Comparison of the Efficacy and Safety of Ultrasound-Guided Percutaneous Balloon Dilatational Tracheotomy and Surgical Tracheotomy in Patients With Acute Respiratory Failure

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AIM: This study aimed to compare the efficacy and safety of ultrasound-guided percutaneous balloon dilatational tracheotomy (US-PDT) versus surgical tracheotomy (ST) in patients with acute respiratory failure (ARF).
METHODS: In this retrospective cohort study, 278 patients with ARF were enrolled from January 2022 to January 2025. These patients were divided into the US-PDT group (n = 135) and the ST group (n = 143) based on the surgical method used. Perioperative indicators, procedural success rates, inflammatory markers, hospitalization outcomes, and complications were systematically compared between the two groups.
RESULTS: The US-PDT group demonstrated superior outcomes across all measures. It was associated with a significantly shorter procedure time, smaller incision length, reduced intraoperative blood loss, and shorter duration of mechanical ventilation (all $p < 0.001$). The US-PDT group also showed a higher single-attempt procedural success rate, alongside a lower accidental extubation rate (all $p < 0.001$). Postoperative inflammatory markers (erythrocyte sedimentation rate [ESR], C-reactive protein [CRP], and procalcitonin [PCT]) were significantly lower in the US-PDT group ($p < 0.001$). Furthermore, the US-PDT group experienced reduced ventilator-associated pneumonia (VAP) incidence, higher weaning success, shorter intensive care unit (ICU) and hospital stays, and lower ICU and overall mortality (all $p < 0.05$). Complication rates were also significantly lower in the US-PDT group ($p < 0.05$).
CONCLUSIONS: US-PDT is a more efficient, safer, and less invasive alternative to ST for ARF patients, resulting in better clinical outcomes, reduced inflammation, fewer complications, and improved survival rates.

Keywords: acute respiratory failure; ultrasound-guided percutaneous balloon dilatational tracheotomy; surgical tracheotomy; mechanical ventilation

Introduction

Acute respiratory failure (ARF) is a clinical syndrome marked by rapid deterioration of pulmonary ventilation and/or gas exchange, often leading to intensive care unit (ICU) admission [1]. Its pathogenesis involves factors such as respiratory insufficiency, diffusion impairment, shunting, and ventilation-perfusion mismatch [2]. Timely assessment and stepwise provision of respiratory support are crucial for improving prognosis [3]. Tracheotomy, as a pivotal approach for establishing an artificial airway, plays a paramount role in the management of patients with ARF [4]. By performing a tracheotomy, it can effectively relieve airway obstruction, reduce airway resistance, minimize respiratory work expenditure, facilitate the clearance of respiratory secretions, improve gas exchange, and create favorable conditions for subsequent patient treatment [5]. Since Chevalier Jackson established the modern surgical technique in 1909, traditional surgical tracheotomy (ST) has long served as a commonly employed method for tracheotomy in clinical practice, characterized by its mature technology and the extensive experience accumulated by practitioners [6]. However, ST is associated with drawbacks such as significant surgical trauma and prolonged operative time, leading to a relatively high incidence of intraoperative and postoperative complications. These complications affect patient prognosis, prolong hospital stays, and even increase the risk of mortality [7].

Ultrasound-guided percutaneous balloon dilatational tracheotomy (US-PDT) represents a novel minimally invasive surgical approach based on percutaneous tracheotomy. With the continuous refinement of electronic imaging and visualization technologies, the application of ultrasound guidance has been extended to the preoperative, intraoperative, and postoperative phases [8]. US-PDT offers several advantages, including short operative time, minimal blood loss, precise positioning, and high surgical success rates. It

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is a straightforward procedure that is easy to master, and owing to minimal equipment requirements, this procedure can be easily completed at the patient's bedside [9]. It is noteworthy that within the PDT technology framework, the Ciaglia–Blue–Dolphin technique represents a widely utilized balloon dilatation method. This approach primarily relies on balloon expansion to establish an airway. By injecting saline into the balloon, it expands and exerts a uniform radial force on the trachea, thereby creating a tracheostomy. This method circumvents direct compression of the anterior tracheal wall by traditional rigid dilators, reducing mechanical trauma associated with conventional dilators. It has emerged as a highly valuable airway management technique in modern intensive care unit (ICU) and is frequently combined with ultrasound guidance in the US-PDT procedure [10].

