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Ultrasound-guided percutaneous tracheostomy

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Abstract

Point-of-care ultrasound in the intensive care unit has emerged as a routine bedside diagnostic tool. This article provides literature review on the ultrasound-guided percutaneous dilational tracheostomy (US-PDT), which is a relatively novel technique. US-PDT reduces periprocedural complication rate, facilitates identification of proper tube insertion site and provides other additional safety-measures versus non-ultrasound Seldinger-based PDT technique.

Key words: tracheostomy, percutaneous tracheostomy, ultrasound, point-of-care ultrasound.

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Point-of-care ultrasound (POCUS) has become a standard diagnostic tool in intensive care units [1]. Thanks to the availability of ultrasound devices, popularisation of training courses and quick mastering of ultrasonographic techniques, the number of anaesthesiologists proficient in performing ultrasound diagnostic procedures in daily practice is becoming increasingly high.

One of the interesting fields of ultrasound applications is ultrasound-guided percutaneous tracheostomy. At present, percutaneous tracheostomy is the method of choice in patients treated in the intensive care units; compared to conventional tracheostomy, the ultrasound-guided procedure is characterised by a reduced risk of wound infections and bleedings, lower mortality rates [2–4] and the possibility of performing the procedure at the bedside. The method is associated with a low incidence of tracheal stenosis after the removal of the tracheostomy tube (1.1–1.6%) [5, 6]. Moreover, it is relatively easy to be mastered by anaesthesiologists due to its similarity to vessel cannulation using the Seldinger technique. Percutaneous tracheostomy is, however, connected with procedure-specific complications, e.g. premature extubation, formation of a false passage (paratracheal instead of endotracheal insertion of the tracheostomy tube) and disruption of the posterolateral tracheal wall). In comparison with open tracheotomy, percutaneous tracheostomy is associated with an increased risk of airway obstruction with its potentially fatal consequences because of an unstable and narrow tracheostomy passage [7]. In Poland, percutaneous dilatational tracheostomy (PDT) using the Griggs method has been most commonly used; therefore, the present paper is mainly focused on the issues connected with this method.

Ultrasound-guided PDT requires the knowledge of anatomical points and sonoanatomy as well as ultrasound operational skills. Moreover, experience in performing classical tracheostomy is needed (in case of unexpected complications) or an experienced specialist should be available. In order to learn the PDT method, at least 20 such procedures should be performed [8]. The use of ultrasound-guided PDT prolongs the procedure yet reduces the risk of complications [9].

SELECTION OF AN ULTRASOUND TRANSDUCER

Percutaneous tracheostomy is preferably performed using a high-frequency linear transducer [10]. Given the shallow location of the relevant anatomical structures as well as the lack of image deformations, linear transducers are the devices of choice. The transducer width depends on the accessibility of the tracheostomy site. In patients with short necks and in children, the smallest possible widths are preferable.

SELECTION OF PROJECTION

The shape of an ultrasound beam generated and received by the US transducer depends on the transducer type used. Once the received data have been processed, the image is displayed, which corresponds to the insonation plane. Linear transducers produce rectangular images with their transverse dimension corresponding to the transducer width.

During the examination, the anatomical structures are typically visualised along their long axis

(LAX) or short axis (SAX), thus LAX or SAX projections can be used (Figure 1).

Moreover, there are two approaches to needle visualisation during real-time ultrasound-guided puncture; in cases of in-plane visualisation, the needle is passed within the insonation plane while in out-of-plane visualisation the needle is placed across the insonation plane.

In practice, the choice of SAX/LAX projection and in-plane or out-of-plane needle passage is mainly dependent on the patient anatomical conditions and the device size. In patients with difficult anatomical conditions for tracheostomy (obese patients, patients with short necks, forced neck flexion, and children), the use of the transducer and its "fitting" into the operative field can be hindered. In such cases, it is necessary to visualise the trachea in the SAX projection and with out-of-plane needle passage.

