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ORIGINAL ARTICLE

To see or not to see: ultrasound-guided percutaneous tracheostomy

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Abstract
Percutaneous dilatational tracheostomy is a common bedside procedure in an intensive care unit. Historically, a technique using bronchoscopic guidance is used. We describe here a new version of this technique in which ultrasound is used to lower the chance of vascular damage and ensure proper placement of the cannula in the midline position at the optimal level. We describe the protocol we use for this intervention at our institution and review the evidence for the feasibility and safety of ultrasound-guided percutaneous dilatational tracheostomy.

Introduction
Percutaneous dilatational tracheostomy (PDT) is a common bedside procedure in an intensive care unit (ICU). Its simplicity, safety profile and lower cost in comparison with a classical surgical tracheostomy has popularised the procedure so that it is now the procedure of choice in most units and intensivist-led PDT.[1] Although safe, the PDT procedure is not exempt of complications such as bleeding, false routes and even death. It has been reported that PDT-related mortality occurs in 1 out of every 600 patients.[2] The vast majority of these PDT-related deaths are due to uncontrollable periprocedural haemorrhage, usually secondary to unanticipated variations in the vascular anatomy in the neck.[2] The implementation of additional safety measures is focussed on the prevention of PDT-related bleeding and is of utmost importance to reduce the rate of complications.[2]

Many institutions have implemented the adjunctive use of bronchoscopic guidance during a PDT as an additional safety measure. This technique enables the confirmation of midline puncture of the trachea and allows for the visualisation of the posterior tracheal wall preventing its potential perforation. Although bronchoscopic guidance is of great help to aid in periprocedural visualisation, it does not prevent the potential laceration of unanticipated vascular abnormalities leading to haemorrhage. Additionally, bronchoscopy during PDT has its drawbacks as well. Not only does it increase the number of people and the skill set needed to perform a PDT but it has also been associated with measurable alveolar derecruitment accompanied by procedural decreases in oxygen saturation.[3]

In recent years, ultrasound has become much more widely available in the ICU environment. Ultrasound is increasingly used to aid in central line placement and visualise organs such as the heart and lungs. Increasingly, vital treatment decisions in the ICU setting, such as whether or not patients may be fluid responsive, are based on intensivist-performed point of care ultrasound. In this short paper, we describe that the use of ultrasound during PDT enables clinicians to not only increase the ease and speed of a PDT procedure but to increase its safety as well. In this article, we will present a brief review of the evidence supporting the use of ultrasound in this procedure and describe the technique we currently use at the Leiden University Medical Centre (LUMC).

Ultrasound-guided PDT
In preparation for PDT, the patient is sedated, and the head is placed in slight hyperextension in order to expose the neck. In this position, the operator will palpate the neck and locate important landmarks such as the thyroid cartilage, cricothyroid membrane, cricoid and sometimes even the tracheal rings. This is essential for choosing the correct localisation for the tracheostomy. In certain groups of patients this procedure is difficult or even impossible to perform because of factors such as obesity or neck deformations.[4] In all patients but especially this group ultrasound can play a pivotal role in helping to distinguish the neck anatomy and still allow the patient to undergo a PDT without having to opt for the more invasive surgical procedure.[5]
The transversal axial view using a high frequency linear probe is the most adequate to determine whether the puncture is actually in the midline and to avoid the thyroid gland.

Furthermore, the transversal axial view is used to determine the presence of vasculature in the pre-tracheal or para-tracheal regions which might be vulnerable to laceration during the procedure. If present, a lower or higher puncture location can be chosen. The longitudinal view has the advantage of giving the operator a 'birds-eye' view of the neck anatomy and the relationship between the different structures. This is the best view when choosing the level of the tracheal puncture. Most authors agree that the point of tracheal puncture should be below the first tracheal ring but above the fourth tracheal ring. The exact location depends on patient (e.g. vascular) anatomy. Having said that, we believe that the puncture should not be too low; preferably try to insert the tracheal cannula between the second and third inter-tracheal membranes.

The pre-tracheal and para-tracheal space can be visualised with the help of ultrasound. Anatomically it allows to identify the cervical vasculature,[6] helps to identify the ideal tracheal puncture site,[7] and helps to calculate the distance from skin to trachea, which in turn allows for the selection of an appropriately sized tracheostomy tube.[8] This is done preferably with a linear high frequency probe either in longitudinal sections or transverse sections *(figure 1)*. The cricoid cartilage *(figure 1A)* can be easily recognised just inferior to the cricothyroid membrane by its relatively large acoustic shadow, followed caudally by the tracheal rings *(figure 1B)*. These cartilaginous structures appear hypoechoic on ultrasound due to their relatively high water content. Transversally they resemble an inverted 'U' and longitudinally these can be identified as round-like hypoechoic structures forming a 'string of beads'. The anterior surface of the trachea is delineated by a bright air-mucosal interface *(figure 1C)* and by reverberation artefacts from intraluminal air.

