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Review
Editor's Choice

Anterior neck and airway ultrasound procedures with emphasis on resuscitation plus video clips

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ABSTRACT

What can anterior neck and airway ultrasound add to the established methods in emergency airway management, including capnography?

The aim of this narrative review is to review relevant methods. We describe three major categories of anterior neck and airway ultrasound exam methods in order to distinguish its applicability within a defined clinical context. We particularly describe two types of focused anterior neck ultrasound exam styles depending on the clinical scenario, post-intubation (type #1 style) and during intubation (type #2 style). Regarding both exam styles, the key message is to identify or rule out a double tract immediately, indicating an esophageal misplacement. For this finding no ventilation trial is mandatory. In case of clinical emergency scenarios, this is the major advantage in comparison to capnometry. Exam type #1 style is a very brief sonoscopy-like exam and can be performed within 10 s in an ALS-conformed way. As these stethoscope-like examinations can be integrated into the advanced life support algorithm, it is suggested that anterior neck and airway ultrasound should be part of the collection of methods of "Resuscitation Ultrasound" and training. To make it available to a wider audience, the exam techniques are visualized in video clips and available at www.yumpu.com/en/SonoABCD.

Considering the evidence and limitations of anterior neck and airway ultrasound procedures in emergencies, training within scenarios or a defined clinical context is recommended. These point-of-care ultrasound methods should be readily accessible for emergency and critical care practitioners.

Contents

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1. Introduction

What is the advantage of anterior neck and airway ultrasound for clinicians? For example, what can those methods add to the established methods in airway management, including capnography, in emergency situations? Almost 20 years after the work of Ma G et al. [1] and Drescher et al. [2] who conceptualized this idea for emergency medicine, and despite ample literature with original studies, reviews and meta-analyses, there is still an ongoing debate around its true value and real-life applicability. Unfortunately, ultrasound procedures “have no face” when printed in a scientific paper. Also, teaching systems failed to adopt those methods, and knowledge transfer is limited. All of these seem to impede a more widespread acceptance.

The aims, purposes and clinical impact of specific airway assessment methods, such as capnography and ultrasound, are slightly divergent. This applies to gold standards as well as alternatives (Table 1). Understanding these differences will help understand the value of the single methods.

All airway management techniques, in general, require some sort of device, technology or additional material, and vary from one operator to a dedicated team. Some could be combined to improve patient outcomes, but for their individual indications, they cannot be replaced by one another. All of them can be used at (any) point-of-care. For example, in airway management, one aim of fiberoptic intubation is to help passing an endotracheal tube (ETT) under direct view through the vocal cords. A laryngoscope (direct or videolaryngoscopy) can visualize the upper entrance of the larynx with the vocal cords, and guide placement of the ETT. Capnography has a different aim: It can be used as a functional real-time measurement of exhaled carbon dioxide, thus assessing CO_2 production (cellular metabolism), transport (hemodynamics), and elimination (ventilation). In the context of airway procedures, it helps to confirm and monitor correct ETT placement, once the intubation process has been completed.

Anterior neck and airway ultrasound is another emerging method since point-of-care ultrasound protocols were introduced and supported by clinical data [3]. Clinician-performed anterior neck and airway ultrasound can therefore be seen as an equal airway assessment method in line with capnography, fiberoptic intubation or laryngoscopy. It can also visualize sonoanatomy and provide findings for decision making. This is based on the

Table 1
Advantages and disadvantages of the different methods to evaluate airway.

Method Grading	Stethoscope	Laryngoscopy Video-Laryngoscopy	Fiberoptic intubation	Capnometry	Anterior neck and Airway Ultrasound
Advantage	easy to handle, low cost, well established	direct view on upper airway vocal cords, well established	direct view, no ventilation required to check if ETT is in place, provides a direct result, can identify main stem intubation, established with specialists	easy to apply, continuous measurements available/ well established	no ventilation required to check if ETT is in the esophagus, provides a direct result, quick evaluation within 10 s possible, can identify main stem intubation (20 s)
Limitation/Disadvantage	tracheal auscultation cannot identify tube, can only be used after intubation for gastric or pulmonal sounds, unsafe method for mainstem intubation in many clinical scenarios	if >/ = C/L 3 states, not sufficient for a safe procedure, in unsecure attempts, it does not provide a direct result, only, costs $	vulnerable endoscope extensive training required, time to result, costs $$	ventilation required to check if ETT is in place in unfasted individuals or CPR, CO_2 does not provide an "on-off" result (and is not immediately = zero in esophageal misplacements or cardiac standstill, can not safely identify main stem intubation, dependent on cardiac motion/blood-alveolar capnography transportation, costs $	only provides a result, costs of an ultrasound machine $$$, need for another method to correct in case of esophageal misplacement, an esophageal misplacement can not be safely ruled out in a posterior position of the esophagus

interpretation of distinct sonographic patterns, within the respective clinical context, in real-time.

The stethoscope is a historically established assessment method mostly used in addition to the above-mentioned methods. However, this is the only device that, in the context of airway management, might well be replaced completely by the anterior neck and airway ultrasound combined with parts of lung ultrasound, in the future - except for the acoustic finding of wheezing, of course.

The aim of this narrative review is to explain and review a systematic understanding of anterior neck and airway ultrasound and, where no further high-level evidence is available, provides theoretical considerations and training suggestions from the author group.

We describe three major categories of anterior neck and airway ultrasound exam methods mainly to serve the purpose to distinguish its usability within a defined clinical context (Table 2):

1) to study sonoanatomy of anterior neck and upper airway
2) in the context of airway management procedures
3) as part of "Resuscitation Ultrasound"

2. Anterior neck and airway ultrasound to study sonoanatomy of upper airway

In general, anterior neck and airway ultrasound contains systematic examinations, as in conventional sonography, or focused assessments, following the concept of point-of-care ultrasound and sonoscopy. This first category is closer to conventional sonography. The exam style is used to obtain standard views, measurements and review images. This all takes at least several minutes, making it rather unfeasible if any immediate action is required. Thus, the practice context could be any learning and teaching for any *planned* assessment.

2.1. Transducers and modes

With conventional ultrasonography (US) main anatomical structures of the human airway can be visualized in sonograms. A curved low-frequency transducer is advocated because of its wider field of view [4] also to assess lateral structures such as esophagus and central neck vessels within one window (Figs. 1–4). A linear transducer (20-5 MHz) may also be sufficient [5,6] for sonoanatomy as it supports near field resolution, however it can require more movements to assess lateral structures (Figs. 1 and 2). Furthermore, in adults more penetration depth will decrease the width of the image obtained. In the inferior front of neck region, this can limit visibility e.g. of the esophagus, and make more transverse to lateral probe movements necessary. B-Mode scans and additional Colour-Mode overlays can be applied.

2.2. Mouth and tongue

For the mouth and tongue ultrasound exam the transducer is placed in a coronal plane posterior to the mentum [7]. Subsequently the transducer is moved posteriorly and caudad towards the hyoid bone, so the dorsal surface of the tongue can be distinguished [8]. On either side the image is limited by the acoustic shadow of the mandible. Tonsils appear hypoechogenic [4].

Table 2
Types of anterior neck and airway ultrasound exams within a defined clinical context.

Action/ultrasound exam type	The aim, emphasis on	Approx. time for the exam (seconds)	Applicable under time pressure?/ remark
Pre-check, e.g. for preparation for a dilatational tracheostomy, difficult laryngoscopy, identify cricoid membrane	planned evaluation of upper airway related sonoanatomy	>60	no, because of quantitative measurements and sophisticated anatomy evaluation
Focused lower anterior ultrasound exam (look for esophagus and trachea) only	only exam style #1 (= post-intubation), after any emergency intubation, double tract or single tract before ventilation	<10, when evaluating post-intubation only	yes, integration into a (fast driving) process
Anterior neck and airway Ultrasound Exam	a routine check for lower anterior neck plus lung sliding or lung pulse or diaphragm or parts of it	<120	no, variety of indications*
Anterior neck and airway Ultrasound as part of Resuscitation Ultrasound	to check for reversible conditions	Airway (A, lower anterior neck check for double airway tract); <10 Breathing (B, check for ventilation); < 20 Circulation (C): < 10 (only for a brief screen)	yes, A, B in addition to C. Define order: CAB or ABC or else
Ruling out pneumothorax only	Trauma, trauma resuscitation, post-interventional (e.g. central venous catheter)	may take 10–30 for both hemithoraces	yes
Ruling in pneumothorax only	Trauma, trauma resuscitation, post-interventional (e.g. central venous catheter)	up to minutes, not Advanced-life conformed (ALS), needs firm findings (lung point)	no
*Confirming or ruling out pleural effusion**	Trauma (within the FAST exam), CPR (treatable condition of hypoxia)	more than 10 s, not ALS-conformed in CPR	none

*Note that pleural effusion can cause hypoxia and be a treatable condition. As the FAST-exam would require a minimum of 120 s for 4 up to 6 probe positions, the search for pleural effusion can be calculated as 20 s per side, thus, not ALS-conformed. However, there is no scientific evidence available whether this was identified as a treatable condition during CPR and if the evaluation can be performed in parallel to chest compressions.
Abbreviations: FAST; focused assessment with sonography in trauma, CPR; cardio-pulmonal resuscitation.

2.3. Hyoid bone

The probe is placed underneath the mandible. The hyoid bone appears in a pattern like the inverted letter “U” with a posterior acoustic shadow. On the sagittal view, the hyoid bone is visible as a small hyperechoic curved structure that produces an acoustic shadow [4,8].

2.4. Larynx

The larynx is located superficially. This facilitates identifying its main structures with US. The epiglottis remains hypoechoic throughout the patient’s life, whereas the thyroid and the cricoid cartilages undergo a calcification process, with variable reflection [9]. The echogenic true vocal cords are covered by muscles that

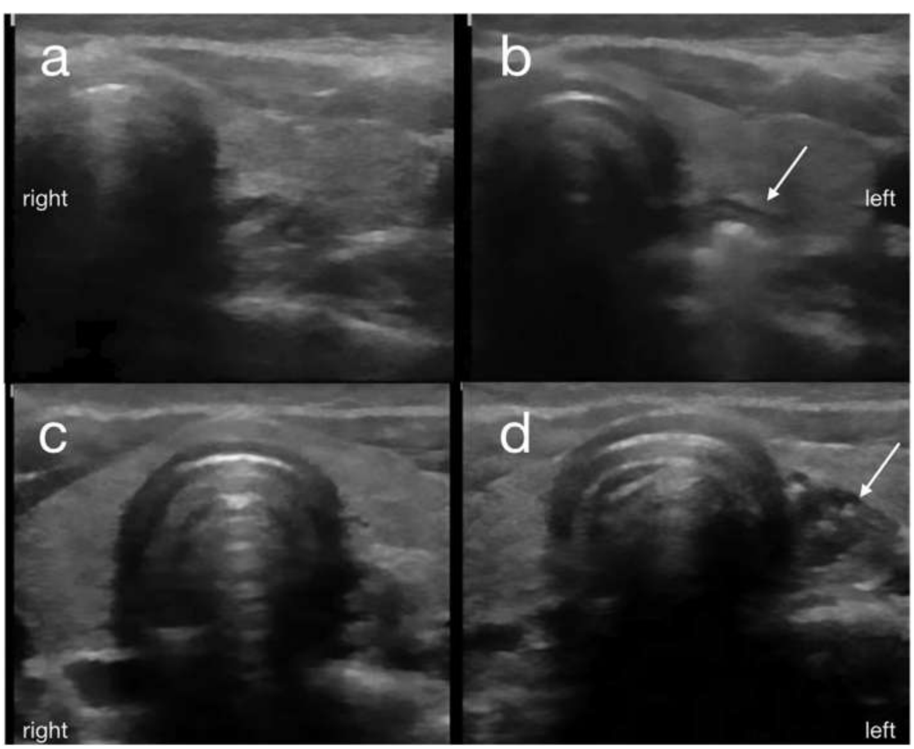

Fig. 1. Static and functional identification methods of the esophagus.
Sonograms of healthy women (upper and lower panel), linear probe, both trachea and esophagus unintubated. Static identification: a, b; Esophagus can appear mostly left of the trachea in depth of the sonogram as bullseye or halo shape, its muscle layer is hypoechogenic. Functional identification: a; before and b; while passing an air-fluid admixture after swallowing saliva, c; before and d; during gentle compression of the trachea with the probe.

