Int J Clin Exp Med 2020;13(2):340-348
www.ijcem.com /ISSN:1940-5901/IJCEM0102249

*Review Article*

# Techniques for improving the safety of percutaneous dilatational tracheotomy with a cuffed endotracheal tube: a literature review

Zhuang Zhao*, Shu Pan*, Na Yan, Zhiwen Li

*Department of Anesthesiology, The First Hospital of Jilin University, Changchun, Jilin, China. *Equal contributors.*

Received September 12, 2019; Accepted January 3, 2020; Epub February 15, 2020; Published February 28, 2020

**Abstract:** Percutaneous dilatational tracheotomy (PDT) is a common bedside surgery for critically ill patients who require prolonged mechanical ventilation. This work reviews the current techniques that improve the safety of PDT. In this article, we review publications reporting the use of PDT with a cuffed endotracheal tube to outline the current technologies that help improve the safety of PDT, which has fewer complications than regular surgical tracheotomy. Several devices and techniques are available to assist anesthetists to maintain the safe use of the cuffed endotracheal tube (ETT) during PDT, such as capnography, fiberoptic bronchoscopy (FOB), ultrasonography, laryngeal mask airway (LMA), endotracheal tube-mounted camera, pediatric uncuffed ETT, and flexible lightwand. However, all of these techniques have certain limitations. Therefore, there are pros and cons of the various PDT techniques, and they should be selected based on a patient's conditions.

**Keywords:** Percutaneous dilatational tracheotomy, cuffed endotracheal tube, safety, ventilation

## Introduction

Due to the simplicity, speed, and low rate of complications, percutaneous dilatational tracheotomy (PDT) has been adopted in many clinical settings [1-3]. Numerous studies have been published regarding the surgical details and outcomes of PDT. However, research from the anesthetists' perspective is very limited, especially on the precise use and withdrawal of the endotracheal tube (ETT) during PDT, which is a key step that impacts patient safety. In the traditional PDT, the ETT is withdrawn to a certain depth based on the patient's gender to avoid tissue damage with the puncture needle. However, this approach has obvious shortcomings that can lead to serious consequences, including the unintentional withdrawal of the ETT and the cuff from the glottis [4, 5]. In this review, we summarize the devices and techniques that are currently available to assist in the accurate repositioning of the ETT during PDT (**Table 1**). They will help improve the safety of PDT, reduce complications such as the puncture of the ETT and cuff by the needle and avoid the insertion of the guidewire into the Murphy's eye [6].

## Current devices and approaches for PDT

### *The traditional ETT withdrawal approach*

In the traditional ETT withdrawal approach, the distances between the glottis and the portal teeth of adult males and females are estimated based on their anatomy and the operator's experience [7]. The tracheal tube is then withdrawn to 17 cm (male) and 15 cm (female) from the catheter scale to the portal teeth, and then the capsule of the ETT is deflated and placed under the vocal cord to prevent injury because of the insertion of puncture needle and the dilation of the ETT during the tracheotomy. However, this approach may unintentionally withdraw a part of - or the entire - ETT from the glottis [4], resulting in a failure of the operation. Fiberoptic bronchoscopy (FOB) has been recommended to accurately position the ETT to avoid complications [8]. However, bronchoscopy itself may cause complications [9, 10]. Several studies have shown that PDT can be

**Table 1.** Summary of percutaneous dilatational tracheotomy with various devices and techniques to ensure surgical safety

