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A clinical retrospective study of percutaneous dilatational tracheostomy without guide wire for critically ill patients

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Summary
Objective This study aimed to introduce a novel tracheostomy method, the non-guide-wire percutaneous dilatational tracheostomy (NGPDT) technique, and evaluate its effectiveness for critically ill patients undergoing neurosurgery under special conditions.
Methods The clinical data of 48 critically ill patients who underwent NGPDT under special conditions with controlled steps were analyzed retrospectively. The patients' demographic, preoperative state of illness, and diagnosis data were collected. Moreover, their intraoperative and postoperative variables were accessed, e.g., operation times, bleeding, saturation of pulse oxygen (SPO_2), and early and late complications related to NGPDT.
Results The mean patient age was 47.7 ± 13.7 years. The mean GCS (Glasgow Coma Scale) was 8.1 ± 2.9, and the mean BMI (Body Mass Index) was 25.2 ± 5.6. There were 38 patients with an endotracheal tube. The mean duration of onset to NGPDT was 4.0 ± 1.3 days. The mean operation time was 4.2 ± 1.9 min. There were 41 patients with mild intraoperative bleeding, 5 with moderate bleeding, and 2 with severe bleeding as well as 46 with mild postoperative bleeding and 2 with moderate bleeding. Additionally, 41 patients required complete extubation after NGPDT. The mean duration of incision healing was 4.8 ± 3.1 days. There was 1 patient with a decrease of SPO_2 ≥ 10%. Three patients presented with a transient violent cough at the primary tracheostomy stage; however, no patients suffered from pneumothorax, subcutaneous emphysema, false passage, or surgery-related death during this procedure.
Conclusion Overall, NGPDT with controlled steps is a fast, safe, and microinvasive procedure. It mildly stimulates the trachea with a low rate of complications.

Keywords Percutaneous dilational tracheostomy · Neurosurgery · Cough · Stimulus · Guide wire

Introduction

Percutaneous dilatational tracheostomy (PDT) is a simple technique that can be performed at the bedside safely and quickly with local anesthesia to create an artificial airway for critically ill patients [1]. Ciaglia et al. reported the classic PDT technique in 1985 [2]. Since then, it has been modified several times to make it safer and faster. Griggs' technique [3], the Ciaglia Blue Rhino technique [4], the Percu Twist technique [5], and PDT performed with bronchoscope assistance [6] are all examples of this. These modified PDT techniques require two key steps: 1) a guide wire inserted into the trachea and 2) further enlargement of the tracheal fistula and subcutaneous tissue by dilation forceps.

A common phenomenon is that of patients presenting with a violent cough, limb action, and hemodynamic disorder when a guide wire is inserted into the trachea. Sedation and analgesia therapeutics have been used in this procedure [7] to effectively diminish these stimulus responses. An international survey [1] of PDT indicated that most patients currently undergo this procedure with sedation/analgesia and lo-

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Availability of data and materials The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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cal anesthesia; however, using adequate sedatives and analgesics to attenuate the PDT stimulus response is dangerous for patients with unstable vital signs or severe craniofacial damage.

In clinical practice, the guide wire can become tortuous in the dilatation and intubation step due to violent tracheal stimulus responses, leading to a false passage. In such cases, we take out the bending guide wire, expand the tracheal fistula and subcutaneous tissue directly along the puncture channel with expansion forceps, and insert a tracheostomy cannula, which is fixed by an inflating balloon and fastened by a belt around the neck. As a result, all cases with tortuous guide wires in PDT were successfully treated by this method, and none required surgical tracheostomy in the operating room. As such, we examined whether PDT can be done without a guide wire. Since 2013, we have tried to perform this procedure without a guide wire in appropriate patients, making a detailed record in every case. All such NGPDT operations have been carried out by Dr. Du, who has conducted over 500 PDTs. Therefore, this study aimed to introduce a novel tracheostomy method, the non-guide-wire PDT (NGPDT) technique, and evaluate its effectiveness for critically ill patients undergoing neurosurgery under special conditions.

Material and methods

Subjects

In this study, the clinical data of patients who underwent NGPDT in the Department of Neurosurgery and Intensive Care Unit of our hospital from March 2013 to July 2019 were analyzed retrospectively. This research was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the First Affiliated Hospital of Hebei North University. All participants provided signed informed consent.

