference of 22 s.[4]

So, how do we deal with this dilemma? We have one technique (palpation) that is not sufficiently precise, but faster when it works, and another technique (ultrasound guidance) that is more precise, but on average takes longer.

An obvious solution is to identify the location of the cricothyroid membrane *before* the need for it arises as a part of the airway evaluation. Does this always have to be with ultrasonography? No! In many slim subjects without airway pathology, it is sufficient just to *look* at the neck and see if the larynx, trachea, and relevant skin creases are easily visible. If looking is not enougthen palpation,[4] possibly including the 'laryngeal handshake', will often be sufficient. However, if identification dubious or impossible, as is often the case in obese patients and patients with airway/neck pathology, then ultrasonography should be used, and the cricothyroid membrane should be marked on the patient with the neck extended. Concomittantly, patients with obesity or with airway/neck pathology are exactly the ones in whom we more often encounter serious airway problems,[1] including the need for emergency front-of-neck airway access. The relevance of having a special focus on these patient categories is confirmed by the meta-analysis:[4] studies that included either morbidly obese patients[6] or patients/cadavers with verified pathology of the neck[7,8] showed greater success with ultrasonography than with palpation, whereas studies with lean subjects without pathology showed less or insignificant differences between ultrasonography and palpation. One of the studies involved not only identification of the cricothyroid membrane, but also subsequent cricothyrotomy on cadavers.[8] In the subgroup of cadavers with a difficult-to-palpate airway, there was a highly significantly higher rate of success of cricothyrotomy when using ultrasonography, and less injury (33% *vs* 100%) to the larynx and trachea.[8]

Is it really necessary to identify the cricothyroid membrane?

Why not just make a sufficiently deep and long sagittal cut in the anterior neck, down to cartilage, to access the cricothyroid membrane? We contend that the answer is NO! It has been suggested that in case one cannot readily identify the cricothyroid membrane, one should make an 8–10 cm vertical incision, caudal to cephalad,[9] but this will not always solve the problems and may even create new ones. Three important reasons are outlined as follows.

(i) It may not be possible to identify the *midline* with palpation alone, and if an incision is made to the side of the airway, airway cartilages will be missed, but not the blood vessels running parallel to the airway. In 20 of 109 patients with airway pathology, the sagittal midline of the airway (at the level of the cricothyroid membrane) was misidentified by 1.5–2.3 cm laterally when identified by palpation.[7] This represents a serious risk of cutting into a major blood vessel if one performs a sagittal cut in what is perceived as the midline of the airway, but is not. When applying ultrasonography for identification of the cricothyroid membrane and the trachea, 100% of identifications were within 10 mm of the true midline.[7]

(ii) Even if the midline is identified, there will often be large blood vessels in front of the trachea. Of patients subjected to CT, 53% had a major blood vessel, most commonly the brachiocephalic artery, anterior to the trachea in the suprasternal notch. At 10, 20, and 30 mm above the suprasternal notch, 126 (25%), 48 (9%), and 5 (1%) of scans, respectively, revealed a major vessel anterior to the trachea,[10] which may result in bleeding[11] and severe morbidity and mortality when front-of-neck airway access is attempted.[12] Increased length of trachea above the manubrium is a strong predictor of major vessels being located anterior to the trachea.[10] In 500 consecutive patients, there were no major blood vessels in front of the cricothyroid membrane itself. When the 'string of pearls'[5,13] technique for identification and marking of the cricothyroid membrane is used, potentially dangerous major blood vessels are inherently identified[14] (Fig. 1).

(iii) Even if we manage to identify the midline of the airway and an 8-cm-long vertical incision is made from 3 cm

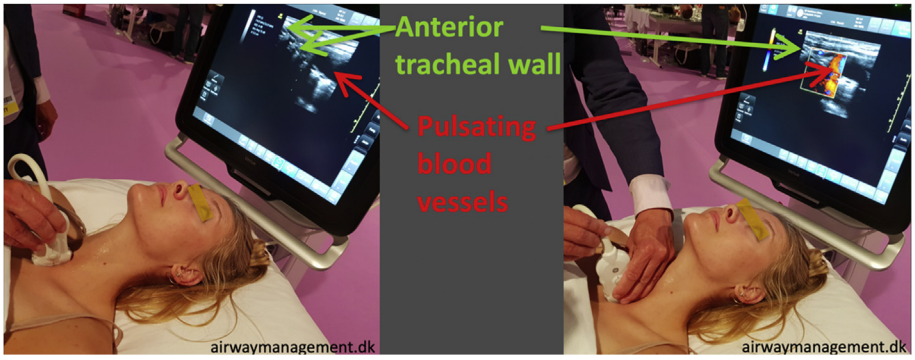

Fig 1. Left: longitudinal ultrasound scan of the neck as part of a routine scan to identify the cricothyroid membrane with the "String of pearls" method. The transducer is in the sagittal midline over the caudal part of the trachea. The anterior part of the tracheal rings are seen as "dark pearls on a white string". A large pulsating blood-vessel is seen superficial to the midline of the caudal part of the trachea. Right: same view but with colour – Doppler that shows pulsation in the artery. A video is available here: https://airwaymanagement.dk/pulsating_vessels. Photos with permission from the Scandinavian Airway management course, www.airwaymanagement.dk.