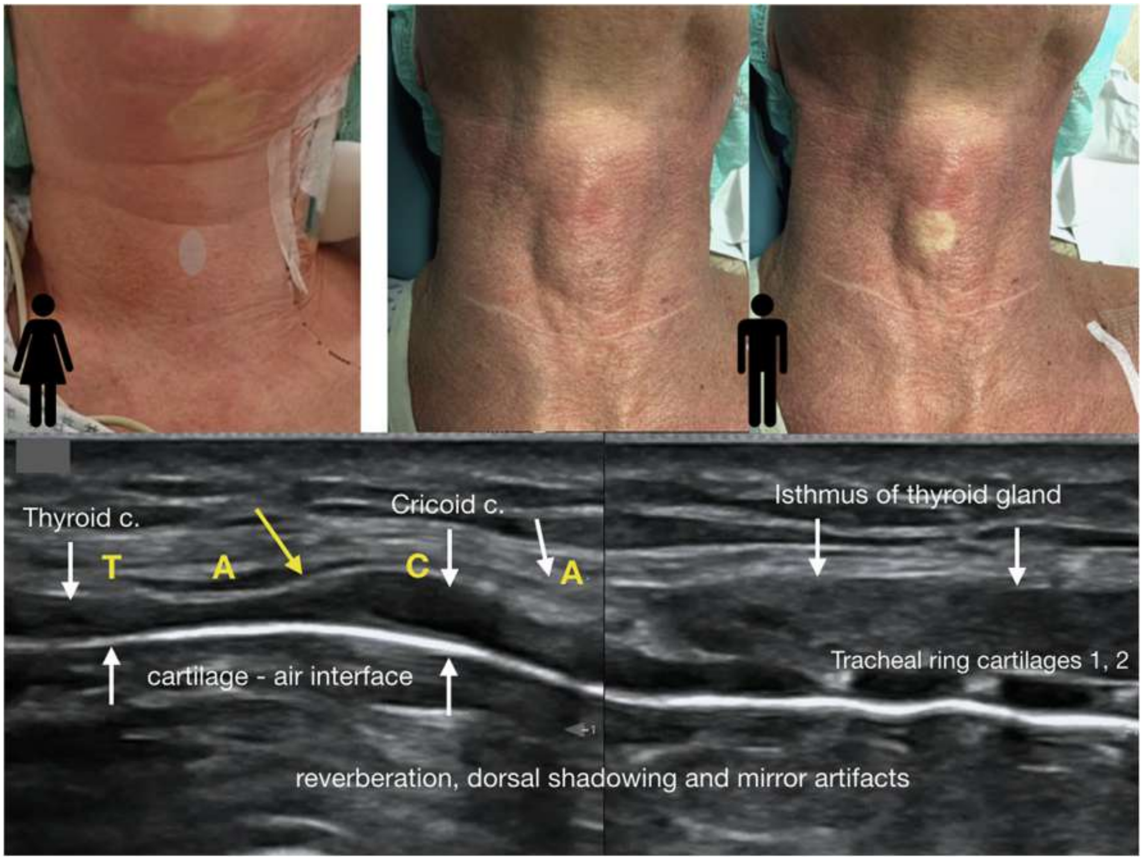

Fig. 2. Anterior neck region and sonoscopy of the Crico-Thyroid Membrane (CTM) of both genders.
The images represent the (middle) anterior neck region of both genders and depict the landmark (left grey oval area, right pale remnant of a palpation action with the index fingertip), directly above and below the cricoid cartilage (c). Linear probe, median cranio-caudal orientation. The haptic sensation when palpating is a flexible-elastic touch leading to superficial depth surrounded by harder borders. This is the area between the cartilages, however, sonographic appearance of the ligament does not correspond to the measured introitus space.
Sonogram shows sonoanatomy of a male individual in a long axis slice, left cephalad, right caudad. Cephalad is cricoid cartilage, then further caudad thyroid cartilage and thereafter the smaller tracheal ring cartilages. The white, hyperechoic line represents the inner mucosa-air interface throughout the complete airway. Note that CTM (yellow arrow) is hypoechogenic and above the hyperechoic line, also anterior of a portion of the cricoid cartilage. Yellow letters TACA indicate both puncture positions (A, A) of Kristensen et al. [26,27]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

appear hypoechoic [9,10]. The thyrohyoid membrane is located and visible between the hyoid bone and the thyroid cartilage. This membrane makes it possible to examine parts of the epiglottis in a transverse plane by a midline sagittal scan of the upper larynx, from the hyoid bone (cephalad) towards the thyroid cartilage (caudad) [2,4].

In the paramedian transverse scan direction from cephalad to caudad, further anatomic structures can be displayed in the sonogram. Those are faucial tonsils, lateral tongue base, lateral vallecula, strap muscles, lamina of the thyroid cartilage, lateral cricoid cartilage and the cervical esophagus [4].

Importantly, laryngeal cartilage is uncalcified in children but shows an increasing calcification with ageing [11]. At the age of 60, all humans show signs of ossification of the cartilage, visualized as a stronger echogenic structure within the cartilage, and with posterior acoustic shadow [11]. In a transverse slice, the cartilage has a shape like an inverted letter “V” with visible vocal cords [4].

2.5. Thyroid and cricoid cartilage

Thyroid and cricoid cartilage are hypoechogenic, can have bony structures and can be distinguished passing by from cephalad to caudad, best sliding the probe in longitudinal midline slices (Fig. 2). In between thyroid and cricoid cartilage, the cricothyroid membrane can be located in a sonogram related to the hyperechoic tissue and a mucosal-air interface deep to it. It cannot be visualized from the skin, however, it can often be palpated - see below. A paramedian position of the probe with a slightly oblique insonation (angle below 20°) can result in the same image and support punctures, whilst keeping the midline free.

2.6. Trachea and ring cartilages

The normal trachea is located in the midline of the neck, and thus is an important landmark in the transverse sonogram of the neck. Often the first six tracheal rings can be visualized in a mild extension of the neck [12]. Tracheal rings are also cartilage and appear hypoechogenic. The sonogram of the trachea shows, starting from the upper part of the image, the sonogram of the skin, subcutaneous fat, strap muscles and, at the level of the second or third tracheal ring, the isthmus of the thyroid [12]. The strap muscles are hypoechoic and encased by thin hyperechoic lines from the cervical fascia [12]. The cartilage rings of the trachea appear hypoechoic as well, and they are similar to a “string of beads” in the (para)-sagittal plane [4]. In the transverse plane, tracheal-rings appear like an inverted “U” with an inner hyperechoic air-mucosa interface and reverberation as well as mirroring artifacts posteriorly [4]. In longitudinal, median or oblique slices, insonating the

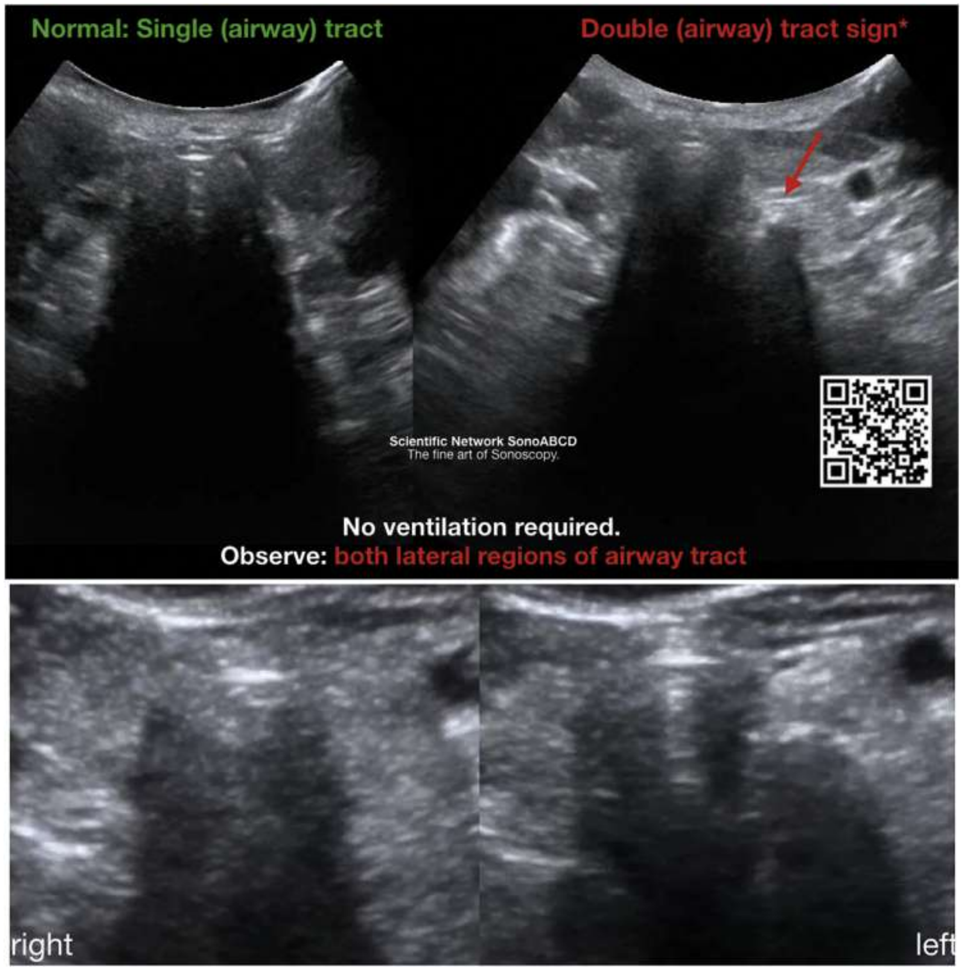

Fig. 3. Double or single airway tract? The central question to be answered by pattern recognition of an anterior neck ultrasound in emergencies.
Right and left, image orientation of sonogram.
Upper panel: Sonograms of single (left image) and double airway tract (right image, see arrow). These are the typical sonogram-patterns to be identified and to be trained in several possible variations, as esophagus appearance can vary. A native esophagus is not always visible. If it is, it does not show dorsal shadowing and thus is markedly different from an intubated esophagus. Note that the dorsal bony hyperechogenic artifact of a vertebra disappears because of dorsal shadowing induced by the ETT in the esophagus. Variation also is derived by the probe used, either convex (upper panel). A first detailed description was by Drescher et al., 2000 [2].
Lower panel: Magnification of representative sonograms for detailed post-procedural analysis. Note that the native esophagus in (a) is (often) not visible when scanning from the front. It is behind the trachea shadow, which can be observed continuously when applying exam style #2. (b) only when the ETT is in the esophagus, sonogram depicts an esophageal misplacement of an ETT, resembling a (double) airway tract which includes dorsal shadowing.

midline area of tracheal cartilages, these can be counted easily, once the cricoid cartilage is distinguished from the first tracheal ring cartilage. This approach again keeps the midline free for punctures. Distances of skin to anterior tracheal wall can be measured quantitatively, which can aid tracheostomy planning prior to procedures. Also, pre-tracheal vessels and unexpected individual pathways of other vessels can be visualized, further supported with Colour-Flow-Mode (C-Mode).

A common critique for Ultrasound-Techniques is the variability inter- and between observer. The reproducibility depends on training to obtain reproducible images. If the examiner ist trained, Ultrasound of the trachea and ring cartilages is a good method to image the structures of the upper airway [13].

2.7. *Esophagus*

The cervical part of the esophagus can be located posterolateral to the trachea on the left (or also to the right) side above the suprasternal notch. It appears weak, like a “bulls-eye” evoked by the concentric layers of the esophagus [12], sometimes with a hyperechoic content, resembling some air-fluid admixture (Fig. 1). To visualize it better, having a sip of water or burping can enhance its sonographic appearance. It is also possible that the esophagus is located directly posterior, hidden in the dorsal shadowing of trachea and thereby completely invisible in the sonogram.

