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

M. S. Kristensen, W. H. Teoh and S. S. Rudolph

1Rigshospitalet, Copenhagen University Hospital, Blegdamsvej, Copenhagen DK-2100, Denmark, and 2Wendy Teoh Pte. Ltd, Private Anaesthesia Practice, Singapore

*Corresponding author. E-mail: michael.seltz.kristensen@regionh.dk

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, because misplacement is the most common complication when attempting cricothyrotomy.8 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

Accepted: April 20, 2016

© The Author 2016. Published by Oxford University Press on behalf of the British Journal of Anaesthesia. All rights reserved. For Permissions, please email: journals.permissions@oup.com
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 and in 39% of obese subjects. In females, success rates were 24, 12 25 (neutral position), 10 29 (hyperextended neck), 10 and 71% in the non-obese, whereas they were found to be 0 (neutral position), 6 (hyperextended neck), 35, 12, 37, and 39% 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, 27, 30, 36, 39 (cadaver), 46, 21, 62, 66.7, and 70%. Identification of the cricothyroid membrane by visual inspection of the overlying skin creases was successful in 50%. The ‘four finger widths technique’ was successful in 46% of patients in a mixed population.

### 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 or as a reference method 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 described 95% success rate in 21 cadavers in a mean of 3.6 s and Nicholls and colleagues 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.

### 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.

A cadaveric 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]. Ultrasound 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. Successful identification of the cricothyroid membrane with palpation alone was reportedly 67% in lean subjects, 46% in a mixed BMI cohort, and 37% in the morbidly obese. With ultrasonography, this improved to 69% in lean subjects, 100% in mixed BMI subjects, and 83% in morbidly obese subjects. Ultrasonography ‘training’ per se was varied, and ranged from a ‘brief surgical airway anatomy and ultrasonography training’ to a ‘theoretical airway ultrasonography and 15 min hands-on training’. Six months after the original ultrasound training, the clinicians still had higher success in finding the cricothyroid membrane using ultrasound than with clinical examination (78% vs 33%, P<0.05).

### Positioning and types of ultrasonographic techniques

Mallin and colleagues 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 noted. 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. 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 s, 37 s (longitudinal technique), respectively. One hundred per cent of the anaesthetists were able to identify the cricothyroid membrane with at least one of the techniques. The ultrasonography education consisted of a 1 h structured training programme that included e-learning, a lecture, and hands-on training.