Inclusion and exclusion criteria

The patients' condition was evaluated by the operator and over three experienced critical medicine doctors. Inclusion criteria: (1) patients who underwent NGPDT in the Department of Neurosurgery and Intensive Care Unit; (2) patients who were older than 18 years; (3) patients with a high cervical spine injury and brain injury requiring an urgent airway opening; (4) patients with such severe craniofacial damage that it was impossible to perform tracheal intubation and those needing long-term mechanical ventilation; (5) patients who had a cough reflex; (6) patients who were at high potential risk if sedation/analgesia were to be used in PDT.

Exclusion criteria: (1) patients who had scar tissue, infection tumor in the anterior neck; (2) patients who had a tumor in the anterior neck; (3) patients who had not provided signed informed consent.

Operative position

Individualized position placement was performed. All patients were placed in the supine position with their necks hyperextended (or not) depending on the recognition degree of the anatomical neck mark. For instance, patients with a high cervical spine injury were placed in the supine position without shoulder elevation or neck hyperextension.

Anesthesia and incision for NGPDT

After sterilization and local anesthesia with lidocaine (0.1 g, 5 ml, Shang Dong Qi Lu Medicine Corporation, Jinan, China) was administered, a transverse incision 1.2–1.5 cm in length was made between the second and fourth tracheal cartilage rings. If the body surface anatomical landmarks of the anterior neck were unclear, the incision was made at least one finger width above the suprasternal fossa. Subcutaneous vessels may be severed during this procedure. To avoid this complication, our solution was to create an artificial skin edema by intradermal injection with local anesthetics. This way, the thickness of the epidermis was increased, and the depth of the incision was easier to control, reducing the injury rate of the subcutaneous vessels. At this time, the syringe needle had to reach the anterior tracheal wall (which was also the puncture point) vertically along the midpoint of the incision, with anesthetics injected along the way.

Tracheal puncture

The thumb and forefinger of one hand were used to fix the trachea on both sides of the incision, while the other hand held the puncture needle perpendicular to the anterior tracheal wall and performed the tracheal puncture along the anesthesia channel. The initial scale was recorded when the puncture needle reached the anterior wall of the trachea, after which the puncture depth was recorded. The puncture needle inclined approximately 15° caudal to perpendicular, with the puncture depth strictly restricted to less than 0.5 cm. By doing this, damage to the posterior tracheal wall and the tracheoesophageal fistula was avoided. As much as possible, we avoided excessively tilting the puncture needle caudally before entering the trachea, as this can lead to pneumothorax in patients with an upper pulmonary apex location. The puncture needle could easily slip by deviating from the trachea and damage the blood vessels on both sides of the midline if the puncture point were not at the midline of the trachea. A sense of breakthrough was important when puncturing the trachea. In this respect, a syringe filled with saline was pumped back from the puncture needle to see if there were bubbles and ensure a successful puncture. It should be noted that a puncture needle block may lead to false judgment by the operator and an increase in the depth of