2.8. *Artificial material and artifacts*

Gastric tubes in the esophagus or endotracheal tubes (ETT) will change native sonograms and enhance the identification of the esophagus. An ETT inserted into the trachea can induce or enhance an air-mucosa artifact of trapped air between the outer surface of the tube and the luminal mucosal layer of the trachea, with the appearance of local reverberation artifacts [3]. This appearance also depends on gain settings. However, this air-mucosa artifact can also be visible without an ETT placed in the trachea (Figs. 3 and 4).

Training remark: Sonoanatomy study of upper airway can be trained on almost every individual outside any clinical scenario.

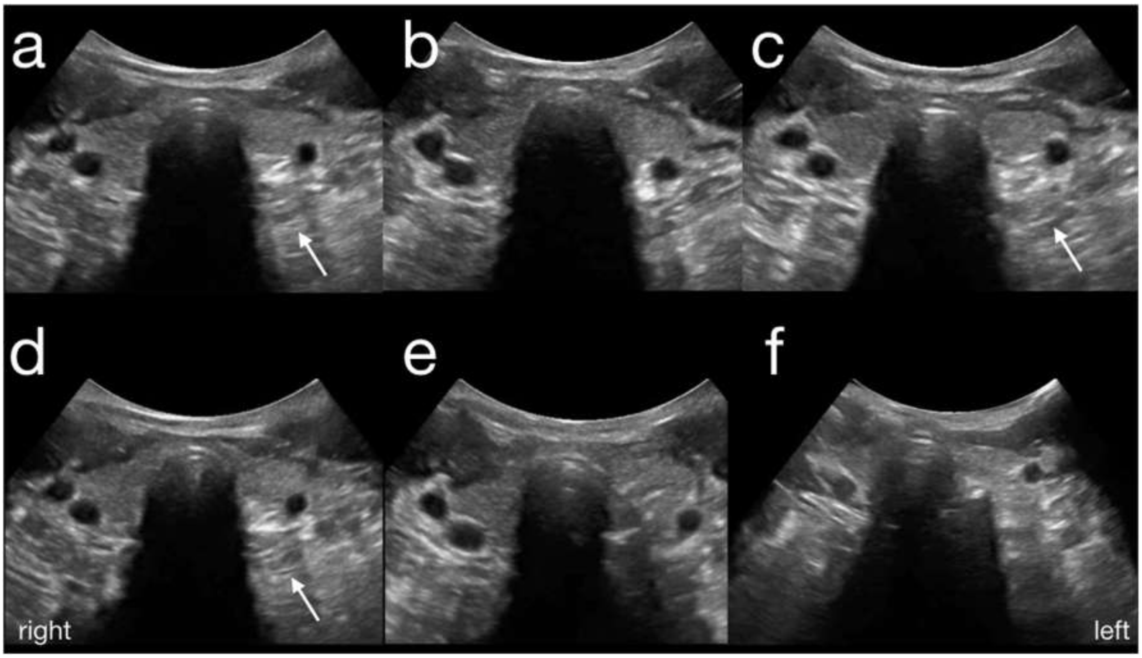

Fig. 4. Comparison of sonograms of the native and intubated trachea and native and intubated esophagus.
Right and left, image orientation of sonogram, convex probe, male individuals. Images do not show the clinical context (whether or not an ETT has been inserted).
Upper panel, a; unintubated trachea and esophagus, b, c; trachea with ETT (ID 7,5) inserted. Note that trachea without ETT (a) or with ETT (b, c) cannot be distinguished in a sonogram. The mucosa-air artifact is visible only, when tracheal cartilage is insonated (c), but not regularly. Esophagus (arrows). Note that in normal front of neck sonoanatomy or endotracheal intubation, the esophagus is not always visible either because of being empty or partially or completely behind tracheal dorsal shadowing.
Lower panel, another individual, d; the native esophagus, e; placement of an ETT into the pharyngeal orifice of the esophagus at the moment when during exam style #2 correction had been suggested. Note that pharyngeal placement is not a pronounced but recognizable change of pattern, f; an esophageal position of an ETT as found in exam styles #1 or #2. Lower panel, linear probe.

3. Anterior neck and airway ultrasound in the context of invasive airway management procedures

This category deals with (a) the use of sonoanatomy and measurements of parts of the upper airway for the prediction of an anticipated difficult airway or laryngoscopy, (b) the support of different invasive airway procedures, especially (c) confirmation of the correct endotracheal tube positioning. Apart from (a), the difference to the first category lies in the more focused, time-critical application of ultrasound within specific clinical contexts.

3.1. *Prediction of a difficult airway*

The clinical context which would apply here is a prescan in the pre-anesthetic assessment or immediately prior to a (planned) induction of anesthesia in order to intubate the trachea [14–19]. In this context, the exam objective is obtaining standard views and also measurements, which can take several minutes. Adhikari et al. suggested in a pilot study that airway ultrasound was able to detect difficult and easy laryngoscopy, indicating limitations of conventional screening tests for predicting difficult laryngoscopy [20]. Fulkerson et al. hypothesized in their current work [21], that sonography of anatomic details of the upper airway can predict difficult laryngoscopy. Although they failed to show advantages, the beauty of this idea was the trial of an imaging-based screening tool for presumably a broad range of patients. They assessed hyoid bone, thyroid membrane, vocal cords and hyomental distance, which in contrast to cartilaginous structures are more difficult to examine with ultrasound. Their idea was that those measurements may result in better risk assessment prior to endotracheal intubation. However, the results show that this approach seemed to have lower success rates than expected in relation to the expected clinical consequence. We learned that such a detailed exam, unfortunately, does not justify the time consumed by the exam, at least within this study population and setting. This conclusion thus helps clinicians avoid unnecessary and time-consuming diagnostics.

Kristensen et al. described scanning techniques such as hyomental distance or quantitative measures of neck soft tissue [22]. Results were conflicting regarding their correlation to difficult laryngoscopic views or airway management, as well as their overall feasibility. Also, in a 2017 systematic review, Fulkerson et al. summarized different modalities and their respective predictive value for a difficult airway, or a Cormack & Lehane grade III-IV view in laryngoscopy [15]. Acquisition times for specific sets of measurements took over 9 min in total. The authors suggest reducing the exam to modalities that showed some predictive value to reduce these times to 2 min or further, but this would require further large scale clinical data for a broad recommendation and applicability.

In summary, despite contrary results [20,21], regarding urgent or emergency clinical scenarios as the clinical context in which this type of evaluation can be applied, it would be common sense that assessing details together with quantitative measurements takes several minutes and cannot be applied under time pressure.

Training remark: This can be trained similarly to sonoanatomy studies.

3.2. *Support of invasive procedures: tracheostomy (percutaneous dilatational, DLT)*

The clinical context here is usually a planned procedure with informed consent. The aim of the exam is to obtain standard views and measurements, taking only a few minutes. Šustić was the first to introduce an ultrasound examination of parts of the upper airway like the trachea and connective tissue, as well as organs and vessels in order to improve safety before and during invasive procedures, such as a dilatational tracheostomy (DLT) [reviewed in 23]. He also included real-time guidance [23]. Instead of blind punctures, he suggested defining insertion depth, height and interspace of distinct tracheal cartilages and the relation to each other prior to the procedure (Fig. 2). By studying pre-tracheal vessels or other vessel anatomy around the trachea, this ultrasound exam can help prevent bleeding complications. It can easily be combined with diaphanoscopy or bronchoscopy with sterile draping and probe covering. Until now, there has been quite a bit of scientific evidence to support this simple method and its adoption into clinical routine for the sake of safety [23]. Thus, studying anatomic details prior to a DLT can be of high significance [23]. Note that this invasive procedure is not related to an emergency procedure like a puncture of cricothyroid membrane, because of a different clinical context (see below).

Training remark: Ultrasound-guided pre-examination for a planned DLT, as a part of studying sonoanatomy of the upper airway (midline and oblique scans) can be trained in any individual outside any clinical scenario. Ultrasound-guided puncture training is trained extensively on phantoms, however the complete procedure is only trainable under supervision in real clinical education.

3.2.1. Sonography and marking of the cricothyroid membrane (CTM) in the anticipated and unanticipated difficult airway and cannot intubate - cannot oxygenate (CICO) scenarios

A rare but dramatic clinical scenario is a *CICO* situation which has the urgent requirement of a Front of Neck Access (FONA, surgical airway). The CTM is the site of access for emergency cricothyrotomy using a FONA in case of a CICO situation. When a CICO is declared, the CTM needs to be identified and accessed as fast as possible.

In normal anatomy, the landmark technique is usually sufficient. However, when landmarks are not clear, a long median scalpel incision and blunt dissection to the larynx and the CTM is recommended [24,25]. In light of this immediately life-threatening situation of a CICO, and the danger of worsening hypoxia by any delay in the range of seconds or a few minutes it is of interest to have the best modalities.

In *anticipated or suspected* difficult airway management scenarios, i.e. clinical evaluation of a potential difficult airway, CTM and access site can be visualized by performing an ultrasound of the long axis slices (Fig. 2), and external landmarks can be pre-marked on the skin surface before the procedure and the induction of anesthesia. In the case of a CICO, the airway can then potentially be accessed faster [26,27]. The exam intention is to obtain slices in between thyroid and cricoid cartilage in order to search for CTM, as well as image interpretation including comprehension of depth and possible site of a puncture, as related to skin and sonogram. Thus, CTM is to be identified *prior* to the airway procedure. Furthermore, also transthyroid or -cricoid topicalization for awake fiberoptic intubations can be guided by ultrasound with a similar pre-examination step.

3.2.2. Team awareness: shared mental models

Finally, such marking of the CTM ahead of an anticipated difficult airway management procedure may help establish a shared mental model within the team and can raise awareness of cricothyrotomy as an option in the case of CICO. This team awareness and shared mental model can help to better overcome late or missing decision making, which is believed to be one of the main challenges and sources of fatal complications in airway resuscitation procedures [24].

To what extent the ultrasound-guided CTM-identification technique can actually be applied under time pressure in an *actual* airway emergency, i.e. an *unanticipated difficult airway and imminent CICO* remains a matter of debate. In a mixed collective of five operators with 24 patients, ultrasound proved to be of similar accuracy as the landmark technique, with six of these patients being overweight and one obese. However, this examination style proved to be slower [28]. In two obese patients with difficult landmarks, Kristensen et al. demonstrated a mean of 24 $\pm$ 12 s in identifying the CTM by 42 clinicians using his Thyroid-Air-Cricoid-Air *(TACA)* approach [26,27]. In a pilot cadaveric study, a median time of 3.6 s (interquartile range, IQR 1.9–15.3 s) was needed to identify the CTM and a median time of 26 s (IQR: 10.7–50.7 s) to complete the whole surgical procedure [29]. Again, if ultrasound is to be leveraged as a viable option in CICO, this warrants to take into account not only the imaging itself, but the entire process, including a rigorous timeline which should be controlled and overseen e.g. by a team leader, like in all resuscitation processes.

Training remark: Diagnostic imaging of CTM and cricoid can be trained in almost every individual outside any clinical scenario (Fig. 2). Specific anatomical puncture training phantoms are rarely available, thus only cadaver training can help prepare for this rare intervention. However, it has to be questioned if a few training attempts in cadavers can prepare for a future emergency. Therefore, regular training of CTM sonography as well as ultrasound-guided invasive procedure training on superficial targets, e.g. vessels, could serve as an alternative for the specific haptic experience of invasive CTM access.

To summarize, CTM ultrasound is an option *prior* to CICO scenarios, in anticipated difficult airways, and should better be planned and performed prior to inducing general anesthesia and apnoea. It is advocated to integrate this type of airway management into the clinical and resuscitation processes as a whole. In individual cases, it might be executed by a trained operator also under time pressure.