Real-time ultrasound guided PDT is the use of ultrasound during the procedure itself. In their review, Alansari et al.[9] describe that the midline for the tracheal puncture is determined in a transversal axis. The puncture is performed with US guidance in real time observing the penetration of the

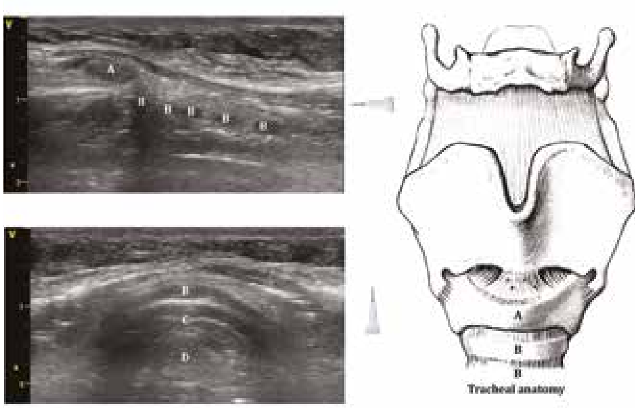

Figure 1.

needle in the midline of the trachea by following the acoustic shadow ahead of the needle, followed by the displacement of the tissue layers observed with the needle passage, allowing correct positioning and avoidance of vascular structures. Intraluminal air prevents the visualisation of structures such as the posterior pharynx and posterior wall of the trachea; therefore, injury at this level cannot be fully avoided using ultrasound alone. Also, a drawback of the procedure is that the guidewire cannot be seen in the trachea. However, its penetration between the tracheal ring can be observed in a longitudinal axis view and a subcutaneous positioning can be discarded.

Using ultrasound during PDT leads to the potential to avoid vascular structures, perfect midline puncture as well as control of intraluminal positioning of the guidewire which largely excludes the necessity of using bronchoscopy for this procedure.

Ultrasound-guided PDT protocol

The patient who has previously fasted for at least five hours is sedated and adequately positioned with hyperextension of the neck. The ultrasound machine is placed at the opposite side of the operator. An ultrasound is performed of the neck in transversal and longitudinal view *(figure 1)*. Cricoid cartilage and tracheal rings are identified, as well as pre-tracheal and para-tracheal regions of the neck searching for unexpected abnormal vasculature.

A sterile field is prepared around the operation site and the linear probe is used.

The skin and subcutaneous tissue in the operation zone is infiltrated with local anaesthetics with adrenalin, which has two functions. The first is vasoconstriction of subcutaneous capillaries/vessels and the second is increasing the resolution of the neck landmarks by placing a depot of liquid which enhances the image quality beneath.

At this point the endotracheal tube is retrieved to just above the vocal cords under visualisation with the use of the laryngoscope. This is only done if the patient has high ventilator support parameters, arbitrarily a PEEP level >8 or high delta pressures. If ventilator parameters are low, which is almost always the case, we usually replace the endotracheal tube with a laryngeal mask since we feel that keeping the tube to facilitate the use of a bronchoscope is not necessary when using this ultrasound-guided technique. Having said that, bronchoscopy through a laryngeal mask is still feasible if needed.

The preferred tracheal ring space is chosen with the longitudinal ultrasonographic view *(figure 1)*. As mentioned earlier this one is located anywhere between tracheal ring 1 and 4. The blue dilatator of the tracheostomy set is used to identify this localisation by pressing lightly on the skin and observing with the ultrasound at which tracheal ring level the pre-tracheal tissue is being pressed *(figure 2A)*. This 'mark' is used as a guide and the linear probe is placed transversally at this level.

The tracheal ring just beneath the tracheal ring space chosen is visualised. The midline of the desired tracheal puncture localisation is placed in the middle of the ultrasound screen, and the puncture needle (coupled to a 5 or 10 ml saline-filled syringe) is introduced perpendicularly to the skin and advanced until the needle is seen to pass the anterior tracheal wall with aspiration of air *(figure 1B and C)*. Once this has been achieved, the ultrasound linear probe is discarded. At this point the needle is angled caudally, and is retrieved leaving the plastic catheter behind. The guidewire is then introduced and once intraluminal placement is confirmed the plastic catheter is removed leaving the guidewire in the trachea *(figure 2D)*. A small horizontal or vertical incision (depending if nearby vessels are observed) is made at each side of the guidewire to allow dilatation. The puncture site is sequentially dilated using the small dilator first followed by the bigger green dilator *(figure 2E)*. Once introduced until the pre-specified marker on the dilator, it is left in situ for 1 minute as specified by its manufacturer *(figure 2F)*. The dilator is then removed leaving the guidewire behind. The trachea cannula is introduced using the guidewire and once in place the latter is removed and the inner cannula is introduced followed by connection to the ventilator.
Correct placement is controlled by the presence of end tidal CO_2 and/or with the use of the linear probe to confirm the presence of 'lung-sliding' bilaterally and/or a 'seas shore sign' on M mode *(figure 2G)* which confirms bilateral ventilation.