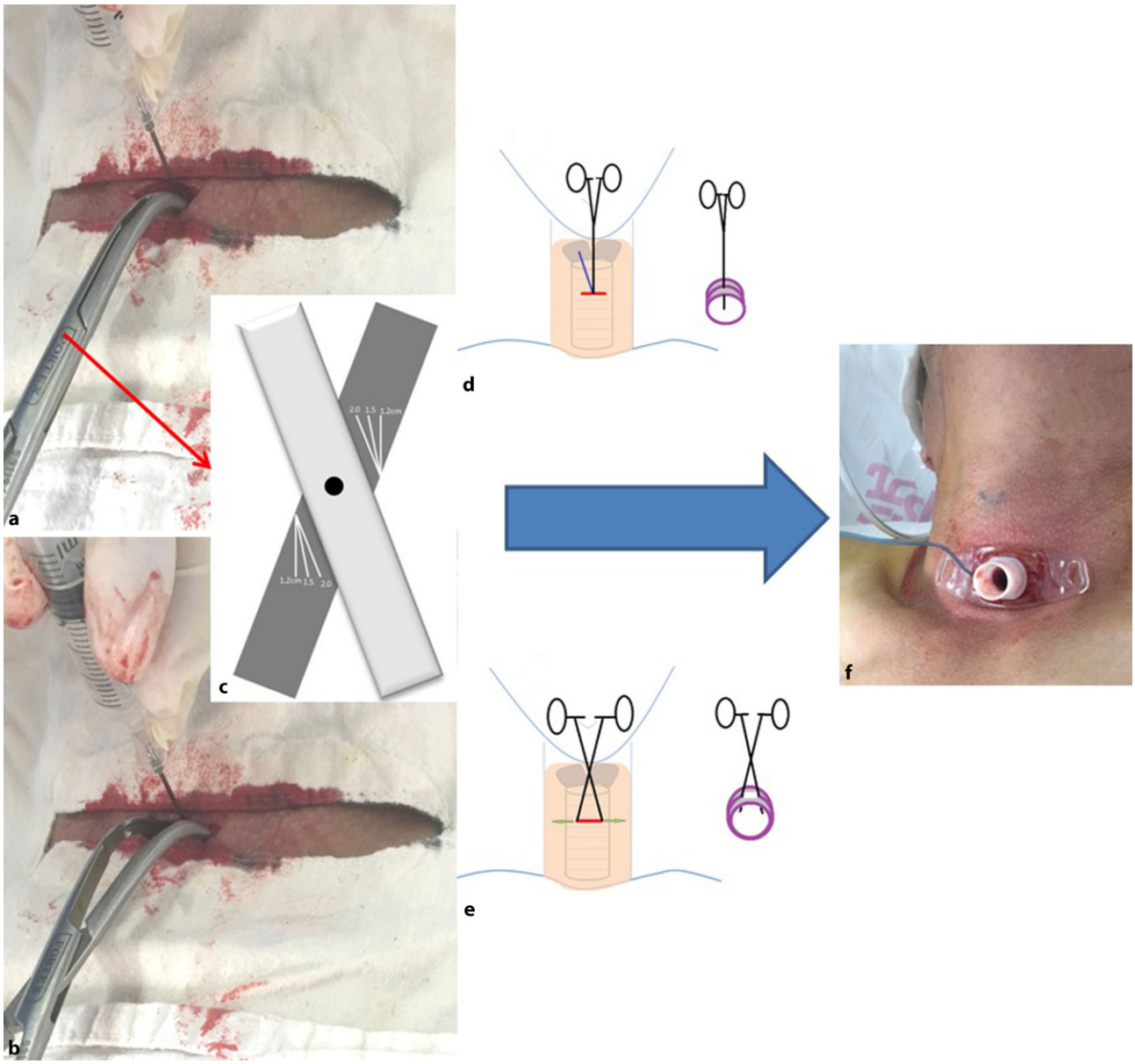

Fig. 1 The dilatation process and sketch map of NGPDT, **a**, **d**, **b** and **e** show a Portex tracheal dilation forceps inserted into the trachea with a puncture needle along the puncture channel, then the tracheal fistula and subcutaneous tissue were further enlarged and the puncture needle was removed. **c** Shows the scale on the cross of the forceps. **f** Shows the tracheal cannula inserted in the trachea

the puncture. Thus, the puncture needle had to be pulled out and checked for a puncture depth of more than 0.5 cm when bubbles were pumped out. Generally speaking, typical blockages were tracheal cartilage, soft tissue, or blood clots. The balloon of the tracheal cannula may break in the process of NGPDT; however, we found that this did not lead to a significant decrease in oxygen saturation. The oral secretion just needed to be cleaned with an aspirator to prevent aspiration.

Preliminary subcutaneous dilation

Following a successful tracheal puncture, the subcutaneous tissue and muscle around the puncture needle were dilated gently along the entrance of the needle with sharp, straight-head mosquito forceps that reached the anterior tracheal wall. During this process, the depth of the needle was kept unchanged.

Expansion of the intubation channel and insertion of the tracheal cannula

Following the initial subcutaneous dilation, modified Portex tracheal dilation forceps were inserted into the

puncture along the channel to reach the puncture point. Then, the puncture needle was clamped by the forceps, and both punctured the trachea (Fig. 1). Following this, the tracheal fistula and subcutaneous tissue were further enlarged, and the needle was removed. In this step, the needle was clamped tightly by the forceps, 0.5 cm from the tip, and the insertion depth of the dilation forceps and needle could be no more than 0.5 cm. The expansion width was calculated as π * D/2, where D is the diameter of the tracheal cannula. For example, for a tracheal cannula with a 0.75cm diameter, the expansion width of the cannula should be 1.18 cm (3.14 * 0.75 cm/2 = 1.18 cm). The appropriate tracheal cannula was then inserted. The judgment of the tracheal diameter depended on the bedside ultrasound measurement and neck computed tomography (CT) measurement data. In emergencies, a 0.75 cm diameter tracheal cannula can be used for male patients, and a 0.7 cm diameter tracheal cannula can be used for female patients.