3.3. Anterior neck ultrasound exam for detection of esophageal misplacement and not for endotracheal tube confirmation in emergency and critical care

Focused anterior neck ultrasound exam is related to the lower portion of the front of neck, i.e. above the suprasternal notch, but below the cricoid cartilage. The term “anterior neck ultrasound exam” thereby refers to the examination of both esophagus and trachea in a transverse slice, because both are a “tract”. This is of importance, because the main pathologic finding is the double airway tract sign, which appears when an ETT is misplaced into the esophagus. Therefore, we do not call the examination “airway or tracheal ultrasound exam”, as the esophagus and a possible misplacement are more in focus in emergencies, rather than the trachea and the correct placement of the endotracheal tube.

In this category, the clinical context is a need for urgent or emergency airway management. Pioneering work from Ma G et al., in 1999 [1, later published as full paper 30] and Drescher MJ et al., in 2000 [2] started a novel approach of the detection of esophageal intubation. Ma et al. introduced the static evaluation after intubation in cadavers. Drescher et al. shifted the focus from correct tracheal placement to intentional esophageal misplacements in cadavers, and described the corresponding sonograms in detail, although this was a type #2 exam style (see below). Before these studies, confirmation of correct tracheal placements was the main focus of scientific literature [31,32]. Werner and coworkers added a clinical pilot study [53] and in the further course of the research, learning curves proved to vary between different providers and different experience levels [33,34].

Undiscovered esophageal intubation can result in a disastrous outcome. Therefore, the main emphasis is on the seamless integration of the ultrasound technology into proven processes of emergency medicine under time pressure. This refers to image acquisition, as well as interpretation and decision making.

As for the lower front of neck ultrasound exam styles, both a discontinuous evaluation (type #1) or continuous observation (type #2) available, depending on clinical scenario type (as reviewed in a meta-analysis by Chou [35]. The European Resuscitation guidelines of 2015 recommended ultrasound of the trachea as a secondary option to confirm a secure airway [36].

Note, as an esophageal misplacement can be life-threatening, the central question has to be “Is there esophageal misplacement?”, which has to be answered immediately. In contrast, the question of correct tracheal tube placement is not the main focus of the imaging.

3.3.1. The key findings: double or single airway tract?

In general, the focused ultrasound exam in the lower front neck region provides binary results, mainly based on simple pattern recognition. The sole aim is to immediately identify or rule out a second airway tract, i.e. an ETT in the esophagus. If one places a probe onto the anterior neck, there is normally only one gross finding visible on the screen of the ultrasound machine, i.e. the artifact caused by the trachea (Fig. 3). The artifacts brought about by air and mucosa or cartilage interfaces of the trachea can be distinguished further (Fig. 3, left sonogram). One should not study any detail at this point, but instead, from a bird’s eye view, recognize this “single airway tract” as a typical pattern in the sonogram. Anatomic details of this sonogram are less relevant within clinical scenarios under time pressure. This pattern is easy to identify even for beginners, and one can get used to the exam styles fairly quickly.

If an ETT is correctly placed in the trachea, the pattern does not change significantly. After multiple examinations, the trained operator may discover the mucosa-air interface. At this interface, a slight difference in the sonogram of the trachea with an ETT inserted in comparison to a trachea without ETT can be noted. However, reporting of a correct ETT placement does not solely depend on this air-mucosa artifact.

If an ETT is inserted into the esophagus, the pattern of the sonogram on the screen is significantly different and shows an additional artificial airway tract, so two distinct tracts are displayed (Fig. 3, right sonogram). This finding therefore was called the “double (airway) tract sign” [3]. It is relatively easy to identify the marked difference of a normal, single tract and of a double tract with the educated eye.

Notably, it also doesn’t matter in which orientation the probe is placed as only the finding of a double or single tract counts. In emergencies there would primarily be no need to show if the esophageal tube is placed right or left-sided within the sonogram.

When a double tract is observed, immediate action is required and the examiner should be prepared to communicate findings, e.g. with a single word such as “misplacement” to the team and command to withdraw the ETT and induce to execute another intubation trial.

Notably, when applying this exam, the first cognitive question the examiner should ask is “is there a double tract sign?”. It should not be “Is there one trachea?”, because the central problem addresses the esophageal misplacement, which should be ruled out immediately.

3.3.2. No ventilation trial is required when using focused anterior neck ultrasound for detection of an esophageal misplacement “double tract”

The most significant advantage of this method is, that no positive pressure bag-tube ventilation is required at any time point when evaluating with anterior neck ultrasound for a double airway tract, in both types of exam styles. Further, this is the most prominent difference in comparison to capnography! It is common sense, that at this stage, test ventilations can harm the patient by air insufflation into the (unfasted) stomach in case of an inadvertent esophageal misplacement of the ETT, and thus result in aspiration of stomach contents.

A limitation of this pattern recognition method is, that there is no reliable scientific data available on how often there is a visible double airway tract in the sonogram when an ETT is in the esophagus. The reason for this is that a posterior position of the esophagus is possible, which may obscure a “typical” double airway tract sign, by not displaying a misplacement, or making it hard to identify. This may happen, especially when the ETT is behind the trachea artifact and also if an ETT is of a small size. This can in part be overcome by a slightly more lateral insonation, visualizing a larger portion of the esophagus, and the area dorsal to the trachea. Thus, following pattern recognition, the key finding has to be captured at a glance. In doubt, another intubation trial should follow, but not extensive sonography. Remember, it would ultimately cause an unintended time loss when the examiner has to search for that sign.

Also, regarding the clinical process, the roles and seniority have to be clearly pre-defined. The ultrasound examiner is the leader as he or she interprets the scan in real-time and must communicate firm information to the team. Mixing the roles can lead to further confusion and disturb the process. Of course, the application of anterior neck and airway ultrasound has to be trained, as much as laryngoscopy, capnometry and fiberoptic intubation have to be.

3.3.3. Two types of focused anterior neck ultrasound exam styles depending on the clinical scenario

Two types of focused lower anterior neck ultrasound exam styles can be distinguished, related to different types of clinical scenarios and workflows. Regarding their implementation into emergency cases, one needs to understand the key elements of those completely different management strategies (Fig. 3). However, both aim to only identify an esophageal misplacement at the earliest possible time point.

Type #1 exam style - Discontinuous “on-off” evaluation, post-intubation.

“Imagine looking outside at a parked car”.

Ma et al. reported [1] and Drescher et al. of a focused anterior neck ultrasound exam post-intubation in cadavers [2]. Both groups called it static, however, they concentrated their scientific understanding and reporting more on the intubation process itself. Only later Zechner et al. suggested a novel point-of-care ultrasound protocol called “the airway ultrasound exam”. It combined a stethoscope-like protocol of the anterior neck post-intubation within a clinical context with a lung sliding evaluation [37]. Later Adi et al., in 2013 and Abbasi in 2015 adopted this clinical practice as well [38,39].

This exam style type #1 is kind of a quick check with putting the probe onto the inferior front of the neck, especially below the cricoid, and above the suprasternal notch, combined with a brief sonoscopy of this anterior neck region (Fig. 5) [4]. However the approach is not just placing the probe in one skin position and producing a single image, but rather a controlled sonoscopy of a 3D-space volume. It should be examined quickly in the vertical axis of the neck from cephalad to caudad, with a sweep of parallel ultrasound image planes or, with oblique planes as well as with a in-plane movement to the right and left or angulation of the probe in the transverse plane of the anterior neck.

In the case of esophageal intubation, the sonogram shows a typical double airway tract (Fig. 3), which is not visible in correct

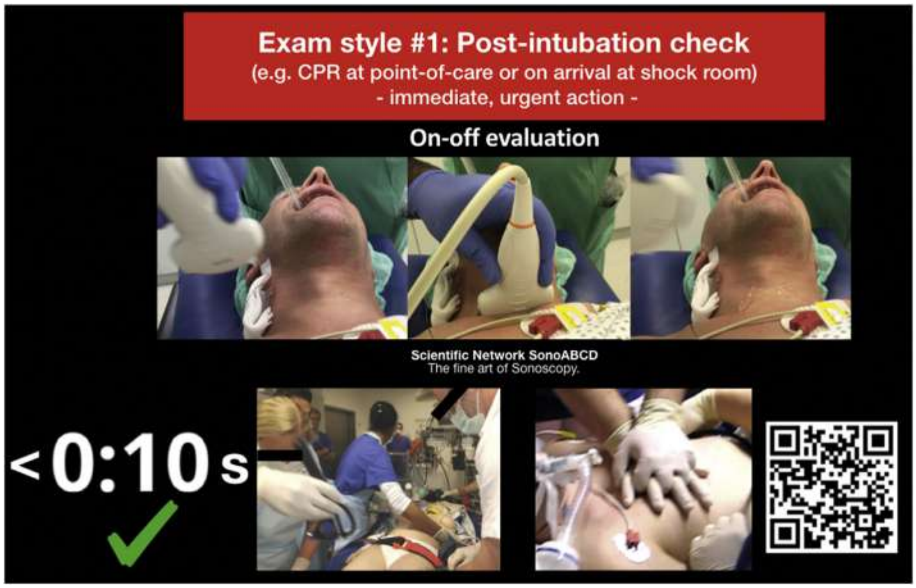

Fig. 5. Post-intubation evaluation of esophagus and trachea “tracts”, exam style #1 (post-intubation).
This exam style #1 has to answer only one key question: Is there an esophageal misplacement? Only exam style type #1 can be applied in an ALS-conformed way of less than 10 s. Remarkably, no ventilation is required for answering the question. The image illustrates the dynamic stethoscope-like approach by putting the probe briefly onto the anterior neck, above the suprasternal notch and removing it after the scan. See the video of the exam at www.yumpu.com/en/SonoABCD [41]. Note that the type #2 exam style is widely different.

tracheal intubation. In contrast to type #2 exam style, the focus is not a dynamic change or movement but a focused observation. This interpretation comprises only the binary question as to whether esophageal intubation is present or not.

This type of sonoscopy of the anterior neck region can be completed within approximately 10 s or fewer (starting from skin contact with the probe until its removal). It is a novel description and interpretation of this method and can be viewed online [40]. In the former cadaver studies, this was not described regarding a clinical context, and there were no movies available showing its details [2,30].

Type #1 exam style applies to clinical scenarios, such as shock room cases when the emergency physician (EP) is handed over a patient whose endotracheal intubation was performed by somebody else. Furthermore, whenever an outreach team, a medical emergency team or prehospital team takes over a patient undergoing CPR, who has been intubated by someone else, this quick “on-off” check would be of interest. Such a discontinuous approach “post-intubation” can be accommodated into an ALS-conformed time frame of 10 s if interruptions of chest compressions are required [40]. This examination can even be performed without any interruption of chest compressions. In this approach, only one examiner and a ready-to-use, booted, mobile point-of-care ultrasound device is required.

Type #2 exam style - Continuous evaluation, also teaching difficult airway, observing with ultrasound.

“Imagine watching a car drive past”.

In contrast, the exam style type #2 (Fig. 6) is a diametrically opposed approach and should not be mixed up with exam type #1 as described above. In 1999 and 2000, Drescher and Ma et al. independently reported a real-time tracheal ultrasound assessment of tube placements by direct observation *during* sections, or all steps of intubation attempts in cadavers [2,29,30]. Chou et al. introduced an exam style called TRUE (the tracheal rapid ultrasound exam) in emergency cases [3]. Although the name of the acronym suggests a type #1 exam style, the scientific study dealt with type #2 only. And again, as the main focus is esophageal misplacement, the name tracheal rapid ultrasound exam is highly

Fig. 6. Anterior neck ultrasound exam style #2.
This is an evaluation during the entire intubation process and cannot be applied in an ALS-conformed way. Note the differences in comparison to type #1 exam style. Remarkably, no ventilation trial is required in either exam styles to answer the question of esophageal or tracheal ETT placement. Regarding this purpose only, this detail is the major advantage in comparison to capnometry or auscultation, because these require ventilation trials.

misleading. A better title would be “anterior neck rapid ultrasound exam” or something similar. Within emergency intubation mostly related to cardiac arrest victims, this rapid ultrasound examination was performed during, i.e. in parallel to the rapid sequence intubation process. The probe was held on the anterior neck to visualize the trachea. The examiner then waited with the probe positioned above the suprasternal notch region and continuously evaluated what would occur on the screen during the real time tube insertion. In the study of Chou et al., post-intubation checks included capnography, auscultation and pulse oximetry [3].