PATIENT POSITIONING

The majority of patients undergoing tracheostomy are positioned with their heads bent off and supported; additionally, a small rolled-up towel is placed at the level of scapulas to provide the best conditions for the procedure (hyperextension). Such positioning results in mutual shifting of the anatomical structures in relation to the neutral position. The site of the procedure should be identified after placing the patient in the target position.

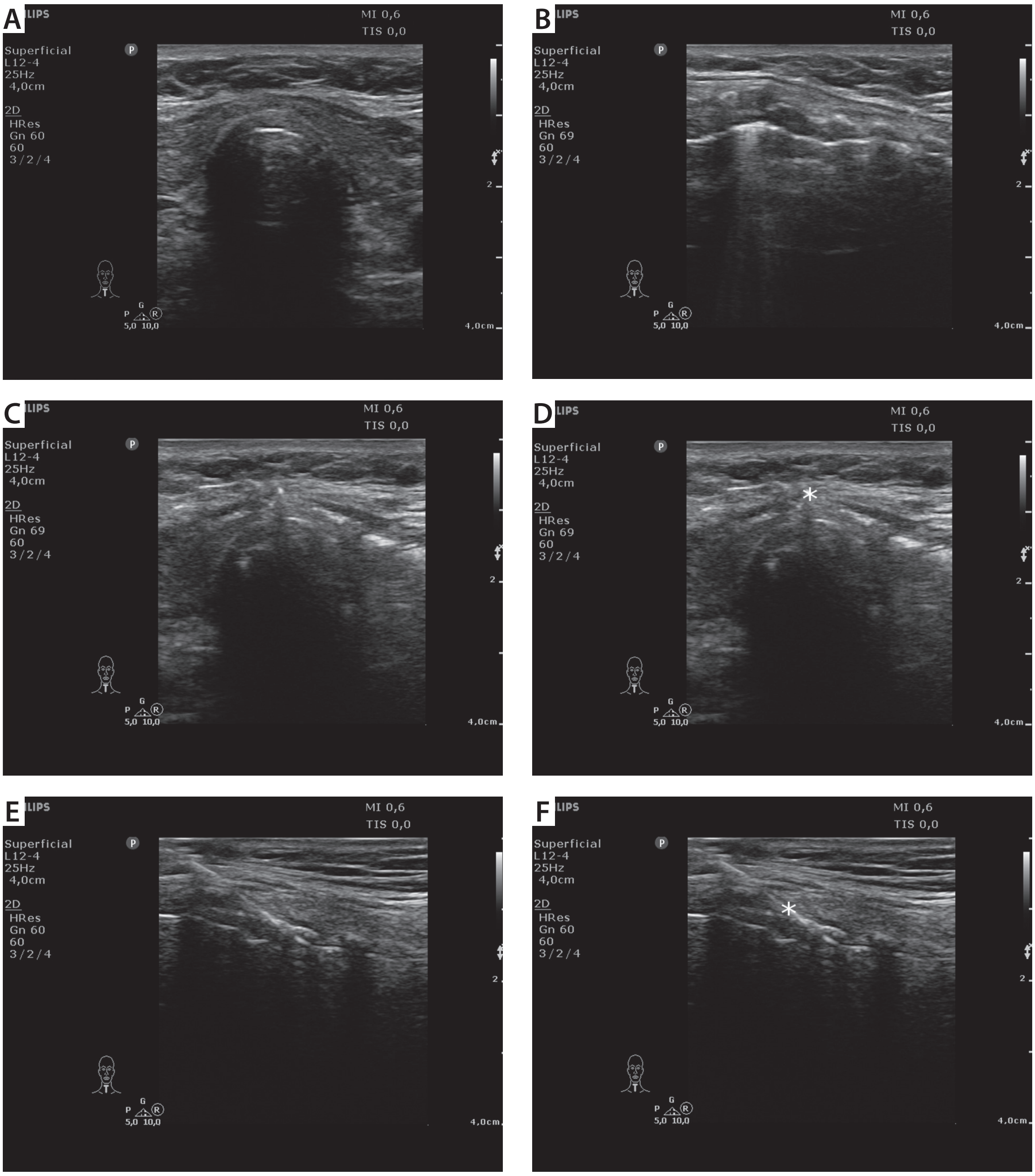

FIGURE 1. A) Trachea – SAX. **B**) Larynx and trachea – LAX. **C-D**) Out-of-plane visualisation of the needle. **E-F**) In-plane visualisation of the needle – the asterisk denotes the needle with acoustic shadowing below