| Technique | Sample size | Methodology |
|---|---|---|
| Real-time ultrasound guidance [66] | 50 patients | Patients undergoing PDT for clinical indications were randomly assigned. The tracheal puncture procedure was carried out using either traditional anatomical landmarks or real-time ultrasound guidance. Puncture position was recorded via bronchoscopy. Blinded assessors determined in a standardized fashion the deviation of the puncture off the midline and whether appropriate longitudinal position between the first and fourth tracheal rings was achieved. |
| Laryngeal mask airway approach [67] | 274 patients | In the guidewire dilating forceps group, patients were treated by endoscopy via LMA-guided bronchoscopy. |
| EtView™ tracheoscopic ventilation tube approach [27] | 24 patients | EtView tracheoscopic ventilation tube is a standard endotracheal tube with a camera and light source embedded at the tip. The objectives of this study were to introduce EtView TVT as a monitoring tool during PDT and to compare it with video assisted FOB via ETT. |
| Uninterrupted translaryngeal open ventilation delivered through a pediatric uncuffed ETT approach [68] | 50 patients | Uninterrupted translaryngeal open ventilation was delivered through a pediatric, uncuffed endotracheal tube during percutaneous endoscopic tracheostomy. |
| Flexible lightwand-assisted approach [4] | 60 patients | A flexible lightwand was inserted into an ETT, the light source was positioned at the base of the cuff, and the depth from the root of the cuff to the end of the ETT was marked. The flexible lightwand was inserted into the patient's ETT to the marked depth. The ETT along with the flexible lightwand was withdrawn until the highlighted spot was located at the level of the thyroid cartilage. The incision site was approximately 3 finger widths (approximately 4.8 cm) below the highlighted spot. |

safely performed without the use of FOB, by using "modified" techniques [11-13], leading to improved procedures [14-16]. Prior to PDT, laryngoscopy was often used to examine the larynx to determine an adequate depth for ETT, while direct or indirect palpation of the trachea is used to measure the appropriate tracheostomy site [10, 11, 16]. The disadvantage of the improved percutaneous method is that it is unable to locate the PDT site precisely [15] and reposition the ETT, which may lead to various complications, such as the puncture of the posterior tracheal wall and the esophageal placement of the PDT. Failure to locate the PDT in the midline of the trachea could lead to a malpositioning of the ETT tip and a failure to insert it into the suction catheter. If the ETT is located too high or too low, it may lead to subglottic stenosis or the touching of the tip with the carina during the PDT. During the PDT, if the ETT is not positioned correctly, the needle may transect the ETT or the cuff. A very proximal tube location has a minimal safety margin against accidental extubation [17]. Although accidental cuff puncture can be avoided with a laryngoscope [12, 13, 18], an endotracheal cuff leak as a result of a needle puncture may still occur. In addition, in contrast to the subcutaneous dissection, physicians using the improved technique may not be able to identify vessels between the trachea and skin [15]. Because of these disadvantages, this approach is not recommended when a bronchoscope is available.

*FOB guidance*

Bronchoscopy is a widely used approach in hospitals [19, 20]. An FOB is usually used through an ETT during PDT procedures when patients are giving mechanical ventilation [21, 22]. Bronchoscopic guidance is frequently adopted as a safety measure during PDT. It facilitates the selection of the tracheostomy site, verifies the presence and position of the intratracheal guidewire, and punches on the midline of the trachea. It also helps place the dilator and position the tracheal cannula [4]. Therefore, the use of FOB is highly recommended whenever possible and may potentially minimize the risk of complications, such as pneumothorax, false passage, subcutaneous emphysema, and especially injury to the posterior tracheal wall [9, 23]. However, bronchoscopy still has limitations because the use of a bronchoscope via an ETT can lead to $CO_2$ retention or hypoxia [24, 25], as well as increased procedural time, cost, and PDT complexity [26, 27]. There are studies showing that FOB itself may cause complications, such as the need for additional medical personnel, equipment [10], prolonged ventilation [11] and an interruption of the operation [9, 10]. For example, a bronchoscope with

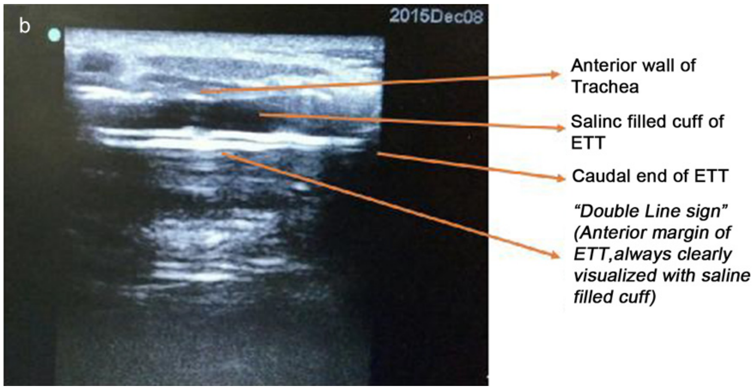


Figure 1. Real-time ultrasound guidance during a percutaneous dilatational tracheotomy (Reprinted with permission from Springer 4160820806104 [6]).