Elucidating the observations of the type #2 exam style, in case of correct tracheal intubation, no marked change of the sonogram will appear, except for a little wiggle movement of the trachea with few air-mucosal reverberation artifacts during the passage of the ETT. In the case of esophageal misplacement, a second airway with a pattern similar to the sonogram of the trachea will suddenly pop up: the double tract sign as described with type #1. This observation focuses on gross dynamic changes in the sonogram, as continuously viewed by the observer, in addition to the binary check for the double tract sign. In contrast, tracheal intubation would not be noted as a spectacular change in the sonogram. A key disadvantage of this application type is its time consumption, going from preparation and execution of laryngoscopy until completion of the ETT insertion. The length of this ultrasound exam lasts for a minimum of 60 s, mainly depending on the time spent for laryngoscopy until tube insertion. This renders an ALS-conformed application very challenging, although an attempt during continuous chest compressions and brief interruptions before final insertion is theoretically conceivable. Nevertheless in our practice, only the portion of the already indwelling of the tube, but not laryngoscopy itself, should be observed by ultrasound, for timing reasons.

The advantage of this type #2 exam style is that this approach is well suited for teaching. However two investigators have to be at the scenario, one performing the (difficult) intubation and one observing with the ultrasound the front of neck during insertion. Chou et al. also added a senior supervisor for the team [3].

Confusion was created by Drescher's original description [2], because the type #2 exam style was named a "dynamic exam". This also may apply to Chou et al. [3] suggested showing a sonogram with a double tract sign in the Tracheal rapid ultrasound exam (TRUE). This is highly suggestive of the much more rapid exam style of type #1, however, they only used exam style #2. In our opinion it depends on the perspective of what the observation target is: In type #2, the clinician sonographer does not move the probe and the intubation can be seen as regular action while a dynamic change may occur in the sonogram. In contrast, in the type #1 exam the clinician sonographer is more dynamic with the probe but indeed acquires a result which is a relatively static sonogram. Thus using the word "dynamic" does not really explain the exam styles and can be misleading. It would be better to explain the action and role of the ultrasound examiner, i.e. more dynamic in the type #1 exam style and more or less static in the type #2 exam style.

Taken together, type #1 and #2 anterior lower neck ultrasound exam styles [40] (Figs. 5 and 6) are two widely different observation methods, but mainly exploit the same sonographic pattern recognition of either a double tract or a single airway tract. These exam styles markedly differ in the underlying manual process, regarding dynamic work with the probe, time and resource requirements, as well as the clinical scenario and context. However they aim to look for the same results of sonogram patterns, regardless of a few changes in the sonogram during type 2# exam style.

Type #1 or Type #2 in teaching critical rapid sequence induction intubation.

There also may be overlaps of clinical scenarios, and when and where type #1 or type #2 airway ultrasound exam styles could be applied. Whilst teaching difficult airway combined with a patient in critical illness, the supervisor would normally assist the more junior doctor to perform a rapid sequence induction. Conventional tools for supervision include watching the videolaryngoscopy at the same time, or only checking the final result with direct laryngoscopy - very much the same dichotomy as between type #1 and type #2 anterior neck ultrasound exam styles. Again, no ventilation trial would be required when applying type #1 or #2 exam styles.

Conventionally, without exploiting ultrasound, significant dynamics of the situation and insecurities arise following a failed intubation attempt, or if direct visualization of the vocal cord passage via laryngoscopy is not possible. In that case, usually ventilation attempts and auscultation will follow. Further stress inoculation results from changes in the tone and numbers of pulse oximetry, potentially aggravated by low or absent capnography readings. If a direct visualization of the insertion is not possible, the judgment remains insecure. Note that insecurities will to date normally result in ventilation attempts in order to check with auscultation and capnography. Then the supervisor is under pressure to take over the laryngoscopy attempt. Further changes in the sound and values of pulse oximetry indicating a beginning desaturation puts more pressure on the team. Unclear capnography results, going from lower values to zero can cause further confusion and will take much longer than the type #1 exam style. This is not an unusual clinical scenario.

3.3.4. *A novel, ultrasound-assisted process for teaching RSI?*

Exactly in such a scenario, either exam style #1 or #2, may add value in assisting teaching and preserving the independence of the junior doctor with "silent" observation by the supervisor (thus enhancing the training effect), but providing reassurance regarding ETT confirmation at an early stage of the process. The supervisor should first choose whether to perform a type #1 or type #2 exam style, depending on the severity of the patient's condition. In elective intubations and clinical routine situations, a supervisor can also support the junior doctor via silent observation if there is no videolaryngoscope in play. This helps to train difficult airways, overseeing but not prematurely disrupting the process. Type #1 could be used to solely observe the result (confirmation of endotracheal tube position), whereas type #2 could also assist during the intubation process itself, i.e. at the earliest time point of observation by the supervisor. This way he or she can give a suggestion for a correction and confirm the correct placement after a further attempt before the ventilation trial [40].

Note the potential conflicting visual distractions between observing a sonogram on a screen of an ultrasound machine and observing laryngoscopy or vital sign monitoring (i.e. pulse oximetry) in parallel on another monitor for both, supervisors and trainees. Therefore a decision should be made before the induction, as to which screen has priority for which team member. Also, all the steps of the process, including the sequence of an ultrasound check prior to ventilation attempts, should be reviewed with the whole team in a pre-briefing.

Without ultrasound, auscultation, as well as capnography, require ventilation attempts in both cases of tracheal or (unknown) esophageal intubation. With focused anterior ultrasound of the anterior neck area/trachea, for a definite result, no ventilation trial is required. Thus the process of a supervised RSI could be improved with anterior neck ultrasound until the check of the placement of the ETT, as unnecessary ventilation attempts can be spared, while esophageal intubation is discovered much earlier.

3.3.5. *Role of capnometry/capnography when questioning tube position: ventilation trials are always required*

Capnometry cannot indicate the tracheal or esophageal position of the ETT immediately. It follows a distinctly different purpose because it can be used for monitoring and thus be viewed as a functional measurement. The advantage of capnometry is the continuous monitoring of ventilation, as well as carbon dioxide production (cellular metabolism), and transport (hemodynamics). Thus, this is a completely different function in comparison to the anterior neck and airway ultrasound. Regarding the question of esophageal intubation, a post-intubation check of the lower anterior neck region via ultrasound will ultimately give a quicker result. Despite major advantages of capnometry in monitoring ventilation, in routine intubations, and even in cardiac arrest states, capnography can be considered a slightly slower, and during the first few moments more uncertain decision maker, as the values do not drop immediately to zero mmHg or fall with a slow slope in case of esophageal intubation [37]. Thus, in direct comparison with front of neck ultrasound, but only for the question of the presence of an esophageal misplacement, directly after intubation, capnometry will always carry the necessity of ventilation trials, until reliable values are recorded. Further capnometry is also slower in comparison to the combined anterior neck and airway ultrasound exam (trachea and together with lung sliding) after emergency intubation scenarios [41].

To be clear, despite these above-mentioned differences, capnography is still considered as the gold standard of endotracheal tube confirmation, together with direct visualization of the passage of the vocal cords, or fiber-optic confirmation. Current resuscitation guidelines recommend ultrasound as an alternative method [36]. However, it is not unusual that capnography is unavailable, or fails, in a given case. Examples are blockage of the CO_2 sensors or lines by airway secretions, or low or absent end-tidal CO_2-readings due to impaired perfusion of the lung or due to calibration latency and technical error. An extreme form is a cardiac arrest due to obstructive pathologies such as pulmonary artery embolism or tamponade, or trauma-induced cardiac arrest due to exsanguination. In all of these cases, capnography can be unreliable. Finally, until now, capnometry is still not always available (in Germany) in every emergency system which is also the case for point-of-care ultrasound devices. Personal ultrasound devices, if available, may aid as a secondary option as well as backup.

3.3.6. Training remarks and ergonomics

Both these types of focused anterior neck ultrasound exam styles have to be trained. There are three major tasks to be trained: i) Probe movement and landmark region, ii) visual perception of two sonographic patterns with firm interpretation and execution of decisions and iii) related clinical scenarios. Probe movement and image acquisition can be trained basically in any individual, but then without the finding of esophageal misplacement. Chenkin et al. described the learning curves of emergency physicians [33].

For the type #1 exam, the normal findings can be trained on healthy individuals as well as intubated patients. We recommend using routine anesthesiology procedures. As a trachea with a correct ETT placement appears similar to an unintubated trachea in the sonogram, one could mainly train this exam style even without an ETT, in any self-made simulation scenario, on anybody. The cognitive focus is on understanding the double negation: not seeing a double tract, then actively confirming correct positioning with a verbal statement ("no double tract" or "airway clear"). It is also important to understand how an empty esophagus can appear on the screen, or even be invisible due to its position behind the trachea (Figs. 3 and 4).

Type #2 exam style normal findings can be trained in any routine intubation process, e.g. in predefined ASA 1 patient with informed consent. The main emphasis should be on role assignment, as holding the probe may compete with the grip of the laryngoscope, and laryngoscopy observation with the pattern recognition of double airway tract sign. The required psychomotor skills, i.e. manual work with the probe and image perception, can be trained during routine anesthesia procedures, as far as a correct ETT placement is concerned.

The challenge is finding alternative technology to observe similar double tract appearance on an ultrasound image mimicking esophageal misplacement, making training of both exam types possible. However, one could also split the exam into sections which can be trained either in the OR or a similar environment, and train pattern recognition of sonograms on a separate computer.

Clinical training opportunities include several options: An intended esophageal misplacement in an ASA 1 individual undergoing elective surgery raises ethical issues and definitely would require informed consent. When informed consent has been obtained, further sufficient preoxygenation and denitrogenation, as well as passive oxygen insufflation and strict time-keeping, is necessary. If a Cormack & Lehane grade 1 laryngoscopy finding reveals easy principal intubation feasibility, a transient esophageal advancement of the ETT, can be observed by a second examiner who holds the probe on the anterior neck and saves a real-time video clip. Both type #1 and #2 exam styles could be applied on the basis of this agreement consecutively.

Immediate withdrawal and correct tracheal intubation would follow, optionally accompanied by a second real-time ultrasound scan. In this way, four serial anterior and airway ultrasound exams could be studied on one patient. However, because of the ethical dimension, further alternatives should be considered as well. We would like to suggest placing an ETT in the clinical routine in an anesthesia department and confirming the correct position first. Only thereafter a second (small) tube can be advanced carefully into the laryngeal esophageal orifice for training purposes, depending on mouth-jaw opening capability. Further options could be the observation of the anterior neck *during or while* (to mimic type #1 or type #2 process) gastric endoscopy, TOE, larger bore stomach tubes or self/proband esophageal intubation with a small, uncuffed ETT of 5 mm inner diameter with lubricant/local spray anesthesia.

3.3.7. Sonoscopy of the airway as an extension of the clinical exam in routine and critical care applications

The term "Sonoscopy" in general describes the art of stethoscope-like use of ultrasound on distinct regions of the body surface. Sonoscopy pronounces the goal-directed dynamic aspect of an ultrasound exam, in which the probe is either moved like the dome of a stethoscope thus looking similar to a stethoscope examination, or explores 3D tissue volumes in one position with the educated eye.

In contrast, the term "point-of-care ultrasound" only implies the variable place (location) where the exam is performed, but not the progress of probe motion or type of the exam itself. The difference between both of these concepts of conventional ultrasound imaging in routine diagnostics, lies in the continuous, dynamic movement of the probe, sliding or hopping, inter-regional, inter-organ or inter-system approach, while both the visual and consecutively the cognitive evaluation focus on fewer, potentially pathognomonic parts of the image information.

Weaver et al. showed that lung sliding principally can confirm tracheal placement in cadavers post-intubation. However, this was an indirect measure only, for study design reasons, as upper airway and trachea had not been examined by the sonologist [42]. Nevertheless, this paper opened up the idea to also functionally assess the airway with ultrasound. This can be done at the level of the anterior chest (lung sliding) and posterobasal (lung sliding, diaphragm motion). Note that lung sliding of the left anterior chest may be confused with the motion of the heart. Therefore a more lateral approach should be considered on this hemithorax.