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>
<thead>
<tr>
<th>Publication</th>
<th>Study design</th>
<th>Subjects (human, cadaver, or manikin); n; characteristics</th>
<th>Physicians identifying the CTM (n)</th>
<th>Physicians who performed the US (n); US training for the study</th>
<th>Description of the US appearance of CTM</th>
<th>Identification of CTM by palpation (success rate; duration)</th>
<th>Identification of CTM with US (success rate; duration)</th>
<th>US technique for identification of the CTM</th>
<th>Technique described in detail for replication and applicable without palpable landmarks (yes/no)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orr and colleagues14</td>
<td>Case report, CTM identified before awake intubation</td>
<td>Human; 1; difficult airway</td>
<td>1</td>
<td>1; n.a.</td>
<td>n.a.</td>
<td>0/1-0%; n.a.</td>
<td>1 of 1-100%; n.a.</td>
<td>n.a.</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Nicholls and colleagues15</td>
<td>Identification of the CTM with US</td>
<td>Humans; 50 patients; mean BMI 26 kg m⁻²</td>
<td>2</td>
<td>2; cadavers</td>
<td>Bordered by the very echogenic thyroid and cricoid cartilages</td>
<td>n.a.</td>
<td>Success in all 50 patients; time to viewing 24.3 s</td>
<td>Longitudinal initially, then transversely on the CTM</td>
<td>No</td>
<td>Palpation before ultrasound</td>
</tr>
<tr>
<td>Elliott and colleagues16</td>
<td>Palpation study, with US as reference</td>
<td>Humans; 2 male and 4 female subjects; BMI 24-53 kg m⁻²</td>
<td>18</td>
<td>2; n.a.</td>
<td>n.a.</td>
<td>30%; n.a.</td>
<td>100%</td>
<td>n.a.</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Singh and colleagues17</td>
<td>Descriptive</td>
<td>Humans; 24 volunteers; mean BMI 24 kg m⁻²</td>
<td>1</td>
<td>1; n.a.</td>
<td>Hyperechoic band</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Kristensen18</td>
<td>Descriptive</td>
<td>Humans</td>
<td>n.a.</td>
<td>n.a.; n.a.</td>
<td>Hyperechoic band</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Stepwise. Transverse, transducer then rotated to sagittal plane.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Kundra and colleagues19</td>
<td>Descriptive</td>
<td>Human, n.a.</td>
<td>n.a.</td>
<td>n.a.; n.a.</td>
<td>Hyperechoic band</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Sagittal, parasagittal, and transverse CTM between inverse V-shaped thyroid cartilage and arch-like cricoid, as in Barbe and colleagues21</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>De Oliveira and colleagues20</td>
<td>Case report. US-guided identification after failed palpation</td>
<td>Human; 1; BMI 57 kg m⁻²</td>
<td>1</td>
<td>1; n.a.</td>
<td>n.a.</td>
<td>0 of 1-0%; n.a.</td>
<td>1 of 1-100%; n.a.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Continued
<table>
<thead>
<tr>
<th>Publication</th>
<th>Study design</th>
<th>Subjects (human, cadaver, or manikin); n; characteristics</th>
<th>Physicians identifying the CTM (n); Physicians who performed the US (n); US training for the study</th>
<th>Description of the US appearance of CTM</th>
<th>Identification of CTM by palpation (success rate; duration)</th>
<th>Identification of CTM with US (success rate; duration)</th>
<th>US technique for identification of the CTM</th>
<th>Technique described in detail for replication and applicable without palpable landmarks (yes/no)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dinsmore and colleagues&lt;sup&gt;22&lt;/sup&gt;</td>
<td>Palpation vs US for cannulation</td>
<td>Manikin, non-anatomical</td>
<td>50; 25; 6 min education</td>
<td>n.a.</td>
<td>Cannulation 44%; median 110 s</td>
<td>Cannulation success 83%</td>
<td>Transverse on the simulated trachea, CTM</td>
<td>Yes</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
</tr>
<tr>
<td>Aslani and colleagues&lt;sup&gt;20&lt;/sup&gt;</td>
<td>Palpation study, with US as reference</td>
<td>Humans; 56 female subjects, 41 non-obese and 15 obese; BMI 40.5 kg m&lt;sup&gt;-2&lt;/sup&gt;</td>
<td>24; 2; n.a.</td>
<td>n.a.</td>
<td>Neutral: obese 0%, non-obese 25%; Extended: obese 6%, non-obese 29%</td>
<td>100% success by the two ultrasound examiners; n.a.</td>
<td>Transducer transversely, moving, vocal cords appeared. The probe was moved to see the CTM as in Barbe and colleagues&lt;sup&gt;21&lt;/sup&gt;</td>
<td>No</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
</tr>
<tr>
<td>Suzuki and colleagues&lt;sup&gt;23&lt;/sup&gt;</td>
<td>Case report. US-guided localization before awake intubation</td>