Although the advantages of US-PDT (Ciaglia–Blue–Dolphin) have been validated in certain contexts, current clinical research predominantly focuses on general surgical patients. For the specific population of patients with ARF, systematic clinical data are lacking to determine whether US-PDT demonstrates superior efficacy compared to traditional ST, whether it effectively reduces the incidence of postoperative complications, and how it impacts key prognostic indicators such as length of hospital stay and mechanical ventilation time. This paucity of evidence makes it challenging for clinicians to make well-informed, evidence-based decisions when selecting tracheotomy techniques for patients with ARF, thereby limiting the broader adoption of this minimally invasive technique in the management of ARF. Therefore, this study employed a retrospective cohort design to systematically compare US-PDT and ST in 278 ARF patients, assessing perioperative indicators, single-attempt procedural success rate, inflammatory markers, complications, and hospitalization outcomes. The aim was to provide evidence-based guidance for optimizing tracheotomy technique selection in this high-risk population.

Methods

Subjects

This retrospective cohort study selected adult patients with ARF who underwent tracheotomy and were hospitalized at Yangzhong Traditional Chinese Medicine Hospital from January 2022 to January 2025.

Inclusion criteria: (1) Patients aged $\geq$18 years; (2) Patients with ARF caused by various etiologies, which are diagnosed according to the following criteria [11]: Respiratory failure is diagnosed based on arterial blood gas analysis when, at rest and while breathing room air, arterial oxygen partial pressure (PaO_2) is $<$60 mmHg, with or without arterial carbon dioxide partial pressure ($PaCO_2$) $>$50 mmHg, after excluding factors such as intracardiac anatomical shunting and primary reductions in cardiac output. When the inspired oxygen concentration (FiO_2) is increased, the oxygenation index (PaO_2/FiO_2) can be used as a diagnostic indicator for respiratory failure. A PaO_2/FiO_2 ratio $\leq$300 mmHg suggests respiratory failure. Patients were included if they presented with a rapid onset of respiratory failure consistent with an acute clinical deterioration; (3) Patients with clear indications for tracheotomy; (4) Patients with complete clinical data available.

Exclusion criteria: (1) Pregnant or lactating women; (2) Patients who abandoned treatment or were transferred to another hospital; (3) Patients undergoing tracheotomy for non-ARF conditions, such as otolaryngological diseases; (4) Patients with a history of prior tracheotomy; (5) Patients with abnormal neck anatomy precluding accurate identification of the tracheal position; (6) Patients with coagulopathy or immunologic dysfunction; (7) Patients with a history of neck malignancy, recent severe neck trauma or surgery, or neck infection; (8) Patients with severe allergic reactions to local anesthetics or analgesic/sedative medications.

This clinical study was conducted in adherence to relevant ethical guidelines, including the Declaration of Helsinki [12], and received prior approval from the Institutional Review Board (IRB) of the Yangzhong Traditional Chinese Medicine Hospital (Ethical Approval Number: 202501). Researchers were required to provide detailed explanations of the study's objectives, procedures, and potential risks to participants or their legal representatives, and obtain written informed consent from all enrolled individuals.

Sample Size Calculation

Given the retrospective nature of this study, a formal *a priori* sample size calculation was not feasible as the number of available cases was determined by historical patient data. However, to assess whether the enrolled sample size provided adequate statistical power to detect clinically meaningful differences, a post-hoc power analysis was performed using G*Power 3.1.9.7 software (Heinrich Heine University Düsseldorf, Düsseldorf, NRW, Germany). The analysis was based on the primary outcome of procedure time, as it is a key metric differentiating the two surgical approaches. The effect size (d = 0.5) was derived from a pilot review of our institutional data and is considered a medium effect according to Cohen's conventions. The analysis was configured with a significance level (α) of 0.05 (two-tailed). With the final sample sizes of 135 (US-PDT) and 143 (ST), the achieved statistical power (1-β) for detecting a medium effect size exceeded 0.95. This indicates that the study was sufficiently powered to identify the observed differences in the primary and secondary outcomes.