We initially explained the concept of a gainful combination of multiple exam positions as the "Airway Ultrasound Exam" in emergencies [29,43]. Thus, ultrasound technology can be applied in a stethoscope-like method within a novel "Airway Ultrasound Exam". The approaches are called "protocols" in the new field of point-of-care ultrasound exams or methods. Airway Ultrasound Exam, therefore, describes the concept of combining different functional modalities of ventilation and examining anatomical locations: e.g. tracheal with lung or diaphragm ultrasound or evaluation of the airway and breathing system without trachea, such as diaphragm function or others, applicable in the routine as well as critical care applications. This is not only one image per probe position but examines and evaluates with the probe in motion, observing the patterns on the ultrasound screen. This is more like a dynamic examination and therefore can also be viewed as "sonoscopy".

3.3.8. Airway ultrasound exam: mainstem intubation?

In anesthesiologic, emergency or critical care scenarios, including CPR, another key question addresses mainstem intubation. Mainstem intubation is more likely to be observed on the right hemithorax. When combining anterior neck evaluation with types of lung sliding (that is lung sliding or the lung pulse) on both sides, it can be used e.g. to assess possible main stem intubation. This is a simple protocol also extending anterior neck ultrasound to the "Airway Ultrasound Exam" [37]. A limitation now is, that this does not contain the complete anterior neck and airway ultrasound needs for emergencies for it is limited to airway and thus does not include esophagus by name. Thus it should be better named "anterior neck and airway ultrasound exam". Lung sliding is the depiction of a regular rhythmic motion synchronized with respiration that occurs between parietal and visceral pleura, that are either in direct apposition or separated by a thin layer of intrapleural fluid [44]. Lung pulse refers to the subtle rhythmic movement of the visceral against the parietal pleura with cardiac oscillations [44] and also most likely lung vessel pulsations. Importantly, in contrast to the above-described exam styles of anterior neck assessment in with ultrasound, the check for mainstem intubation with ultrasound always requires one or more ventilation actions. In this question both airway and lung ultrasound and capnography can be weighted as alternative methods. However, for special clinical circumstances such as CPR, capnography can take more time and ventilation attempts and may theoretically be more insecure [37]. If continuous monitoring is required, capnography is better suited, as lung ultrasound can be only applied discontinuously. In a randomized-controlled, double-blinded study by Ramsingh et al. in 42 patients undergoing general anesthesia, an ultrasound showed significantly higher sensitivity and specificity than auscultation in detecting bronchial main stem intubation [45].

To rule out right mainstem intubation, it is advisable to start with the left hemithorax. If a lung pulse is visible, but lung sliding is not, there is a high possibility of mainstem intubation, which can be communicated within the team and corrected immediately. If there is no time pressure, one can begin the examination on the right hemithorax and compare the sides.

3.3.9. B-Mode or M-Mode?

B-Mode exploits all the width and length of a probe so it will normally provide enough information, which can be quickly assessed with the educated eye. M-Mode is another method to display movement (Motion Mode). It is a dependent modality and only focuses on one particular area which the examiner can specify. It can be used to visualize lung sliding more sensitively if lung motion is in doubt whilst in the B-Mode. However, as the M-Mode observes a point rather than a region, it is necessary to scan many positions. Sonoscopy with the M-Mode is rather unfeasible, as the image is always disturbed when the probe is moved at the same time. Further, the front of neck region does not need M-Mode assessments, so that anterior neck ultrasound exam would require switching from B-Mode to M-Mode, taking additional time. This is especially relevant in the context of resuscitation scenarios with time pressure. The M-Mode function only shows a small section of the region of interest and is, therefore, more time consuming going from the start of function until interpretation. This again makes an ALS-conformed application unfeasible.

4. Anterior neck an airway ultrasound is part of "resuscitation ultrasound" [40]

Anterior neck and airway ultrasound, capnometry and -graphy, laryngoscopy, as well as videolaryngoscopy and fiberoptic intubation are independent airway or functional control methods with distinct aims.

Previously, focused cardiac ultrasound was in the centre of interest to detect reversible causes of cardiac arrest [46]. In emergency and critical care medicine, anterior neck and airway ultrasound can now be regarded as a part of "Resuscitation Ultrasound". This now is a powerful collection of methods with modern (small) ultrasound devices to check and monitor for vital functions within the circulation, airway and ventilation [4,22,40,46–48].

Resuscitation can be structured in A, B, C and D problems or phases. A common problem in all phases is time pressure. Therefore the processes of sonoscopy require brief, focused exam styles, strictly compliant with ALS-rules, with rather qualitative or semi-quantitative ("eye-balling") than quantitative evaluation by trained operators to recognize typical patterns. In contrast to traditional ultrasound applications, detailed assessments or measurements are de-emphasized.

Following a broader definition, resuscitation ultrasound contains the following exam options: First, focused assessment with a combined sweep of the heart including IVC to search for treatable conditions of a cardiac standstill, corresponds with the "C", circulatory problems. Second, this now could be extended with anterior neck and airway ultrasound exams corresponding with the "A" and "B" parts. Airway and functional lung ultrasound, therefore, is a part of "Resuscitation Ultrasound" in clinical scenarios of peri-resuscitation, the core part being a type #1 anterior neck exam style, which can be performed in fewer than 10 s. If esophageal misplacement is ruled out (and thereby tracheal placement confirmed), the assessment of lung sliding can be added to check for mainstem intubation. In trauma or post-interventional cases, this stethoscope-like ultrasound exam style of lung sliding and/or lung pulse can also help rule out a pneumothorax at the same time [40]. Note that scientific evidence has been acknowledged in the ERC-guidelines of 2015, where ultrasound is regarded as the "secondary option to confirm a secure airway" [46]. Again, the core problem is not reflected in the guidelines by the term "to confirm a secure airway". As the life threatening problem in resuscitation is esophageal misplacement, a stronger emphasis should lie on the fact that anterior neck ultrasound is considered as a "secondary option to rule out esophageal misplacement" will be available faster. Conversely, capnography remains a first option to rule in correct tracheal placement of the endotracheal tube. However the cited studies only tested the type #2 exam style *(continuous evaluation)*, disregarding the possibly better fitting type #1 exam style (*discontinuous approach as "on-off" evaluation, post-intubation).*

4.1. Limitations of anterior neck and airway ultrasound exams in resuscitation

Regarding the clinical context of emergencies and the application of ultrasound of the anterior neck exam style #1, a ready-to-use, booted, mobile point-of-care ultrasound device, which had been put a standard preset is obligatory. This requires an ultramobile, lightweight or even personal ultrasound device as well as a clear predefined procedure description. These items, as well as training, should be just as available to clinicians as oximetry or ECG monitoring, especially as the exam itself is relatively simple.

To respect the rules of the ALS-guidelines, all ultrasound exams should be conformed to the ALS processes and the ALS should be viewed as the driving force. Any possible interference with chest compressions must be prevented. The check for mainstem intubation, ruling out a pneumothorax or obtaining findings for it would require ventilation [49] and may take longer than 10 s. Therefore the examiner should be monitored by other team members, to ensure minimum time loss. For these procedural aspects, (simulation) training is essential.

4.2. Known or unknown cardiac standstill

In phases of cardiac arrest or EMD/PEA states, focused sonography of the anterior neck and trachea is applicable and can still show esophageal or tracheal intubation in both type #1 or type #2 exam styles. However, lung ultrasound cannot distinguish between mainstem intubation and pneumothorax during cardiac arrest states. Within mechanical CPR, it would be hard to look for lung sliding, although it can be possible for a trained and experienced physician in phases without chest compressions.

A problem arises when there is no heartbeat. *In this case mainstem intubation would mimic a pneumothorax on the non-ventilated hemithorax, despite there not being a pneumothorax.* The typical finding of a lung pulse in main stem intubation on the non-ventilated hemithorax requires a heartbeat, as it derives from the passive motion of the lung due to the heartbeat and lung vessel pulsations. Further, observing the lung pulse is not a secure method whilst significant myocardial contractions can not be clearly distinguished, causing prolonged intervals between chest compressions. Also, no publication served with findings of a lung pulse in pseudo-PEA states, when the ejection fraction is just less than 10%. In phases of cardiac standstill therefore, the observation of “no lung sliding and of no lung pulse” during a check for main stem intubation is not reliable, because if indeed mainstem intubation is present it will mimic a pneumothorax, although there is none.

4.3. Known or unknown pneumothorax

A complicated clinical scenario is, for instance, the problem with trauma patients under running mechanical resuscitation, where an anterior (occult) pneumothorax can not be ruled out. In this case, confirming a pneumothorax with airway ultrasound exam methods can be difficult and cannot rule out such a diagnosis with certainty.

The first problem is questioning secure an upper airway when the peripheral oxygen saturation is not above 90%. As explained above, whenever a known or unknown pneumothorax is present, focused sonography of the anterior neck can still show esophageal or tracheal intubation in both type #1 or type #2 exam styles. If there is no double airway tract sign, ruling out a mainstem intubation would be the next step.

Further, in contrast to routine punctures close to the thorax (e.g. CVK insertions), complex polytraumatized victims are more likely to have mediastinal and posterior pneumothorax. Thus ultrasound cannot rule out or diagnose it entirely [50]. A CAT scan is extremely challenging during mechanical CPR whilst conforming to an ALS standard, but remains the gold standard in this overall clinical context. Decisions for rescue punctures have to be based solely on clinical evidence.

However, in the presence of a pneumothorax, again, ultrasound findings of lung sliding and lung pulse are not visible, as the ultrasound beam is reflected by the trapped air of the pneumothorax completely before it can reach lung surface. Therefore, there is no chance of distinguishing between the presence of a pneumothorax or a mainstem intubation, as the pneumothorax will obscure findings of lung sliding and lung pulse in this case.

Taken together, unveiling a pneumothorax or even a tension pneumothorax in an ALS-conformed way, is therefore not possible. This is opposing a small detail of the ERC guidelines 2015 where it had been recommended, without citing any evidence [46]. Therefore we provide our theoretical explanation.

4.4. Known or unknown pneumothorax in combination with cardiac standstill

The known or unknown combination of both pneumothorax and cardiac arrest states or pseudo-PEA/EMD states with weak contractions is even worse. Again, focused sonography of the anterior neck and trachea still can show esophageal or tracheal intubation in both type #1 or type #2 exam styles. However, regarding lung ultrasound, neither mainstem intubation nor pneumothorax can be firmly ruled out or diagnosed in cardiac arrest states.

Training remark: These observations can be trained on cadavers, but also cognitively by reading, in classroom training with sonograms, arranged to depict each finding. It can also be included in modern simulation technology. Clinical training alone seems not to be appropriate.

4.5. Suction catheters or stomach tubes to mimic a double tract sign

Soft stomach tubes (SST) and suction catheters (SC) can mimic a double tract sign (Fig. 7). Remarkably, this has been possible with sizes as small as CH16 with an outer diameter (OD) of 5.3 mm. This is only half of the OD of an ETT (OD of 10.6 mm, equivalent to inner D 7.5). Depending on OD size, it is likely that not every SST or SC will produce dorsal shadowing. It may also depend on the echogenicity of the material (plastic will mimic, silicon may not) (Fig. 7).

In a clinical setting, it is a rare situation in emergency medicine that a SST or SC is placed before emergency intubation and would confuse a type #1 exam style. However, if this was the case, a double tract sign caused by a SST or SC could result in a false-positive interpretation of an esophageal misplacement of an ETT, although the ETT is endotracheal.

Regarding the type #2 exam style, in the clinical context of unfasted individuals who received an SST (e.g. ileus or ICU-patients with remaining stomach tube) prior to RSI- intubation, this can be kept observed. The insertion of an ETT in addition to an SST into the esophagus can be visualized in real time.