<td>Human; 1; cervical spine disease</td>
<td>n.a.; 1; n.a.</td>
<td>n.a.</td>
<td>1 of 1=100%</td>
<td>Transverse approach</td>
<td>No</td>
<td>No</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
</tr>
<tr>
<td>Curtis and colleagues&lt;sup&gt;24&lt;/sup&gt;</td>
<td>US-guided cricothyrotomy</td>
<td>Cadavers; 12 female and 9 male cadavers; mean BMI 21.9 kg m&lt;sup&gt;-2&lt;/sup&gt;</td>
<td>2; 2; n.a.</td>
<td>n.a.</td>
<td>95%; 3.6 s (cricothyrotomy median 26.2 s)</td>
<td>Sagittal orientation placed just lateral to the midline of the trachea</td>
<td>No</td>
<td>No</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
</tr>
<tr>
<td>Tsui and colleagues&lt;sup&gt;25&lt;/sup&gt;</td>
<td>Comparing US in humans and cadavers</td>
<td>Humans and cadavers; n.a.</td>
<td>n.a.; n.a.; n.a.</td>
<td>n.a.</td>
<td>n.a.; n.a.</td>
<td>n.a.; n.a.</td>
<td>Gradual change of the CTM to the cricoid arch</td>
<td>No</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
</tr>
<tr>
<td>Or and colleagues&lt;sup&gt;26&lt;/sup&gt;</td>
<td>Comparing 3D US and MRI</td>
<td>Humans; 11 volunteers; BMI&lt;35 kg m&lt;sup&gt;-2&lt;/sup&gt;</td>
<td>n.a.</td>
<td>1; n.a.</td>
<td>A hyperechoic band between the cartilages</td>
<td>n.a.; n.a.</td>
<td>3D US images correlate well with MRI</td>
<td>No</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
</tr>
<tr>
<td>Mallin and colleagues&lt;sup&gt;27&lt;/sup&gt;</td>
<td>Identified CTM. Changed position of subjects. Subsequently, rescanned</td>
<td>Humans; 23; healthy volunteers</td>
<td>23; 23; n.a.</td>
<td>n.a.; n.a.</td>
<td>23 of 23=100%; n.a.; n.a.</td>
<td>Longitudinal lateral to midline, followed by 90° rotation and marking</td>
<td>No</td>
<td>Externally palpable landmarks, CTM technique described in detail for replication and applicable without palpable landmarks (yes/no)</td>
<td>No</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Participants</td>
<td>Methods</td>
<td>Results</td>
<td>Conclusion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>--------</td>
<td>--------------</td>
<td>---------</td>
<td>---------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barbe and colleagues</td>
<td>Compared palpation with US</td>
<td>Humans; 2, female and male; BMI 35.4 and 29.8 kg m$^{-2}$</td>
<td>12 (+2 instructors); theoretical airway US training plus 15 min hands on</td>
<td>Hyperechoic line with a posterior artefact</td>
<td>Transversely, thyroid cartilage “V”, then CTM delimitation caudally by arch-like cricoid cartilage</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kristensen and colleagues</td>
<td>Descriptive</td>
<td>Humans</td>
<td>n.a.</td>
<td>n.a.</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campbell and colleagues</td>
<td>Palpation study, with US as reference method</td>
<td>Human; 44 patients and staff, 24 females</td>
<td>23</td>
<td>2; n.a.</td>
<td>Male 70% Female 19%</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owada and colleagues</td>
<td>Case report. Pre-induction US of CTM for cricothyrotomy</td>
<td>Human; 1 patient with tracheal displacement</td>
<td>n.a.</td>
<td>1; n.a.</td>
<td>1 of 1=100%; n.a.</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parmar and colleagues</td>
<td>Descriptive</td>
<td>Human; 100 volunteers, 52 male and 48 female; mean BMI 23 kg m$^{-2}$</td>
<td>1; n.a.</td>
<td>Hyperechoic band</td>
<td>Longitudinal and parasagittal</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lamb and colleagues</td>
<td>Palpation study, with US as reference</td>
<td>Human; 12 subjects, 6 men and 6 women; 3 obese in each group, with BMI 30.1–38 kg m$^{-2}$</td>
<td>41</td>
<td>1; n.a.</td>
<td>Men: non-obese 72%, obese 39%; women: non-obese 24%, obese 35%</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kristensen and colleagues</td>
<td>Palpation vs US, randomized crossover</td>
<td>Human; 1 female; BMI 45.3 kg m$^{-2}$</td>
<td>35; e-learning, 20 min lecture, 20 min hands on</td>
<td>n.a.</td>
<td>Same longitudinal approach as described by Kristensen</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siddiqui and colleagues</td>
<td>Randomized to palpation or US for percutaneous cricothyrotomy with trocar device</td>
<td>Cadaver; 47, 28 female and 19 male</td>
<td>47; 10 min lecture, 3 min video, and 5 times hands on</td>
<td>Identification and trocar cricothyrotomy: 39.1%, mean 110.5 s</td>
<td>Same longitudinal approach as described by Kristensen</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Continued*
<table>
<thead>
<tr>