above the supra-sternal notch,[15] it may not identify the cricothyroid membrane that will be located caudal to that level in a significant number of cases.[10]

These three factors combined make it attractive to identify the exact position of the cricothyroid membrane *before* airway management in patients where inspection or palpation is not straightforward so that a long vertical incision becomes unnecessary if a front-of-neck airway access is suddenly needed.

Will marking the cricothyroid membrane still be in the right place if needed later?

When the midpoint of the cricothyroid membrane is marked in the neutral position and the neck is subsequently extended into the position recommended for cricothyrotomy, the marking will move in the sagittal plane and no longer be over the cricothyroid membrane in many subjects.[16] This led the authors to recommend that marking the skin in preparation for cricothyrotomy should be performed with the neck extended. However, a crucial question is, 'If we mark the cricothyroid membrane *before* induction of anaesthesia and then move/manipulate the head and neck, or the whole patient, and then reposition the patient back to the position, in which the original marking was performed, will the marking be in the original correct position?'.

This was first studied in a predominantly male population[17]: the cricothyroid membrane was identified with ultrasonography before a simulated failed intubation, including cricoid pressure, flexion, extension, and rotation of the subject's neck. After simulated intubation, the membrane was again identified and the midpoint was found to be displaced less than 1.7 mm in any direction.[17] This finding was recently confirmed in a population of female subjects who had their cricothyroid membrane identified in the extended-neck position, and then moved off the operating table.[18] Subsequently, the subject was returned to the operating table and to the extended-neck position. The location of the cricothyroid membrane was again identified with ultrasonography and the new position was compared with the initial position by two methods: (i) comparing the before and after distance from the jugular notch and (ii) comparing the initial marking of the borders of the cricothyroid membrane. The new marking was within 2 mm of the initial marking in all subjects. Combining the results from the two studies reveals that the marking returned to the correct position in all 34 cases.[18]

Becoming competent at identifying the cricothyroid membrane and midline of the airway with ultrasonography

In five of the eight studies in the meta-analysis,[4] the method for ultrasound-guided identification used was the longitudinal string of pearls technique described in 2011[5,13] (Fig. 2), and in two of these five studies, it was supplemented by the transverse thyroid–airline–cricoid–airline (TACA) approach.[19] These techniques, individually or combined, can be applied in patients, where the cricothyroid membrane is not visible or palpable as preparation for possible scalpel or needle cricothyrotomy.[20] A video demonstrating this is available[20] (https://airwaymanagement.dk/ultrasound_needle_cricothyrotomy). The *ultrasonographic approach* seems to be best learned by adopting a structured stepwise technique,[6] preferably combined with a structured learning programme and supervised practice.

Oliveira and colleagues[21] subjected anaesthesia trainees to a 2 h training programme consisting of reading the original paper describing the longitudinal string of pearls technique,[13] an educational video, and a slide presentation and supervised hands-on training with one-to-one feedback. Subsequently, each trainee performed consecutive supervised scans on 20 subjects with moderate-to-difficult neck landmarks. The group reached an overall 88% success rate in identification, and amongst the two-thirds who reached the predetermined confidence level, the success rate was 94%. Repeat testing after 3 months revealed a mean success rate of 87%, which was considered reasonable competence. The authors concluded that, 'The learning curve seems to be short and most anaesthesia residents achieved confidence in less than 20 scans and performed successful identification in less than 60 s'. A 1 h