Training remark: The main training problem addresses how to practically train a “double tract sign” within type #1 exam style in airway management, ALS or ultrasound courses (on healthy individuals) and outside of the operation theatre. In critical care medicine, it would be possible to train this method on intubated patients who have an inserted ST or SST. In clinical anesthesiology the use of laryngeal mask airways with “gastric access” could also be exploited in routine work. In both options, the trainees would be able to identify a double tract sign. However, these are not likely to represent a training scenario in emergency cases.

Regarding hands-on training in courses, a SST or SC could be placed in healthy volunteers, by gentle assistance with a sip of water. In addition, a truncated ETT could be held in the mouth to simulate an intubation. For the clinician sonographer this would enable the examination of an apparently intubated individual with the sonographic double tract sign finding.

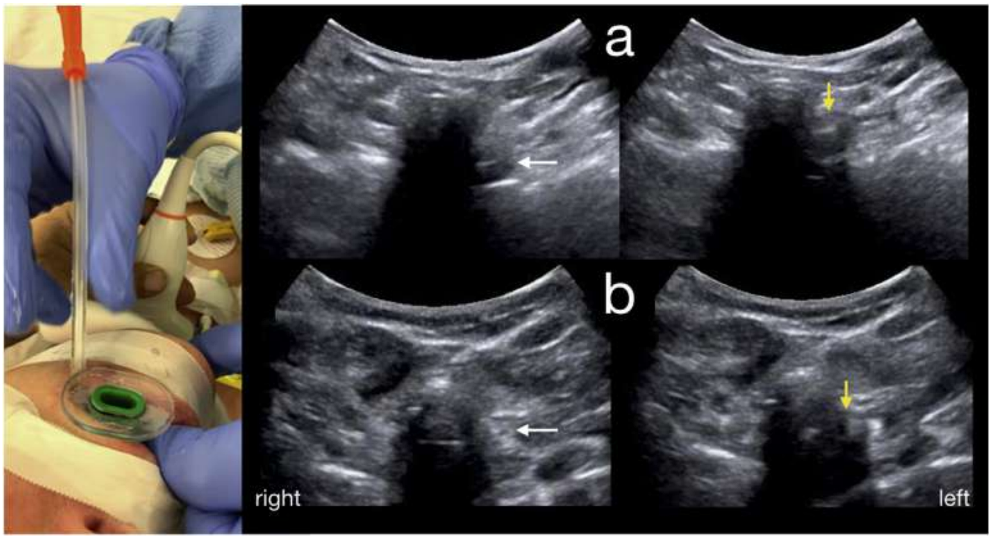

Fig. 7. Suction catheters (SC) and soft stomach tubes (SST) can mimic a double tract sign.
Representative image of clinical context when obtaining the sonogram.
a; patient #1, female, spontaneously breathing, w/o ETT, before (left sonogram) and after insertion (right) of a SC (CH16, DCT, Servoprax, Wesel, Germany, outer diameter 5.3 mm).
b; patient #2, female, w/o ETT, before (left) and after insertion (right) of a SST (CH16, Unomedical, ConvaTec, Deeside Ltd., UK).
White arrows indicate the esophagus short axis slice and position before insertions. Yellow arrows show the midline of the catheter or tube resembling a double airway tract with dorsal shadowing. Mucosa is hypoechogenic (dark, halo). Plastic material of SST appears stronger in dorsal shadowing than silicon material of SC. These double airway tract signs induced with SC or SST, look quite similar in comparison to an ETT of CH 32 (OD 10.6 mm). Compare also with Fig. 4. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4.6. What do anterior neck and airway ultrasound look like?

Although represented in the scientific literature for more than 10 years, literature can hardly give an authentic real-life clinical impression of the exam. To provide a solution for this problem, we produced short movies to show the procedures at SonoABCD's I Knowledge & Ressources on Yumpu, see www.yumpu.com/en/SonoABCD [51]. The video clips represent the anterior neck and airway ultrasound exams to prepare and train for resuscitation scenarios. Those video clips can also be downloaded and used for free for educational purposes.

4.7. Future directions

4.7.1. Expand toolbox for airway management, establish novel processes and train

Based on the evidence, the challenge in the future will be widespread availability of devices to apply point-ultrasound for clinicians, just as EKG or defibrillator or mobile airway management devices have been established. For example, a lower anterior neck ultrasound exam style #1 can only be applied, if the managing "systems" serves clinicians with suitable point-of-care ultrasound devices. This also means establishing regular processes for the general and difficult airway management toolbox. Regarding fast driving clinical processes and decision making, ad hoc calling for an ultrasound device or sonographer to get it with time latency in an emergency environment will not be beneficial. Therefore we advocate standard protocols for the system to integrate the anterior neck and airway ultrasound methods, which need to be trained regularly.

Regular training-scenarios are essential to keep up acquired skills against the background of patient safety [52,53] Simulation is an important tool in learning and keeping skills, especially in context of airway management with an improvement of patient safety [54].

4.7.2. Collection of anterior neck and airway ultrasound exams: further protocols

Historically, saline-mediated cuff filling started to explain tracheal tube positions [31].

Šustić et al. extended the number of possible indications for anterior neck and airway ultrasound applications [23] regarding safety for dilatational tracheostomy as well as the function check of a double-lumen tube [55]. Those combined assessments relate more to clinical routine such as ventilation checks of double-lumen intubation, main stem intubation of a tracheal cannula in critical care, in children or in ambulances/helicopters with higher loudness. Other methods such as isolated exams of lung sliding only play key roles in ruling out pneumothorax (within the eFAST exam). Diaphragm motion examinations to assess tube placements gained interest but did not establish. However, diaphragm motion can be of interest after regional anesthesia procedures, e.g. in postoperative dyspnoea or when extubation trials fail, to look for underlying causes. Another direction could be the novel stethoscope-like exams.

4.7.3. Anterior neck and airway ultrasound protocols: stethoscope-like exams!

Regarding anterior neck and airway ultrasound to assess also functional observations, the ultrasound probe can be used in a stethoscope-like way to assess ventilation. Regarding airway management the stethoscope can easily be replaced by a pocket-sized ultrasound device. If clinicians have access to a personal ultrasound device, the examinations can be superior to other diagnostics via stethoscopes. This way, the anterior neck and airway ultrasound exams can vary depending on its clinical question. Dynamic stethoscope-like exams of the thorax with lung ultrasound can also assist detection of congestion (B-line assessment), ruling out pneumothorax or examining for effusions. The latter can also be of interest in resuscitation ultrasound because it can be another reason for hypoxia, which is a treatable cause of cardiac arrest. Those exam styles may look similar, however, they differ in clinical context and question, and include distinct cognitive processes of the clinician sonographer. Note that not all questions can be answered in this way. Wheezing can not be detected with ultrasound and the diagnosis of a pneumothorax, or peripheral pulmonary emboli require the examination of more thoracal areas, increasing time requirements. *Training remarks:* For example clips and impressions of exam styles, see Refs. [50].

4.7.4. Gastric ultrasound in unfasted individuals

To think further, regarding front of neck ultrasound type #2 exam style in unfasted individuals, it would be of interest to assess gastric content prior to an RSI. Gastric ultrasound methods are also readily available and simple and can be used as an extension of the physical exam. These can be applied in the clinical context when planning exam style #2 (see www.gastricultrasound.org and video clips on www.yumpu.com/de/SonoABCD) [51].

4.7.5. Pediatric airway management

Anterior neck and airway ultrasound techniques started with their very first innovations in neonates [31]. All protocols mentioned in this paper can be applied to children as well. Confirmation of tracheal tube placement and insertion depth [5,6,56,57], as well as the identification of the cricothyroid membrane and other airway structures, have been described [58,59]. Technical limitations include the surface area of the ultrasound probe, while image resolution and visibility of structures are usually better than in adults. Because pediatric ETT with inner diameter (ID) sizes of 3 mm or less are uncuffed, main stem intubation can be underdiagnosed due to a higher probability of retrograde ventilation. Remarkably, this can also not be firmly diagnosed with a stethoscope.

The current role of anterior neck and airway ultrasound in pediatric airway management seems to be even less clear than in adults. Other than with the rapid surgical techniques in adults, there is a paucity of alternatives in a pediatric CICO situation ("call for expert help"), and considerable danger of complications [60–63]. Future directions of research should at least include ultrasound-support for interventions into their considerations. A prerequisite will again be growing familiarity with the modalities and views during the clinical routine.

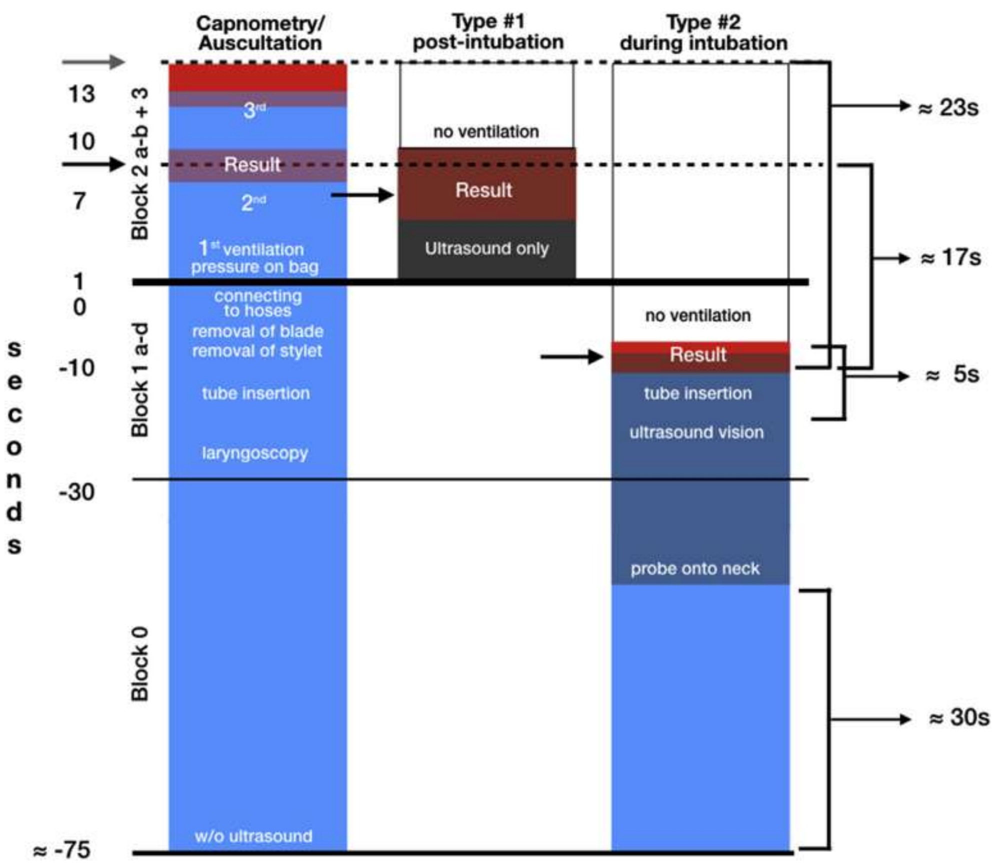

Fig. 8. Workflow and time course during and after an optimal RSI with measures of capnometry and ultrasound for comparing methods.

Numbers are based on time tracking video clips of representative airway management procedures. Stacked bars indicate presumed workflow steps and timings of a rapid sequence induction (RSI) until confirmation of (endotracheal) tube placement. Comparison of capnometry/auscultation (bar graph 1) against anterior neck ultrasound exam styles #1 (bar 2) or #2 (bar 3). An ideal conduct (blue) for all workflow steps is presumed. Ultrasound application phases darken the bar portions for the time of its use. Red squares show if the final result is dependent from the respective method and mark its time span.

Horizontal arrows mark the expected mean time point for results and decision making. Left column, numbers 1, 2 and 3 indicate reservoir bag pressure. The capnography result follows directly thereafter only. Exam style #1 starts with the method itself by definition. The first portion of exam style #2 commences with probe placement and is in parallel with intubation conduct. For details to workflow steps see text.