Perioperative Management

To ensure the comparability of postoperative outcomes between the two groups, all patients adhered to standardized perioperative management protocols, as detailed below:

• Analgesia: Postoperative analgesia was managed uniformly using intravenous patient-controlled analgesia (PCA) with sufentanil for the first 48 hours. The PCA was

set to a background infusion of 1 μg/h, with a bolus dose of 1 μg and a lockout interval of 15 minutes. Subsequent analgesia was administered with intravenous flurbiprofen axetil 50 mg every 12 hours, with doses adjusted according to the patient's pain assessment (Numerical Rating Scale, NRS) to maintain an NRS score of ≤3.

• Anti-infective Prophylaxis: All patients received prophylactic intravenous cefuroxime (1.5 g) 30 minutes before skin incision. Postoperatively, the same dose was administered every 12 hours for 24 hours. Further antibiotic use was guided by clinical signs of infection and microbiological culture results.

• Airway Care: Standardized airway care protocols were implemented for all patients. This included humidified oxygen via a heated humidifier, closed-system suctioning performed as needed, and routine oral care with chlorhexidine gluconate (0.12%) every 6 hours.

Surgical Procedures

To minimize operator-dependent bias, all tracheotomy procedures (both US-PDT and ST) in this study were performed by the same group of three attending surgeons, each with over 5 years of experience in critical care airway management and formally trained in both surgical techniques. All US-PDT procedures were performed by intensivists or surgeons who had extensive experience in ultrasound-guided interventions and had each successfully performed at least 50 US-PDT procedures prior to the study, thereby minimizing the influence of the learning curve on the procedural outcomes.

Prior to the surgery, both groups of patients underwent comprehensive preoperative evaluations, including complete blood count, liver and renal function tests, arterial blood gas analysis, coagulation profile, and electrocardiogram. Preoperative routine oxygen inhalation was administered, and oxygen saturation was monitored. Once surgical instruments were prepared, the procedure commenced.

For the ST group, patients were positioned supine with shoulder elevation to achieve neck hyperextension, ensuring adequate exposure of the anterior neck. Standard surgical draping and disinfection were performed. Local anesthesia was applied to every patient in this group, consistent with standard practice for this procedure in hemodynamically stable patients. Local anesthesia was induced using lidocaine hydrochloride injection. A vertical midline incision was made from approximately 1 cm above the suprasternal notch to the inferior border of the cricoid cartilage. The skin and subcutaneous tissues were dissected, followed by separation of the anterior cervical muscle groups to expose the anterior tracheal wall. Under direct visualization, a horizontal incision was made through the anterior tracheal wall at the level of the 2nd–3rd tracheal rings. The anterior tracheal wall was dilated, and an appropriately sized tracheostomy tube was inserted. The tube was then secured in place with sutures and tracheostomy ties. Correct tube placement within the tracheal lumen was confirmed by means of capnography and visualization of condensed vapor within the tube during exhalation. Mechanical ventilation was initiated via the tracheostomy tube connected to a ventilator.

For the US-PDT group, the procedure was performed at the patient's bedside in the ICU by experienced intensivists trained in the technique, utilizing the Ciaglia–Blue–Dolphin system. Following standard monitoring, the patient's neck was positioned and prepped. A pre-procedural ultrasound examination was conducted using a high-frequency linear probe to identify key anatomical structures, namely the cricoid cartilage, tracheal rings (targeting the space between the 2nd and 3rd rings, or the 3rd and 4th rings), thyroid isthmus, and anterior jugular vessels. The optimal puncture site, avoiding vascular structures and the thyroid isthmus, was marked. Under continuous real-time ultrasound guidance in a sterile sheath, the endotracheal tube was carefully withdrawn under direct vision to a position just below the vocal cords, ensuring the cuff remained above the planned puncture site to avoid puncture. Mechanical ventilation was briefly paused during the critical moments of needle puncture and dilatation to minimize tracheal movement and the risk of cuff damage, with ventilation resumed between steps as needed. After local anesthesia, a 1–2 cm transverse skin incision was made. Under continuous ultrasound visualization, the puncture needle attached to a syringe was advanced into the tracheal lumen, with correct intratracheal position confirmed by air aspiration. A guidewire was then introduced through the needle using the Seldinger technique. Sequential dilatation was initiated with a 14F dilator. The Ciaglia–Blue–Dolphin balloon catheter, pre-filled with 20 mL of 0.9% sodium chloride solution and connected to the inflation pump, was then advanced over the guidewire. The balloon was positioned across the tracheal wall and inflated to a maximum pressure of 11 atmospheres for 15 seconds to create the stoma via radial expansion. The balloon was then completely deflated and removed. The pre-loaded tracheostomy tube was subsequently advanced over the guidewire and introducer into the trachea with minimal resistance. Correct tube placement was confirmed by capnography and bilateral chest auscultation. The guidewire and introducer were then removed. The tracheostomy tube was secured in place using both tracheostomy ties and sutures to the skin to prevent accidental dislodgement. The original endotracheal tube was removed only after secure placement and confirmation of adequate ventilation through the tracheostomy tube.