Hyperextension, i.e. excessive neck bending off, increases the risk of vascular injuries in the vicinity of the jugular notch due to cephalad shifting of vessels and compression of the superficial veins caused by the resultant tissue tension. The mutual translocation of neck structures during the procedure with a substantial neck bending off leads to the oblique (in the sagittal plane) course of the tracheostomy opening (stoma) once the neutral position has been restored. This unfavourably affects wound healing due to the pressure of the upper surface of the tracheostomy tube on the tissues.

Head extension for PDT is contraindicated in cases of unstable injuries to the cervical spine.

INITIAL ASSESSMENT OF SONOANATOMY

Before the procedure of tracheostomy, the initial ultrasound exam is performed to identify the anatomical structures, determine the tracheal axis, evaluate the skin-tracheal wall distance at the site of planned tracheostomy as well as the trachea diameter, and find possible pathologies. During the initial evaluation of sonoanatomy, the presence of vascularisation in the region of planned tracheostomy should be particularly focused on. This stage enables to take decisions about the technical possibilities to perform the procedure and possible contraindications (Table 1) [11], the choice of an adequate tracheostomy tube (its diameter and use of the tube of proximally increased length), and potential peri-procedural complications. In many cases, the endotracheal tube can be visualised before its removal during the procedure.

The traditional method used to identify the site of percutaneous tracheostomy based on anatomical points can prove unreliable [11]. Thanks to the use of ultrasound, the procedure performed in the recommended space below the first or second tracheal cartilage is safer [12]. According to one prospective study, the ultrasound examination before percutaneous tracheostomy resulted in the change of the originally determined site of tracheal puncture into more optimal one in 24% of cases [13]. Tracheostomy performed between the cricoid cartilage and the first tracheal cartilage increases the risk of trachea constriction. The autopsy findings in patients who underwent US-guided percutaneous tracheostomy have demonstrated that tracheostomy performed at the level of cricoid-tracheal membrane was completely avoided [14].

SONOANATOMY OF THE LARYNX, TRACHEA AND SOME NECK STRUCTURES

In the LAX projection, the important landmarks within the larynx are the thyroid cartilage, the hypoechoic cricoid cartilage and the cricothyroid ligament extending between them. In this projection, the cricoid cartilage forms the colliculus prominence from which the cricotracheal ligament and tracheal cartilages resembling a string of beads are visible cephalad. In the SAX projection, the cricoid cartilage and the tracheal cartilages form the reverse U letter (Figure 2E,F). At the level of the first and second tracheal cartilage, the oesophagus is visible on the left and posteriorly to the thyroid lobe (Figure 2C).

TABLE 1. Contraindications for percutaneous dilatational tracheostomy

Absolute
Unstable cervical spine fracture
Children < 12 years of age
Uncorrected coagulopathy
Infection of the tracheostomy site*
Malignant tumour at the tracheostomy site*
Relative
Large goitre*
Rescue airway access
Morbid obesity*
Children > 12 years of age
Tracheomalacia*
Ventilation with $FiO_2 > 0.6$
Haemodynamic instability
Significant coagulopathy/thrombocytopaenia
Previous tracheostomy*
History of surgery/neck radiotherapy*
Surgical wound in the region of tracheostomy*
Anatomical anomalies of the neck*
Extensive neck burns*
Expected survival < 48 h

*Contraindications that can be assessed during prescan

The identification of pretracheal vessels involves the Doppler visualisation of the pretracheal veins and arteries. When the pretracheal veins are present (Figure 3A) and located in the midline, the site of puncture in the Griggs method has to be changed. It may be necessary to widen the incision during the procedure and to ligate the vessels. Fatal haemorrhages have been described in cases of the puncture of the left brachiocephalic vein.