<th>Publication</th>
<th>Study design</th>
<th>Subjects (human, cadaver, or manikin); characteristics</th>
<th>Physicians identifying the CTM (n)</th>
<th>Physicians who performed the US (n); US training for the study</th>
<th>Description of the US appearance of CTM</th>
<th>Identification of CTM by palpation (success rate; duration)</th>
<th>Identification of CTM with US (success rate; duration)</th>
<th>US technique for identification of the CTM</th>
<th>Technique described in detail for replication and applicable without palpable landmarks (yes/no)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>You-Ten and colleagues&lt;sup&gt;13&lt;/sup&gt;</td>
<td>Palpation study, with US as reference</td>
<td>Human; 56; women in labour, 28 non-obese and 28 obese, mean BMI 39.2 kg m&lt;sup&gt;−2&lt;/sup&gt;</td>
<td>41; trained in neck US</td>
<td>n.a.</td>
<td>71% non-obese women; 39% obese women; obese 23 s, non-obese 12 s, median 41 s; trained in neck US</td>
<td>(100% by the expert sonographer)</td>
<td>Same longitudinal approach as described by Kristensen&lt;sup&gt;18&lt;/sup&gt;</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bair and colleagues&lt;sup&gt;11&lt;/sup&gt;</td>
<td>Comparing three different clinical methods, with US as reference</td>
<td>Human; 50; mean BMI 28 kg m&lt;sup&gt;−2&lt;/sup&gt;</td>
<td>49; n.a.</td>
<td>n.a.</td>
<td>Palpation 62%, four finger widths 46%, visually identifying overlying skin crevasses 50%; 5–45 s (range)</td>
<td>1 of 1=100%</td>
<td>Not described</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yildiz and colleagues&lt;sup&gt;34&lt;/sup&gt;</td>
<td>Palpation vs US</td>
<td>Humans; 24 volunteers; mean BMI 23.8 kg m&lt;sup&gt;−2&lt;/sup&gt;, mean age 24 yr</td>
<td>5; brief training to detect the CTM</td>
<td>n.a.</td>
<td>66.7%; 8.3 s (7.3–9.1), mean (95% CI)</td>
<td>69.2%; 17 s (15.3–18.7), mean (95% CI)</td>
<td>Parasagittal and transverse scan. Relies on being able to identify initially with palpation</td>
<td>No</td>
<td>The sequence was not randomized</td>
<td></td>
</tr>
<tr>
<td>Kristensen and colleagues&lt;sup&gt;35&lt;/sup&gt;</td>
<td>Descriptive</td>
<td>Humans; n.a.; n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Longitudinal as described by Kristensen&lt;sup&gt;13&lt;/sup&gt;, transverse as in Barbe and colleagues&lt;sup&gt;21&lt;/sup&gt;</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Votruba and colleagues&lt;sup&gt;36&lt;/sup&gt;</td>
<td>Descriptive</td>
<td>Humans</td>
<td>n.a.</td>
<td>n.a.</td>
<td>‘A hyperechogenic membrane’</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Median or paramedial sagittal view</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Stafrac and colleagues&lt;sup&gt;38&lt;/sup&gt;</td>
<td>Descriptive, paediatric airway in US</td>
<td>Humans (children)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Sagittal midline</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
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-naive clinicians. We saw success rates in human subjects ranging from 69.2% after ‘brief surgical airway anatomy and ultrasonography training’ to 100% after ‘theoretical airway ultrasonography and 15 min hands-on training’. 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 (100% with at least one of two techniques applied).

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’ and the ‘longitudinal’ 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.

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).

(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.

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 (hyperechoic) rings will be seen anterior to the white hyperechoic line.
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.

Each of these two techniques functions well individually and has its own advantages. 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, 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 and tracheostomy should be evaluated, and an attempt should be made to identify the cricothyroid membrane. The pre-anæsthetic 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 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.

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.21 22 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, collateral of equipment, and formulation of a plan for airway management, including a plan for failure. In the NAP4 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.

Funding
Departmental funding.

References

Handling editor: T. Asai