Observation Indicators

A range of observation indicators was adopted in this study:

• Perioperative Indicators: The following indicators were recorded and compared between the two groups: (i) Incision length (cm), which was measured as the final skin incision length after completion of the procedure; (ii) To-

Table 1. Comparison of baseline data between the ST group and the US-PDT group.

Variables	Total (n = 278)	ST group (n = 143)	US-PDT group (n = 135)	Statistic	p
Age (years), mean ± SD	67.17 ± 11.71	67.55 ± 12.18	66.76 ± 11.21	t = 0.556	0.578
BMI (kg/m^2), mean ± SD	23.28 ± 2.46	23.45 ± 2.41	23.11 ± 2.51	t = 1.119	0.264
Gender, n (%)					
Female	79 (28.42)	38 (26.57)	41 (30.37)	χ^2 = 0.492	0.483
Male	199 (71.58)	105 (73.43)	94 (69.63)		
Underlying diseases, n (%)					
Disorders of the circulatory system	169 (60.79)	83 (58.04)	86 (63.70)	χ^2 = 0.934	0.334
Respiratory diseases	45 (16.19)	22 (15.38)	23 (17.04)	χ^2 = 0.140	0.709
Kidney dysfunction	24 (8.63)	12 (8.39)	12 (8.89)	χ^2 = 0.022	0.883
Neurological dysfunction	69 (24.82)	38 (26.57)	31 (22.96)	χ^2 = 0.485	0.486
Endocrine system disorders	81 (29.14)	46 (32.17)	35 (25.93)	χ^2 = 1.310	0.252
Multiple system dysfunction	107 (38.49)	61 (42.66)	46 (34.07)	χ^2 = 2.161	0.142
Vital signs					
Body temperature (°C), mean ± SD	37.09 ± 0.56	37.07 ± 0.50	37.10 ± 0.61	t = –0.523	0.601
Heart rate (beats/minute), mean ± SD	87 ± 13	88 ± 11	85 ± 15	t = 1.442	0.151
Mean arterial pressure (mmHg), mean ± SD	89.40 ± 7.31	89.66 ± 7.20	89.12 ± 7.44	t = 0.614	0.540
Respiratory rate (breaths/minute), M (Q_1, Q_3)	18 (17, 20)	18 (17, 20)	19 (17, 20)	Z = –1.606	0.108
APACHE II Score (points), M (Q_1, Q_3)	20 (16, 23)	20 (17, 23)	20 (16, 23)	Z = –0.518	0.604
GCS Score (points), M (Q_1, Q_3)	7 (5, 9)	6 (5, 9)	7 (5, 8)	Z = –1.029	0.304
PT (s), M (Q_1, Q_3)	12 (11, 13)	12 (12, 13)	12 (11, 13)	Z = –1.317	0.188
APTT (s), M (Q_1, Q_3)	29 (26, 33)	29 (26, 34)	29 (26, 33)	Z = –0.737	0.461
Preoperative PLT (×10^9/L), M (Q_1, Q_3)	223.50 (160.50, 311.75)	218.00 (164.50, 317.50)	228.00 (159.00, 308.50)	Z = –0.421	0.674
Causes of ARF, n (%)					
Respiratory diseases	121 (43.53)	66 (46.15)	55 (40.74)		
Diseases of the central nervous system	107 (38.49)	54 (37.76)	53 (39.26)		
Diseases of the circulatory system	26 (9.35)	12 (8.39)	14 (10.37)	χ^2 = 1.102	0.894
Infection	13 (4.68)	6 (4.20)	7 (5.19)		
Others	11 (3.96)	5 (3.50)	6 (4.44)		