The pretracheal areterial vessels important for performing tracheostomy include the inferior thyroid artery (up to 10% f the population) and the anatomical variant - the highly located brachiocephalic trunk (0.9% of patients) [15]. The inferior thyroid artery branches from the brachiocephalic trunk, less commonly from the aortic arch, running along the anterior tracheal wall and usually supplies the lower part of the thyroid gland; bleedings associated with the injury to this artery during PDT have

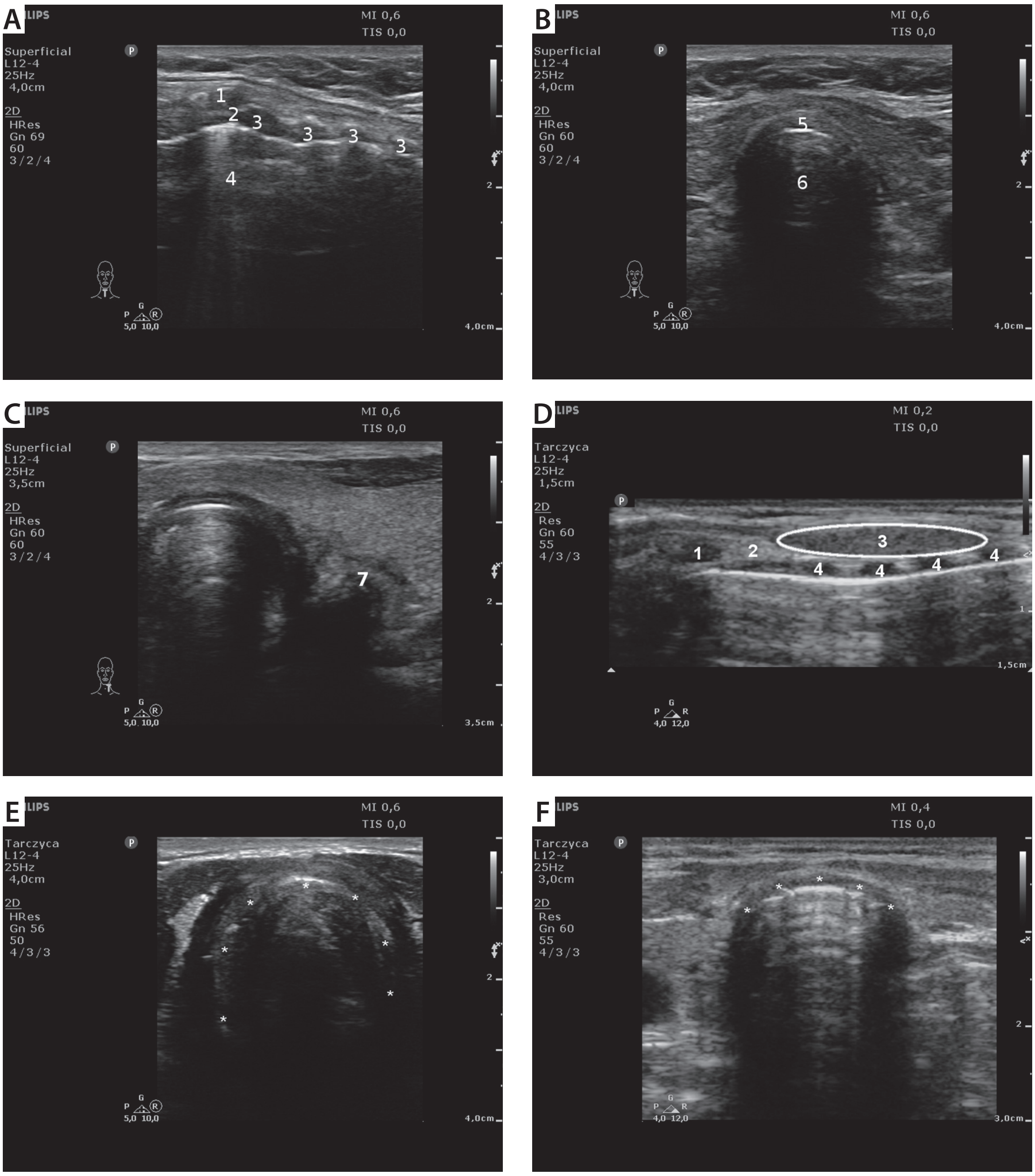

FIGURE 2. A) Larynx and trachea – LAX. The successive numbers denote: 1) cricoid cartilage, 2) cricotracheal membrane, 3) tracheal rings, 4) tracheal lumen. **B**) Larynx and trachea – SAX. The successive numbers denote: 5) tracheal ring, 6) tracheal lumen. **C**) Oesophagus: 7) visible left-handedly and laterally to the midline. **D**) Tracheal isthmus – LAX. The successive numbers denote: 1) cricoid cartilage, 2) cricothyroid membrane, 3) thyroid isthmus, 4) tracheal cartilages. **E**) Cricoid cartilage (SAX) – asterisks (reverse U). **F**) Tracheal cartilage (SAX) – asterisks (reverse U)

been reported in literature [16]. A high location of the trunk (Figure 3B) generates not only the direct risk of intraoperative haemorrhage but also remote and potentially fatal complications connected with the artery wall erosion due to the development of tube-associated inflammatory conditions [17]. Moreover, the cases of an atypical location of the cervical arteries and the aortic arch have been described, particularly in the presence of the dissecting aneurism of the aorta [18].

The thyroid isthmus (Figure 2D) in adults is located at the level of the second-forth tracheal cartilage. In 10-30% of the population, the pyramidal lobe is also present, which is usually directed cephalad or to the left side. During classical open tracheotomy, the extent of the operative field enables blunt preparation and liberation of the thyroid as well as retraction of the isthmus or ligation and cutting when the thyroid gland is enlarged. Unfortunately, this is not possible in PDT and the maneuver described in literature involves pulling upward and pressing of the cricoid cartilage, which reduces the thickness of the isthmus [19]. The number of percutaneous tracheostomies through the thyroid isthmus is most likely markedly underestimated. The use of ultrasound during PDT decreases the risk of thyroid puncture.