3.7 mm diameter may obstruct about 28% of the airflow in an ETT with a 7 mm internal diameter. Umutoglu et al. noted that there is increased airway resistance and leakage around the puncture sites, so the ETT cuffs and catheter stents would result in significant reduction of airflow in mechanical ventilation [27]. Reliable ventilation is crucial for critically ill patients because they cannot tolerate the risks of accidental extubation or prolonged apnea. However, an accidental puncture with the bronchoscope is very common and can lead to high repair costs [28, 29]. Anyway, the use of FOB in PDT is recommended in the guidelines, although in developing countries or some regions, the ICU may not be equipped with a fiberoptic bronchoscope or the clinic cannot afford to use a fiberoptic bronchoscope as it involves high maintenance costs and skill to operate.

*Real-time ultrasound (US) guidance*

The first real-time US-guided PDT was described in 1999 [30], and several reports were subsequently published, including a systematic review [15, 31-33]. High-resolution diagnostic US imaging can be used to measure the inner and outer transverse diameters of the trachea as well as the depth from the skin surface to the trachea (**Figure 1**). These data are used to select the appropriate type of tracheostomy tube and even to customize the tube before an operation.

Ultrasonography before and during PDT is shown to improve the safety of the procedure [34-36]. Alansari et al. analyzed the potential advantages of US, revealing that it is able to locate the cervical blood vessels [37, 38], assist in selecting the size and length of the ETT [39], avoid hemorrhage and injury in the neck structures, guide the insertion of needle into the trachea, and help identify the optimal site for the tracheal puncture. Advances in medical technology have made US imaging easier to use, less costly, more precise, and portable enough to be truly hand-carried equipment. It can be used while mechanical ventilation is under way during the whole PDT procedure [28]. Axial and transverse real-time ultrasonography imaging of the trachea allows continuous visualization of the tracheal midline. Since the guidewire may deviate from the midline, it may damage the paratracheal tissue during the subsequent dilatation [28]. Recently, Shankar et al. filled an ETT cuff with 5-8 ml saline and used ultrasonography to accurately reposition the tube during PDT [6]. This technique may enhance the safety and accuracy of withdrawing the ETT. Therefore, US guidance has become a potential first-line noninvasive airway assessment tool in intensive care practice. It can track the path of the needle during a tracheal puncture and determine the final position of the tracheostomy tube [40, 41]. However, intraluminal air may obstruct the visualization of some structures such as the posterior wall and the posterior pharynx. Therefore, damage to the posterior wall cannot be completely avoided [42]. Moreover, real-time US guidance cannot guide the withdrawal of the ETT to the most suitable position. Although Shankar et al. filled an ETT cuff with saline and used ultrasonography to accurately reposition the tube during PDT, the posterior margin of the ETT was still not visualized [6], which increases the risk of saline aspiration if the cuff is ruptured. Although US does not help one view the posterior wall, it can be performed (with color doppler) to assess the vascular structure in high risk bleeding cases.

*Laryngeal mask airway (LMA) approach*

This traditional technique requires deflating the ETT cuff and placing the tube just below the vocal chords to prevent damaging the airway when the needle is being inserted and advanced [41, 43]. However, this increases the risk of

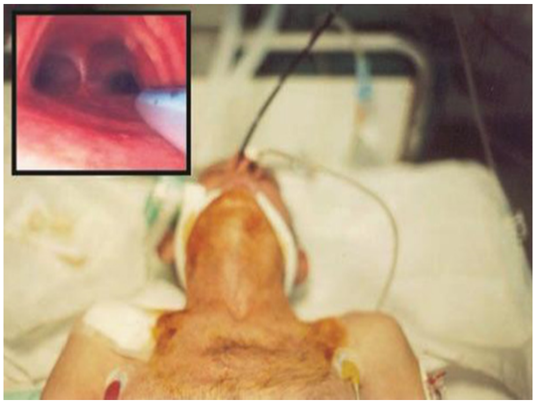

**Figure 2.** The use of laryngeal mask airway guidance during a percutaneous dilatational tracheotomy (Reprinted with permission from Springer 4160810685560 [61]).