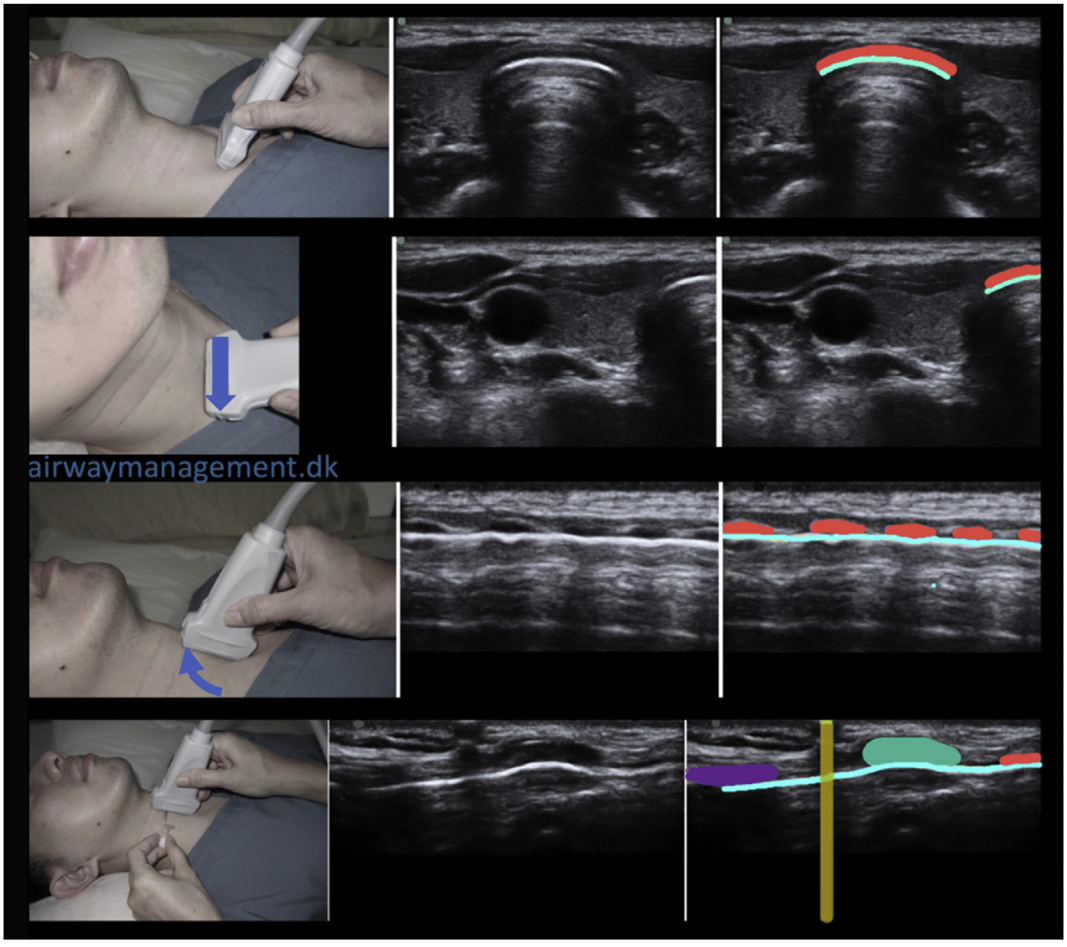

Fig 2. The longitudinal ''String of Pearls'' technique for identifying the cricothyroid membrane, the midline of the airway and the interspaces between tracheal rings. See reference #5 and video at www.airwaymanagement.dk/pearls for a detailed guidance. Orange-red = anterior part of tracheal rings; light blue = the tissue-air border; green = the cricoid cartilage; purple = the distal end of the thyroid cartilage. Yellow = the shadow from the needle slid in between the transducer and the skin. With permission from The Scandinavian Airway Management course ''www.airwaymanagement.dk''.

training was sufficient to train airway ultrasound-naive anaesthesiologists to reach 90% success with both the original longitudinal string of pearls[5,13] technique and the transverse TACA[19] technique in morbidly obese females, reaching a 100% success with at least one of these techniques.[19] The *combination* of the two techniques was taught to anaesthesia fellows who rehearsed until they had performed 20 successful cricothyroid membrane identifications and thereafter used the combination in patients with neck pathologies, including previous neck surgery, irradiation, and neck mass, which led to 81% success in identifying the membrane within 5 mm from the midpoint compared with only 8% success with palpation.[7] All identifications with the combined ultrasound techniques were within 10 mm from the sagittal midline as opposed to only 61% for palpation. The true location of the midpoint was identified with CT.[7]

Both stepwise techniques are described in detail in the literature[5,13,19] and in freely accessible videos.[22,23] In line with the findings that a certain number of supervised scans are proved to promote education, we suggest that each clinical unit/institution that deals with treatment of patients with at-risk airways, or educates anaesthesiologists, appoints a person to reach expert level, preferably by seeking expert supervision, and subsequently supervise colleagues as a supplement to the theoretical education. Once the techniques have been learned, maintenance of skills is easy as any patient neck can be scanned as part of routine anaesthesia to maintain competence.