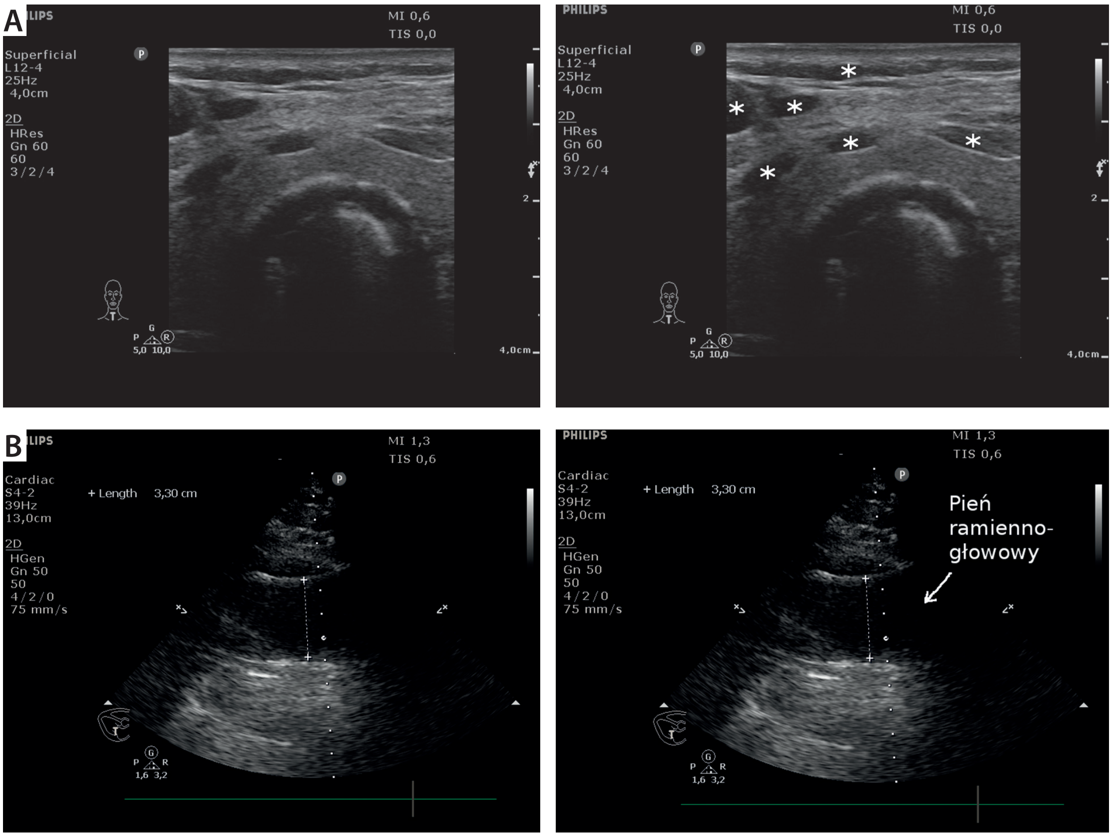

FIGURE 3. Neck vessels. Pretracheal veins (**A**) denoted with an asterisk. Brachiocephalic trunk (**B**) visualised over the jugular notch using a sector transducer

BRONCHOFIBROSCOPIC VERSUS ULTRASOUND CONTROL

The use of bronchofibroscopy during PDT has the undoubted benefits [20–22] yet can also generate potentially severe complications. The significant impediments to the use of this method are associated with the need to have well-trained personnel, availability and cost of equipment, its servicing and disinfection. The advantages of bronchoscopy include the assessment of the depth of endotracheal tube location, confirmation of the needle location in the trachea axis, insertion of the guide-wire in the proper direction, control of the use of a dilator, detection of possible fractures of the tracheal rings and proper insertion of the tracheostomy tube. In cases of incidental withdrawal of the guide-wire, the method allows to identify the tube insertion into the false canal. The adequate use of bronchofibroscopy during PDT reduces the risk of posterior tracheal wall injuries, provided that the proper procedural technique is applied- appropriate stabilisation and tension of the guide-wire during the successive stages of tracheostomy using the Griggs method [23]. Moreover, the bronchofibroscope enables airway control after tracheostomy in terms of possible postoperative bleedings to the airways and bronchial tree toilet.

The negative consequences of bronchofibroscopy include damage to the device (damage to the external sheath and bronchofibroscope unsealing, optics damage, fracture or tearing off of the bronchoscope elements), possible infections resulting from neglecting the disinfection procedures and quality control of the device [24], ventilation disturbances, hypoxaemia, hypercarbia and unintended extubation. In patients with cerebrocranial injuries, bronchofibroscopy can result in a substantial increase in intracranial pressure [25]. The use of bronchofibroscopy in obese patients increases the risk of complications; furthermore, it prolongs the duration of PDT [26, 27].

To date, there have been no multicentre, randomised and blind studies demonstrating the superiority of ultrasound over bronchofibroscopy in PDT. In 2016, the first randomised study, i.e. TRACHUS [28], was completed evidencing that the use ultrasound in PDT is at least equally good as the use of bronchofibroscopic control. Since the study was single-centre, unblinded in nature and did not assess long-term complications, further research is needed to explicitly confirm the superiority of US in PDT.

SELECTION OF THE TRACHEOSTOMY TUBE LENGTH

Once the proper anatomical conditions for PDT have been confirmed in the prescan and the appropriate area of the procedure selected, the distance between the skin surface and the anterior tracheal wall should be measured. The measurement is essential to select the tube of a suitable length: standard or proximally lengthened. In obese patients, the thickness of pretracheal tissues is larger [29], which is also true about the majority of ICU patients [30].