Note that the ultrasound exam style #1 would be roughly as fast as capnometry/auscultation, or even earlier, depending on the time the ultrasound exam would take. In our experience this is in between 5 and 10 s. However, in exam style #2 results would be approx. 17 s earlier than a first capnometry or -graphy result, because the misplacement can be interrupted when noting the double airway tract had been passing the plane of the ultrasound beam. Nevertheless, major advantages of the ultrasound exam styles are the facts of the direct vision to the esophagus (double airway tract sign) and that no ventilations are required for confirming an esophageal misplacement. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

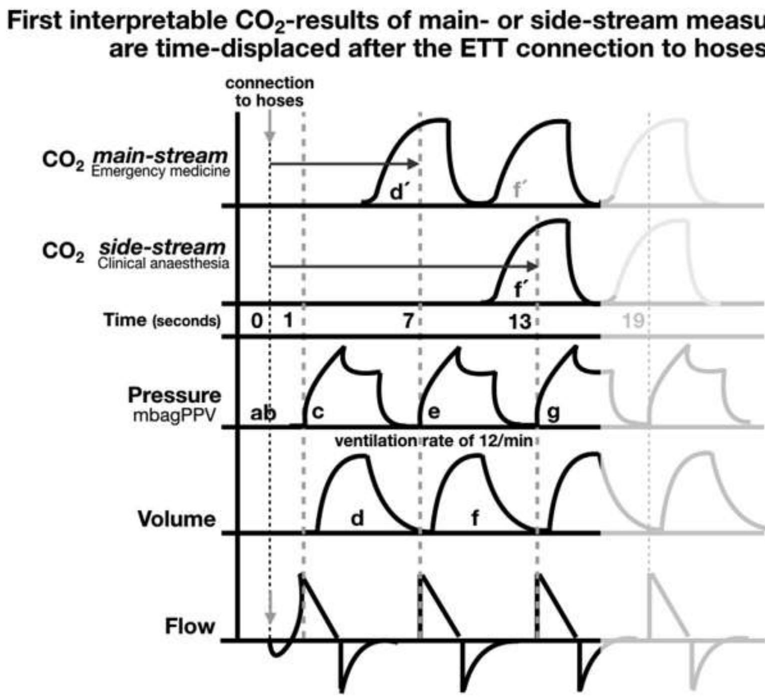

Fig. 9. Graphs indicate process after completing ETT placement in a real RSI.
M; main-stream measurement, S; side-stream measurement. a; ETT insertion completed, b; connecting to hoses, c; begin of first manual reservoir-bag positive pressure ventilation (mbag-PPV), d; first exhalation, d'; start of first capnography curve in M, e; second mbag-PPV, f; second exhalation, f'; first capnography curve in S, g; third mbag-PPV. M; Regarding emergency equipment (such as Dräger Oxylog 3000), CO_2 -line is processed from air mainstream with infrared measurements and available already at d', in between the first exhalation, i.e. within 6 seconds after commencing mbag-PPV (c). Note that only at the beginning of (e) the numeric capnometry result is available in M. S; Regarding operation theatre, as in clinical anaesthesia, probe air samples are pulled through a CO_2 -line, "side-stream", at a flow rate of 200 ml/min, depending on the line length and its diameter. Therefore no curve is available within first exhalation (d) and no d'. Only approx. 12 seconds after commencing mbag-PPV (c) at a ventilation rate of 12 per min the capnography provides a curve (f'). Both CO_2 graphs for M and S explain the delay in the process of confirmation of ETT-placement or, in case, esophageal misplacement. Of note, if a CO_2 signal is not clear, uncertainty of the team may even prolong time to decisions.

4.7.6. Ultrasound and airway research

Ultrasound has been used as an alternative tool to expand clinical research on airway management. With the increasing experience in its historical and future potential clinical applications, as well as the availability of data on its diagnostic accuracy, it can be expected that its role as a readily available research tool will gain importance. Implementation and estimated or measured times of the processing of the novel defined exams and because of the merits of novel simulation technology results from near-realistic scenarios (e.g. "lab data" rather than real clinical studies) would be of interest. This also addresses the need for ultrasound training for new user groups, because the device and purpose is novel in emergency scenarios.

4.7.7. Comparison of the workflows of capnometry with anterior airway ultrasound exam styles

Regarding the debate, whether capnometry can be the gold standard for confirming tracheal tube placement, we here compare the workflow details of capnometry/auscultation with the anterior neck ultrasound exam styles #1 and #2 on a theoretical basis. Our hypothesis is that, because ventilation is mandatory for capnometry, the whole confirmation process will last longer when using this method.

To have a fair comparison, minimum values for each workflow step were considered. Those are based on preliminary measures of video clips of intubation procedures in our clinical practice.

We identified four main blocks of the workflow and broke these down to workflow steps. Either block comprises listed details:

- Block 0; all measures of an RSI before insertion of the ETT. Those are all independent from capnometry or ultrasound.
- Block 1; a) insertion of ETT, b) removal of stylet and in parallel inflation of cuff, c) withdrawal of blade, and d) taking the connector and connecting it to the hoses of the breathing circuit of the ventilator.
- Block 2; a) taking the reservoir bag and start of forced ventilation, b) time until the end of the first interpretable signal of capnometry and c) until 2 more forced reservoir bag compressions have been completed.
- Block 3; a) auscultation, including two auscultations points (one per hemithorax) plus one stomach auscultation and including b) decision "airway clear". This block was considered to be performed in parallel to Block 2 interventions within an RSI, and, of a trained team.

According to the German airway management expert guidelines of 2015, actions after securing the airway should be i) "expiratory CO_2-measurement via capnography and intubation under (direct or indirect) vision" and ii) "Auscultation of the thorax … to prevent an excessively deep position of the tube." [64]. Visualization of esophageal misplacement can be considered as direct vision (because of double tract sign) as well as indirect vision (because it is exploiting ultrasound) and is thus in line with this statement. The up to date prehospital airway management guideline even mentions ultrasound as an alternative after capnometry and for premarking CTM [65]. Canadian evidence based recommendations by anesthesiologists, intensivists and emergency physicians recommend capnometry and -graphy, but do not state auscultation [66]. American Society of Anesthesiologists expert statements do not cite evidence for capnometry and do not state auscultation [67]. Therefore our comparison included both capnometry and

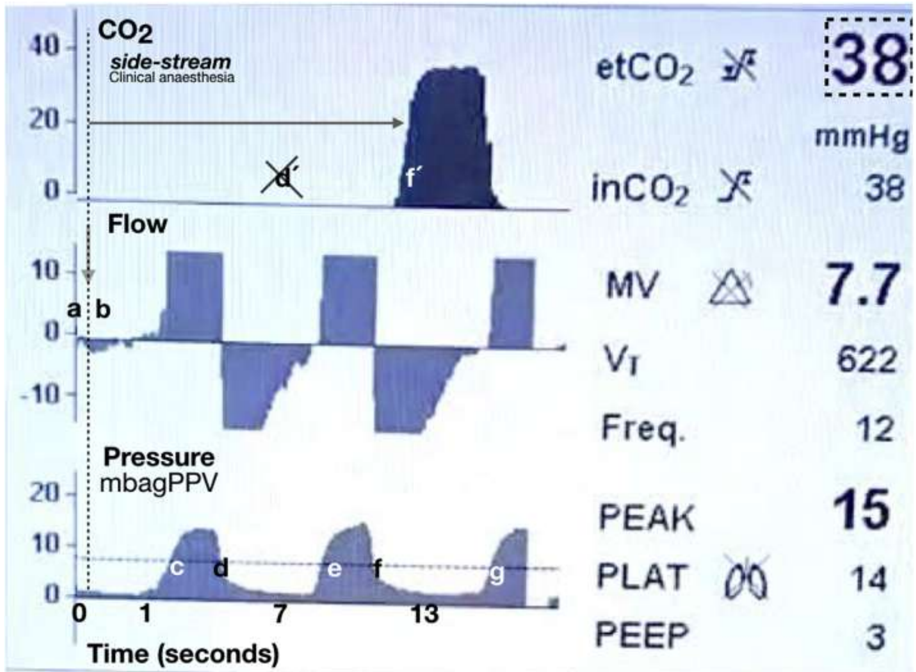

Fig. 10. Photograph represents a real-life example (ventilator display from Dräger Primus) within clinical anaesthesia. For details of a-g, see Fig 9. Note that only at the beginning of (g), the numeric capnometry result (dashed square upper right) pops up only 12 seconds after commencing mbag-PPV at a ventilation frequency of 12 per minute. The x-axis write-speed may be equivalent to 6.5 cm per second.

auscultation, and it was merged into block 2, because it can be done in parallel with capnometry and addresses the question of main stem intubation only.

To illustrate this comparison, we provide the workflows as stacked bar graphs (Fig. 8). Note that the time to decision upon a result depends on the different confirmation methods. Regarding capnometry, a result is depending on completion of ETT insertion, time span until ventilations can commence and curve visibility (i.e. air sample measurement, different in sidestream and mainstream-capnography). For anterior neck ultrasound exam style #1 (post-intubation) the result merely depends on the duration of the ultrasound exam itself. In exam style #2 (during intubation) it is depending on the time point of the ETT advancement to the ultrasound beam only, but not on the completion of the intubation process as a whole (Fig. 8).

- Capnometry vs. anterior neck ultrasound exam style #1

We considered as the starting point for time tracking the beginning of reservoir bag ventilations. The positive signal for capnometry is delayed (Figs. 9 and 10) already in normal ETT placements. However, in an emergency scenario or CPR, additional confusion over an unsecure result can occur [68–70]. Moreover, if no clear values have been displayed, as it would be in esophageal misplacements or CPR, capnometry or auscultation results and time to decision will be delayed.

Thereafter, in a normal conduct of an RSI with tracheal placement, all further parts of the completion were analysed until the end of the first and third positive capnometry curve. Nevertheless, when capnometry and auscultation are performed in parallel, both workflow tracks of either capnometry/auscultation or ultrasound exam style #1 seem to be almost equally fast.

- Capnometry vs. anterior neck ultrasound exam style #2

Divergent to exam style #1, in exam style #2, we considered as a starting point for time tracking the end of insertion of the ETT, before withdrawal of the inlay/stylet. Because this is exactly the time point that anterior neck ultrasound can stop the process when identifying an advancement into the deep pharynx and esophagus, there would be no need to wait for a complete “double tract sign” by the supervisor. Thereafter, all further workflow details of the confirmation in block 2 und 3 were considered.

Regardless whether waiting for the first positive capnometry result or until the third, anterior neck ultrasound exam, style #2 will be faster than capnometry/auscultation.

Taken together, ultrasound can be considered at least as good as capnometry for the purpose of detecting an esophageal misplacement in both exam styles. Nevertheless in exam style #2 it will be markedly faster. The obvious reason in behind is that capnometry/auscultation require ventilations to obtain a decision.

However, in this ideal approach, no repeated measures, mixed teams, noise etc. are modeled. It would be common sense that in real life ventilation and confirmation will last longer and especially in the confusion and insecurity whether there is a suspected esophageal or endobronchial intubation. It thus can be presumed that exam times in capnometry/auscultation and the decision to re-insert the ETT will even take longer, when there is not a normal finding.

Although real-life data are not available yet for both capnometry/auscultation and anterior neck ultrasound exam styles to support this opinion, our workflow model can be seen as hypothesis for an ideal definition. Clinical data will have to show the safety of the procedures.

5. Conclusion

Our main message for emergencies is that there is the method of a post-intubation check in order to rule out or in esophageal misplacement without the necessity of ventilation. A second exam style for continuous anterior neck ultrasound observation during intubations is available. Moreover confirmation of esophageal misplacement seems to be faster than with capnometry. Considering the evidence and limitations of focused anterior neck ultrasound procedures in emergencies, training within scenarios or a defined clinical context is recommended. The methods should be readily accessible for emergency and critical care practitioners.

Acknowledgment

This work is dedicated to WINFOCUS, a non-profit organization that supports science and exchange in the field of point-of-care ultrasound and thereby to its expert group of the International Consensus on point-of-care Lung Ultrasound 2012 [44].

Appendix A. Supplementary data

Supplementary data to this article can be found online at www.yumpu.com/en/SonoABCD.

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