Clinicians who have learned ultrasound-guided identification of the cricothyroid membrane also improve their subsequent success with palpation. Clinicians, anaesthesia residents, fellows, and anaesthesia assistants were randomised to either ultrasound or palpation groups.[24] All received a 15 min presentation on relevant anatomy. Thereafter, the ultrasound group had a demonstration of both the longitudinal string of pearls and the transverse TACA technique, and practised the techniques on each other. Subsequently, each participant practised palpation with ultrasound guidance until the neck landmarks and cricothyroid membrane were correctly localised in five or more attempts. The duration of

this practice session was 1 h. The participants in the non-ultrasound group had a similar 1 h session, but without the use of ultrasonography, and also practised until their ability to localise neck landmarks and cricothyroid membrane was confirmed a minimum of five times by a staff anaesthesiologist using palpation. After the practice interventions, each participant in both groups was asked to identify the cricothyroid membrane of 10 healthy volunteers using external palpation alone. The correct identification rate, within 5 mm from the true midpoint of the cricothyroid membrane, was 65% for the group that had trained with ultrasound and 30% (P=0.025) in those who had trained palpation alone.[24]

By practising ultrasound-guided identification of the cricothyroid membrane, we will thus not only achieve a higher success rate in identification, but in the rare event that one must access the cricothyroid membrane without having access to ultrasonography, or time to perform it, we will have improved our chance of success. Pre-emptive use of ultrasonography also reveals the *depth* to the airway lumen to guide incision requirements. If no ultrasonography equipment, experience in using it, or time is available, a recent study provided clinicians with an algorithm to estimate the depth to the airway lumen at the level of the cricothyroid membrane (DACM) based only on the weight of the patient[25]: upper 95% CI of DACM (in mm)=(0.13×weight in kg)+0.86.

Conclusions

The meta-analysis by Hung and colleagues[4] unequivocally documents the superiority of ultrasound for guiding identification and marking of the cricothyroid membrane, and the limitations of palpation methods, especially in the obese and in those with pathology of the neck. The clinical consequences should be that, in cases where pre-induction visual inspection or palpation methods do not with certainty identify the cricothyroid membrane and the midline of the airway, the cricothyroid membrane should be identified with ultrasonography and marked with the patient in extended-neck position. Subsequently, the patient can be placed in the desired position for airway management and induction. In case that the initial airway management fails and front-of-neck airway access is needed, the patient can be returned to the extended-neck position, and the marking of the centre of the cricothyroid membrane will again be correct.

Authors' contributions

Both authors wrote, edited, and approved the final version.

Declaration of interest

The authors declare that they have no conflicts of interest.

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British Journal of Anaesthesia, 126 (1): 27–30 (2021)
doi: 10.1016/j.bja.2020.09.015
Advance Access Publication Date: 21 October 2020

Occam's razor at the sharp end: simplified preoperative risk assessment

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This editorial accompanies: A simplified (modified) Duke Activity Status Index (M-DASI) to characterise functional capacity: a secondary analysis of the Measurement of Exercise Tolerance before Surgery (METS) study by Riedel et al., *Br J Anaesth* 2021:126:181–190, doi: 10.1016/j.bja.2020.06.016

Keywords: anaerobic threshold; cardiopulmonary exercise test; Duke Activity Status Index; maximal oxygen uptake; perioperative outcome; preoperative risk assessment

Prediction of outcome after major surgery is a complex process. Clinicians' subjective assessment does not work.[1] An array of scoring systems, biochemical markers, investigations, and tools to estimate functional capacity are now available to attempt to quantify the likelihood of a good recovery so that this information can be used in shared decision making and perioperative planning.

The Duke Activity Status Index (DASI) questionnaire is a 12-part questionnaire that aims to estimate functional status through questions about activity of daily life,[2] and is advocated by the American College of Cardiology and American Heart Association to be incorporated in a decision tree to alter preoperative investigations and management before major or intermediate risk surgery.[3] In the Measurement of Exercise Tolerance before Surgery (METS) study, one of the largest observational studies to date of risk assessment tools in the perioperative setting, the DASI score was a better predictor than clinicians' subjective assessment, serum brain natriuretic peptide, and some functional capacity variables measured with cardiopulmonary exercise testing (CPET) of death or myocardial infarction within 30 days of elective major surgery.[1]

However, the DASI is not straightforward to administer. The DASI is the aggregate score of all self-reported 'yes' answers, weighted from 1.75 to 8.0, with a range of possible scores between 0 and 58.2, and VO_2 peak can then be estimated from an algorithm.[2] This relative complexity may have limited clinical use of DASI. The search continues for the elusive ideal tool that balances accurate risk prediction with clinical utility.

Occam's razor is the rule that, when faced with several solutions for a problem, the simplest one is usually the best. So the work of Riedel and colleagues[4] published in this issue of

DOI of original article: 10.1016/j.bja.2020.06.016.