Observational index

The patients' demographic, preoperative state of illness, and diagnosis data were collected. Their intraoperative and postoperative variables were accessed, e.g., operation times, bleeding, saturation of pulse oxygen (SPO_2), and early and late complications related to NGPDT. The degree of bleeding was defined as: mild, i.e., bleeding was stopped by local compression and tracheal cannula saccule were inflated; moderate, i.e., bleeding was stopped by bedside ligation; severe, i.e., surgery was required to stop the bleeding.

Statistical analysis

We used the software program SPSS 21.0 (IBM, Chicago, IL, U.S.A.) to conduct the statistical analysis. The continuous variables of normal distribution were expressed as the mean ± standard deviation, the continuous variables of non-normal distribution were expressed as the median (interquartile range), and the categorical variables were expressed as the frequency (percentage, %). A value of $P<0.05$ was considered statistically significant.

Results

General characteristics

A total of 48 patients who underwent the NGPDT procedure from March 2013 to July 2019 were recruited for this study. Among these patients, 28 were male and 20 female. The mean age was 47.7 ± 13.7 years (ranging from 23 to 75 years). The mean Glasgow Coma Scale (GCS) was 8.1 ± 2.9 (ranging from 4 to 15). The mean Body Mass Index (BMI) was 25.2 ± 5.6 (ranging from 18 to 40).

Table 1 Demographic characteristic of patients who underwent NGPDT

Variables	Number (percentage, %)	Number range	Mean ± SD
Age (years)	–	23–75	47.7 ± 13.7
Gender			
Male	28 (58.3)	–	–
Female	20 (41.7)	–	–
GCS	–	4–15	8.1 ± 2.9
BMI	–	18–40	25.2 ± 5.6
Endotracheal tube			
Yes	38 (79.2)	–	–
No	10 (20.8)	–	–
Diagnosis			
Cerebral hemorrhagic stroke	16 (33.3)	–	–
Cerebral ischemic stroke	19 (39.6)	–	–
Traumatic brain injury	8 (16.7)	–	–
Cervical spine injury	3 (6.3)	–	–
Severe pneumonia	1 (2.1)	–	–
Multiple organ failure	1 (2.1)	–	–
Duration of onset to NGPDT[a]	–	1–19	4.0 ± 1.3

Note: [a] 1 day means the duration of onset to NGPDT ≤ 24 h
BMI Body Mass Index, *NGPDT* non-guide-wire percutaneous dilatational tracheostomy, *GCS* Glasgow Coma Scale

Diagnosis before operation

There were 38 patients (79.2%) with an endotracheal tube before the operation. Moreover, 16 (33.3%) patients were diagnosed with cerebral hemorrhagic stroke, 19 (39.6%) with cerebral ischemic stroke, 8 (16.7%) with traumatic brain injury, 3 (6.3%) with high cervical spine injuries, 1 (2.1%) with severe pneumonia, and 1 (2.1%) with multiple organ failure. Three patients presented with a transient violent cough at the primary tracheostomy stage. The duration of onset to NGPDT ranged from 1 to 19 days, and the mean duration was 4.0 ± 1.3 days. The details are shown in Table 1.

Mean operation time

In this study, the mean operation time was 4.2 ± 1.9 min; the shortest time was only 2.1 min. The mean size of the skin incision was 1.4 ± 0.1 cm (ranging from 1.2 to 1.7 cm).

Intraoperative bleeding

There were 41 patients with mild intraoperative bleeding, 5 with moderate intraoperative bleeding, and 2 with severe intraoperative bleeding, where the bleeding was stopped by local compression and ligation. Moreover, there were 46 patients with mild

postoperative bleeding and 2 with moderate intraoperative bleeding.

Intraoperative complications

In this study, there were no patients with pneumothorax, subcutaneous emphysema, or GCS decline after NGPDT and false passage in the procedure. One patient experienced an SPO_2 drop of over 10% after intubation but returned to normal within a short time. One patient with a recurring cough 45 days after NGPDT was diagnosed with tracheoesophageal fistula by bronchoscopy.

Extubation and duration of incision healing time

A total of 41 patients (85.4%) had a complete extubation after NGPDT. The duration of incision healing ranged from 2 to 14 days; the mean duration was 4.8 ± 3.1 days. There were 34 patients (82.9%) with an incision healing time of less than 1 week, while 7 patients (17.1%) experienced a healing time of more than 1 week. In two patients (4.2%), the puncture needle was blocked by blood during the tracheal puncture step, but the blockage was subsequently cleared. No surgery-related deaths of any of the patients were recorded. The details are shown in Table 2.