**Figure 3.** The EtView tracheoscopic ventilation tube for percutaneous dilatational tracheotomy (Reprinted with permission from Springer 4160811351568 [27]).

unintentional extubation during the procedure and cuff rupture [44]. It is suggested that the use of a supraglottic airway such as the LMA could help avoid these risks and may provide a safe alternative for the ETT during PDT (**Figure 2**). Although it is hard to figure out the efficacy precisely or the study the clinical effect due the small number of cases analyzed [45, 46], LMA does provide more ventilation capacity and may be favored by patients who are very sensitive to hypercarbia. Pratt et al. reviewed the studies reporting on the use of LMA for airway management during PDT [47], and concluded that endoscopic visualization of the trachea and ventilation are significantly improved by using LMA during PDT. However, how this technique improves patient outcomes has not been reported. Ambesh et al. found that a considerable proportion of patients (16.7%) did not achieve satisfactory ventilation using this technique due to large air leaks [48]. For critically ill patients, the risk for aspiration is extremely high even during an elective tracheostomy when LMA is used despite the maximal precautions [49, 50]. Furthermore, LMA may not be suitable for patients who require high airway pressure and positive end-expiratory pressure (PEEP). Otherwise, it may increase the risk of aspiration and the complexity of the PDT procedure due to the need to replace the ETT with an LMA prior to the tracheostomy. So far, the persistent problems with ventilation and the safety of LMA in PDT have not been well addressed or established [51]. As such, LMA is not recommended for percutaneous tracheotomy in intensive care [52].

*EtView™ tracheoscopic ventilation tube approach*

The EtView tracheoscopic ventilation tube (EtView TVT) is a variant of standard ETT, with a camera embedded at the top for the continuous visualization of the ETT position and intratracheal structures during mechanical ventilation support [27] (**Figure 3**). It was sold to Ambu and used under the name VivaSight (VivaSight™-SL, ET View, Misgav, Israel). It has been used for monitoring the ETT position and airway structures, assisting difficult intubation and airway management during one-lung ventilation, and avoiding the rupture of FOB [53-57]. Although LMA is a commonly used technique for monitoring PDT while maintaining mechanical ventilation support [46, 57], and endoscopic guidance improves the safety of this procedure, the use of a bronchoscope through ETT or LMA may potentially deteriorate the ventilation and lead to hypoxia, hypercarbia, or alveolar de-recruitment [58, 59]. Umutoglu et al. demonstrated that the EtView TVT has a comparable airway monitoring effectiveness with video-assisted fiberoptic bronchoscopy and may reduce the deterioration in the process of minute ventilation [27], although their study included only 12 patients. Patients who depend on stable mechanical ventilation to avoid complications, such as increased intracranial pressure or increased pulmonary vascular resistance in pulmonary hypertension, may benefit from EtView TVT because it offers optical guid-

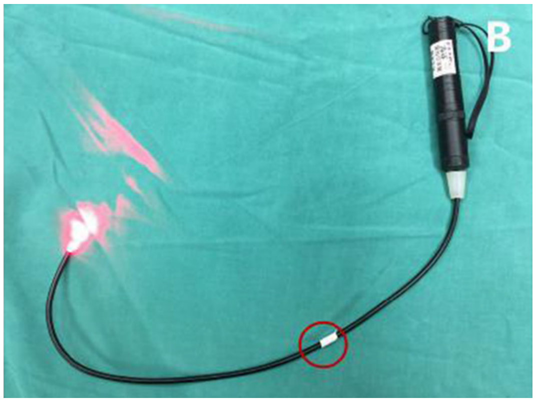


**Figure 4.** A flexible lightwand for percutaneous dilatational tracheotomy (Reprinted with permission from ELSEVIER 4160830212339 [65]).

ance without increasing $pCO_2$ during the intervention [60]. For patients with poor pulmonary reserve, EtView TVT guidance may be a good alternative to FOB, in which the tube-mounted camera is attached to the anterior wall of the tube. When the patient's head is reclined for the tracheostomy followed by the retraction of the ETT to identify the cricoid, the camera can show the ventral wall of the trachea. EtView TVT may be manipulated to optimize the visualization of the tracheal structures, but this may increase the risk for tube displacement compared to bronchoscopy. However, EtView TVT is still costly and not available in the majority of centers. It requires extubation/re-intubation and is not a standard care yet.