REAL-TIME PDT VISUALISATION

After the patient has been generally anaesthetised and positioned, the real-time ultrasound-guided tracheostomy is possible. It is necessary to withdraw the endotracheal tube above the planned site of insertion. The tube is normally withdrawn under direct laryngoscopy guidance although the location of the tube tip can also be assessed using the Doppler method [31]. After a sterile protective cover with gel is placed over the disinfected transducer and the target area between the tracheal rings is re-identified, the trachea is punctured. Ultrasound increases the probability of trachea identification during the first puncture and the cannula insertion in the midline [32–34]. The course of the needle is steep; therefore, its visualisation is possible only in the out-of-plane technique. The ultrasound-guided PDT does not ensure the control of the needle tip position when the needle is already in the air space of the trachea due to ultrasound dispersion; thus, there is no effective method to avoid an injury to the posterior tracheal wall using US. Sustić [10] has suggested that the target depth of the needle tip be marked on the cannula for trachea identification. Bronchofibroscopy is the only method to visualise the intratracheal needle location.

After the insertion of the guide-wire through the cannula, the rotation of the probe to the LAX visualises the guide-wire passage through the tissues. At this stage, it is possible to evaluate the future tracheostomy passage and confirm the level of the tracheal puncture performed. Moreover, whenever the improper area has been unintentionally punctured, the guide-wire can be withdrawn and the trachea re-punctured.

Subsequently, the opening is enlarged with a dilator and forceps and the tracheostomy tube is inserted.

Attempts have been made to visualise ultrasonographically the tracheostomy tube balloon after filling it with 0.9% sodium chloride solution [35], yet this method is found to be unreliable. The most reliable methods to confirm the location of the tube tip in the trachea include bronchoscopy through the tracheostomy tube, ventilation through the tube together with capnogram evaluation as well as confirmation of mobility of both diaphragmatic domes during controlled ventilation in muscularly related patients; for this purpose, bilateral diaphragmatic ultrasound examination can be carried out in the subcostal projection and lung-sliding assessed [36].

TABLE 2. Tracheostomy-associated complications

Complications
Pneumothorax
Haemorrhage
Improper tube location
Perforation of the posterior tracheal wall
Thyroid injury
Recurrent laryngeal nerve damage
Subcutaneous emphysema
Cardiac arrest

ULTRASOUND ASSESSMENT OF PDT COMPLICATIONS

The tracheostomy-associated peri-procedural complications are listed in Table 2.

A relatively common tracheostomy-associated complication is pneumothorax, most likely caused by direct pleura puncture, dissection of the deep cervical fascia and transfer of the respiratory mixture to the mediastinum or disruption of the pulmonary alveoli. Chest X-ray after the procedure is advocated in patients with PDT difficulties or deterioration of their clinical conditions [37]. Ultrasound enables bedside assessment of the risk of pneumothorax and is characterised by shorter duration and higher sensitivity, as compared to chest X-ray [38, 39].

Improper placement of the tracheostomy tube and lack of airway patency are potentially fatal complications [40]. Thanks to ultrasound examinations, the mobility of diaphragmatic domes can be assessed and lung-sliding detected, as mentioned earlier, even in cases of abnormal capnography recordings.

CONCLUSIONS

In patients undergoing long-term ventilation, the introduction of percutaneous tracheostomy instead of the classical method has significantly reduced the number of complications associated with artificial airway and enabled bedside performance of the procedure. Bronchofibroscopy provides the possibility to assess the course of percutaneous tracheostomy methods and is the only option for meticulous visual assessment of the trachea lumen; thanks to this method, the procedure can be monitored and the potential complications avoided, most importantly, the unintended injury to the posterior tracheal wall.

Ultrasonography is a useful and indispensible tool for intensivists. Its use to assess the airways and support percutaneous tracheostomy procedures is a relatively new method. The reports and study findings described in the present review encourage introducing US-PDT to everyday practice. Ultrasound guidance shortens the procedure duration, increases the probability of proper placement of the tracheostomy tube, allows the identification of the course of neck vessels, location and structure of the trachea, its adjacent structures and their changes in the pathological processes, and reduces the number of peri-procedural complications.

Many issues connected with ultrasound-guided percutaneous tracheostomy have not been fully explained and further studies are needed to elucidate them.

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