Table 2 Intraoperative and postoperative NGPDT related index of every patients

Variables	Number (percentage, %)	Number range	Mean ± SD
Operation time (min)	–	2.1–12.5	4.2 ± 1.9
Skin incision (cm)	–	1.2–1.7	1.4 ± 0.1
Intraoperative bleeding	–	–	–
Mild	41 (85.4)	–	–
Moderate	5 (10.4)	–	–
Severe	2 (4.2)	–	–
Postoperative bleeding	–	–	–
Mild	46 (95.8)	–	–
Moderate	2 (4.2)	–	–
Severe	0	–	–
Pneumothorax/subcutaneous emphysema	0	–	–
False passage [a]	0	–	–
Decreasing of $SPO_2 \geq 10\%$	1 (2.1)	–	–
Postoperative GCS decline	0	–	–
Tracheoesophageal fistula	1 (2.1)	–	–
Surger-related death	0	–	–
Duration of Incision healing (day)	–	2–14	4.8 ± 3.1
Less than 1 week	34/41 (82.9)	–	–
More than 1 week	7/41 (17.1)	–	–
Blockage of puncture needle	2 (4.2)	–	–

Note: [a] means failure to complete NGPDT and turn to surgical tracheostomy
GCS Glasgow Coma Scale

Discussion

The outcomes of this study showed that the mean patient age was 47.7 ± 13.7 years. The mean GCS was 8.1 ± 2.9, and the mean BMI was 25.2 ± 5.6. There were 38 patients (79.2%) with an endotracheal tube. The mean duration of onset to NGPDT was 4.0 ± 1.3 days. The mean operation time was 4.2 ± 1.9 min. There were 41 patients that experienced mild intraoperative bleeding, 5 with moderate intraoperative bleeding, and 2 with severe intraoperative bleeding. There were 46 patients with mild postoperative bleeding and 2 with moderate intraoperative bleeding. Moreover, 41 patients had a complete extubation after NGPDT. The mean duration of incision healing was 4.8 ± 3.1 days. There was one patient with a decrease of $SPO_2 \geq 10\%$. Three patients presented with a transient violent cough in the primary tracheostomy stage; however, none of the patients suffered from pneumothorax, subcutaneous emphysema, or false passage during this procedure, and there were no surgery-related deaths.

Compared with surgical tracheostomy, PDT requires a small incision and has a shorter operation time, with fewer surgical instruments and no illumination. It is now widely used in intensive care units (ICU) and general wards [1, 8, 9]. Obvious tracheal stimulus responses caused by guide wires have been observed in most patients, but this does not happen in surgical tracheostomy [7, 10]; however, both surgical methods have their own advantages and disadvantages [11]. In our study, the guide wire was abandoned in the NGPDT process. Following the tracheal puncture, tracheal dilation forceps were inserted into the tracheal tunnel directly from the anterior tracheal wall, after which the tracheal fistula and subcutaneous tissue were dilated. Three aged patients with calcification of the anterior tracheal wall developed a transient violent cough due to the forced tracheal puncture, but the other patients did not. One patient had an SPO_2 drop of over 10% but recovered shortly after intubation. None of the patients presented with a GCS decline after NGPDT. These results were in consensus with those of Maddali and Pratap [12], who reported on the PDT procedure without bronchoscope guidance. The process was simpler in this method without the assistance of the guide wire than in other PDT methods. In this study, the shortest time was only 2.1 min. A series of controlled steps were performed to guarantee the entire process was feasible and safe.

The aim of position placement is not only to meet surgical demands but also to keep patients comfortable and safe. A study [13] of 88 patients who underwent PDT indicated that there was no significant difference in the surgery success rate regarding whether the neck was extended. Thus, not all patients were placed with their necks hyperextended. Except for obese patients whose necks required a hyperextension

for the clear neck anatomical mark, the other patients only needed slightly extended necks. Three patients with high cervical spine injuries were placed in a general supine position without their shoulders elevated or their necks extended.

Theoretically speaking, when the incision length is equal to half the permeation of the tracheal cannula, the tissue tension strain is optimal. In previous studies, a vague description of the incision was reported by most authors, and there are no guidelines providing objective data about the incision and dilatation. Little research exists [14] to explore how to accurately prevent injury in PDT. In this study, the incision length in the skin and the dilatation width were accurately calculated according to the formula $\pi * D/2$ in NGPDT. The actual incision length was adjusted slightly based on individual body shape. The mean incision length was 1.4 ± 0.1 cm, no larger than that in other studies [15, 16].