Discussion

Ultrasound technology is rapidly advancing, ranging from bulky machines to ultraportable pocket sized equipment.[10]. This progressive innovation and decrease in costs has brought the ultrasound outside the radiology departments directly to the bedside. With regards to the evidence for the use of ultrasound during PDT, four randomised controlled trials have compared ultrasound-guided PDT (US-PDT) with bronchoscopic guided PDT(B-PDT).[7,11-13] Yavuz et al. randomised 341 patients to US-PDT or PDT only guided by landmarks and showed that in the US-PDT group, the puncture site designated before the ultrasound analysis was reconsidered in 23.8% of the cases.[12] Complication rates were lower in the US-PDT group although not statistically significantly, reflecting the general relative safety of the procedure. A study in 74 patients compared, among other endpoints, the ease of the procedure as well as the rate of complications between US-PDT and B-PDT. In line with other reports the procedure was significantly shorter in the US-PDT group when compared with the B-PDT group (14 vs 18 min).[13] In terms of complications, 8 tracheal cuff punctures (22.2%) were observed in the B-PDT group and zero cuff punctures in the US-PDT group ($p < 0.05$). Whereas all US-PDT guided procedures only needed one tracheal puncture in the B-PDT group several punctures were needed in some patients. A recent randomised controlled trial with a total of 118 patients was set up as a non-inferiority study comparing US-PDT and B-PDT.[7] The results showed that US-PDT was equally fast and safe to B-PDT. There were no major complications in the two groups. Minor complications were slightly more frequent in the US-PDT group but this was not statistically significant (33.3% vs 22.7%). Finally, in a retrospective study involving 200 patients the use of ultrasound during PDT was associated with a significantly lower rate of procedure-related complications in a propensity score matched analysis.[14] The use of ultrasound speeds up the procedure considerably since the median time between puncture and guidewire insertion has been reported to be around 12 seconds whereas completion of the entire procedure only takes about 12 minutes.[15] Other authors have reported even faster average times of up to 8 minutes for the full procedure, which in the study of Sustic et al.[16] was significantly faster when compared with surgical tracheostomy, which took an average of 12 minutes.

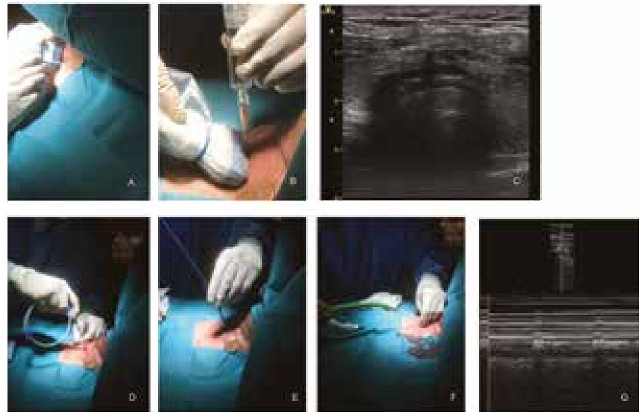

Figure 2.

Every new procedure has a learning curve. At our centre we have not yet reached agreement as to the number of US-PDT procedures that must be correctly performed to be considered proficient. Our staff and fellows use ultrasound daily, which helps. We feel that the procedure is not very difficult for physicians with ultrasound experience and experience with previous techniques and we expect the average learning curve to be between 10-20 procedures. However, given the fact that not many PDT procedures are carried out each month, departments might consider restricting the technique initially to certain staff members to allow them to build up some experience. To facilitate training, we are busy setting up a 'dummy' in which this technique can be practised on by other staff members as well as fellows.
Taken together, the results of the randomised controlled trials which have been performed in this field show no inferiority but also no clear preference for the use of US-PDT. Although clear significant benefits from a US-PDT technique are not shown in the literature one should bear in mind that the complication rates of this procedure are very low and that the number of included patients in all studies was too low to be able to show

any significant benefit. However, we feel that the benefits of this technique are quite important. First of all, the technique adds a layer of safety to the procedure since vascular structures in the neck are clearly visualised. Second the technique does not require the use and availability of a bronchoscope which significantly increases flexibility and reduces preparatory time. Also, since a continuously patent airway (e.g. a tube) is not required, one may opt to replace the tube by a laryngeal mask before the procedure, which significantly decreases the time and effort needed for airway handling. Finally, since airway and bronchoscope handling are omitted the procedure may easily be performed by a single operator.

Disclosures

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