*Uninterrupted translaryngeal open ventilation delivered through a pediatric uncuffed ETT approach*

Ventilation is one of the necessary conditions during PDT, especially when the patient is in a critical condition, because they cannot tolerate the risks associated with accidental extubation or prolonged apnea. Ferraro et al. reported PDT under bronchoscopic visualization while using an alternative method to provide continuous ventilation, in which a pediatric, uncuffed ETT with an internal diameter of 4.0 mm and length of 220 to 245 mm was used [61]. Their results showed that $PaCO_2$ increased smoothly as reported [9, 46]. They concluded that this technique is reliable and safe for airway management during PDT. They demonstrated that the oxygenation was sufficient to achieve arterial saturation and had no transient decrease even during the dilation phase. Since tracheal reintubation is required during their ventilation management, it has some risks because of the complexity of the airway management when tracheal stenosis, laryngeal edema, and inflammation occur. We tested the translaryngeal open ventilation (TOV) as reported by Uchiyama et al. [62] and found that it could effectively assist the respiration of patients after extubation and with severe upper airway resistance. When a small size tube is used, high airway pressure (40 to 45 cm $H_2O$) in the ventilator circuit needs to be generated during TOV. An effective method to achieve this is to use a pressure target mode [63]. The inspiratory/expiratory ratio used by Ferraro et al. was 1:1 [61]; however, breathing in for a short time may reduce the effect of the inspiratory resistance, and breathing in for a long time may lead to expiratory resistance. However, this finding is still experimental and the method has not been standardized for medical care.

*Flexible lightwand-assisted approach*

A lightwand is a flexible metal tube with a light source at its front and batteries or a switch at the other end (**Figure 4**). In contrast to an ordinary lightwand, a flexible lightwand uses flexible rubber material in the metal tube region and an intensely-bright source of red light at its front. Since the flexible wand is able to alter its shape to fit an ETT, it is commonly utilized in nasotracheal intubation [4, 64]. Zhao et al. compared the safety of flexible lightwands with the traditional approach, and found that the lightwands appeared as a red spot at the roof of the ETT and were able to precisely guide the ETT withdrawal and confirm the incision site during the PDT procedure [4, 65]. They found that flexible lightwands could significantly reduce the occurrence of inadvertent cuff withdrawal from the glottis and the frequency of ETT puncture and cuff rupture. It also could increase the success rate of the first puncture and the $SpO_2$ at the time of tracheostomy cannula intubation. The approach can be used effectively and directly to guide precise ETT repositioning. It also provides information about the punch site and results in less intra- and postoperative anesthesia-related operative complications.

However, the flexible lightwand has several limitations. First, the approach still needs to interrupt the ventilation to reposition the ETT and confirm the incision site. Secondly, the approach does not avoid the risk of punching the great vessels. Thirdly, the approach cannot visualize the tracheal structures to avoid injury on the posterior wall. Furthermore, this approach is still experimental and no standard of care is available.

## Conclusions

In this review, we have summarized the current devices and techniques for accurately repositioning the ETT during PDT to avoid complications and procedural difficulties. Moreover, we described the advantages and limitations of each approach concerning safety and efficacy and presented a brief discussion on the best options for the current PDT procedures. FOB guidance for PDT is recommended by the most studies, and, although it is not perfect, the benefits outweigh the risks, so if it is available, it should be used.

## Acknowledgements

This work is supported by Fundamental Research Funds for the Central Universities to Zhiwen Li (grant no. 451170306057).

## Disclosure of conflict of interest

None.

**Address correspondence to:** Zhiwen Li, Department of Anesthesiology, The First Hospital of Jilin University, 71 Xinmim Street, Changchun 130021, Jilin, China. Tel: +86-0431-88782955; Fax: +86-0431-88782955; E-mail: lizhiwen@jlu.edu.cn

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