The blindness of percutaneous tracheostomy lies in the uncertainty of the artery from the skin to the anterior wall of trachea, and it is difficult to keep away from the artery. A consensus has not yet been reached for the evaluation of bleeding in percutaneous tracheostomy. The definition of bleeding in PDT varies significantly. Pilarczyk defined it as weight changing before and after the procedure and included endobronchial bleeding [17]. Añón et al. [18] defined it as a drop in the hematocrit level to below three points during the first 24 h after the procedure. In this study, we defined bleeding in three levels, i.e., mild, moderate, and severe, according to a deferent approach to stopping the bleeding. Intraoperative bleeding that required treatment through a surgical procedure was regarded as severe. In this study, the severe bleeding rate was 4.2%. This was similar to a study of 497 patients who underwent PDT, wherein the rate was 4.8% [19].

Herein, the vessels responsible for the bleeding during the NGPDT operation included the thyroid blood vessel, subcutaneous blood vessel, intramuscular blood vessel, and anterior tracheal blood vessel. There were two instances of moderate bleeding in this study, caused by subcutaneous artery rupture. These were stopped by suturing the neighboring skin. In our experience, conducting the puncture and dilation strictly along the midline significantly reduced blood vessel injury. There was no uncontrollable massive hemorrhaging in this study.

We believe that there is no absolute contraindication for NGPDT. Herein, there were 3 patients with cervical spine injuries and 9 patients with a BMI higher than 30 for whom NGPDT was performed successfully. Moreover, there were also 19 patients who had experienced cerebral ischemic strokes, all of whom received anticoagulant therapy. No severe bleeding was observed in the duration of the NGPDT, in consensus with Pasin's report [20]. Based on our team's experience with obese patients with PDT [21], we did not encounter significant difficulty with NGPDT in such patients; in the current study, the highest BMI was 40.

All NGPDT procedures in this study were performed without bronchoscope assistance in a blind manner; however, the strictly controlled standards at every step made the procedure feasible and safe.

The use of ultrasound and bronchoscope made the procedure even safer and has been reported by many authors [22, 23]. In our opinion, NGPDT or PDT is a simple, microinvasive, and rapid method for patients who require mechanical ventilation. Simplicity should be its intrinsic characteristic—auxiliary equipment is not necessary for every patient as it requires additional professionals and additional costs. Such equipment is mainly used to ensure the puncture location and depth to guarantee the safety of the endotracheal operation [24] and avoid damaging blood vessels in the puncture passage.

The puncture depth and direction were strictly controlled during the puncture process using a scaled puncture needle; the final inserted depth of the dilatation forceps and needle was limited to no more than 1.0 cm. This way, injuries to the apex of the lung and the posterior tracheal wall could be avoided. In this study, no patients suffered pneumothorax/subcutaneous emphysema, false passage, postoperative GCS decline, or surgery-related death. One patient had a recurring cough for 45 days after NGPDT diagnosed as tracheoesophageal fistula by bronchoscopy, the reason for which was unclear.

When it comes to decannulation, we believe that it mainly depends on personal illness circumstances rather than the operation type. In our study, 41 patients (85.4%) had complete extubation after NGPDT. The duration of the incision healing ranged from 2 to 14 days, with the mean duration being 4.8 ± 3.1 days. Being limited to a small sample and heterogeneity, we did not make a multivariate analysis for this index; however, we found that lengthy time in the hospital and older patient were risk factors for poor incision healing. In our study, for 6 patients under 30 years old who had a tracheal cannula for less than 1 month, the duration of the incision healing was less than 3 days.

Limitations

There are several limitations to this study. First, this trial was not a randomized controlled trial, and no control group was designed. Second, this study was only a single-center trial, and the sample size was limited, which merits further research with a larger sample size. Third, the clinical follow-up was short. Fourth, there was no quantitative analysis of the tracheal stimulus response. Fifth, the complication rate was low, mainly due to the fact that all steps were completed by only one experienced surgeon.

Conclusion

Overall, NGPDT is a simple method for critically ill patients who require an artificial airway established for mechanical ventilation. A series of controlled steps make this method microinvasive, feasible, and safe, and with a lower rate of complications. In this study, without the use of a guide wire, the tracheal stimulus response was mild.

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Conflict of interest X.-Y. Du, X.-D. Zhai and Z. Liu declare that they have no competing interests.

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