Notes: Underlying diseases were classified according to the International Classification of Diseases, 10th Revision (ICD-10). Multiple system dysfunction was defined as the simultaneous dysfunction of two or more organ systems (e.g., cardiovascular, respiratory, renal, neurological) based on clinical and laboratory criteria. Causes of ARF were categorized as follows: respiratory diseases (including pneumonia, chronic obstructive pulmonary disease, and acute respiratory distress syndrome); central nervous system diseases (e.g., stroke, encephalitis, brain injury), circulatory system diseases (e.g., heart failure, myocardial infarction); infection (i.e., systemic infection leading to ARF); and others (including trauma and poisoning).

Abbreviations: SD, standard deviation; M, median; ST, surgical tracheotomy; US-PDT, ultrasound-guided percutaneous balloon dilatational tracheotomy; APACHE II, Acute Physiology and Chronic Health Evaluation II; APTT, Activated Partial Thromboplastin Time; ARF, acute respiratory failure; BMI, body mass index; GCS, Glasgow Coma Scale; PT, Prothrombin Time; PLT, Platelet Count.

tal procedure duration (minutes), which was defined differently for the two techniques to accurately reflect the respective critical procedural phases. For the ST group, it was defined as the time from the initial skin incision to the successful placement of the tracheostomy tube. For the US-PDT group, it was defined as the time from the commencement of endotracheal tube repositioning under real-time ultrasound guidance to the successful placement of the tracheostomy tube; (iii) Intraoperative blood loss (mL), which was estimated by measuring the volume of blood in the suction container and weighing saturated gauzes; (iv) Duration of mechanical ventilation (days), which was calculated from the initiation of invasive mechanical ventilation via the tracheostomy tube until successful weaning.

• Procedural Success and Safety Metrics: The following metrics were recorded and compared between the two groups: (i) Single-attempt procedural success rate, which was defined as the successful placement of the tracheostomy tube into the correct position and the establishment of effective ventilation via the ventilator on the first attempt. This metric evaluates the one-time success efficiency of the procedure and is applicable to both the ST and US-PDT groups; (ii) Accidental extubation rate, which was defined as any unplanned tracheostomy tube dislodgement, balloon slippage, or incident leading to interruption of ventilation that occurred during the procedure or within 24 hours postoperatively.

• Inflammatory Markers: Venous blood samples were collected from all patients preoperatively, one day postoper-

Table 2. Comparison of perioperative indicators between the ST group and the US-PDT group.

Variables	Total (n = 278)	ST group (n = 143)	US-PDT group (n = 135)	Statistic	p
Duration of procedure (min), M (Q_1, Q_3)	7 (5, 11)	11 (9, 13)	5 (3, 6)	Z = –13.041	<0.001
Incision length (cm), mean ± SD	2.10 ± 0.81	2.72 ± 0.62	1.45 ± 0.33	t = 21.530	<0.001
Intraoperative blood loss (mL), M (Q_1, Q_3)	5 (3, 8)	7 (5, 10)	3 (2, 5)	Z = –10.922	<0.001
Duration of mechanical ventilation (days), M (Q_1, Q_3)	17 (13, 20)	20 (18, 22)	13 (11, 16)	Z = –11.949	<0.001

Table 3. Comparison of procedural success and safety between the ST group and the US-PDT group.

Variables	Total (n = 278)	ST group (n = 143)	US-PDT group (n = 135)	Statistic	p
Single-attempt procedural success rate, n (%)	236 (84.89)	104 (72.73)	132 (97.78)	χ^2 = 33.977	<0.001
Accidental extubation rate for tracheal intubation, n (%)	7 (2.52)	7 (4.90)	0 (0.00)	χ^2 = 4.931	<0.001

atively, and one week postoperatively. Systemic inflammatory response in the patients was assessed by computing erythrocyte sedimentation rate (ESR) and measuring serum levels of C-reactive protein (CRP) and procalcitonin (PCT) by means of enzyme-linked immunosorbent assay (ELISA).

• Hospitalization Outcomes: Incidence of ventilator-associated pneumonia (VAP), successful weaning rate, length of stay in the ICU, total length of hospital stay, ICU mortality, and overall in-hospital mortality were collected and compared between the two groups of patients.

• Complications: The occurrence of procedure-related complications was monitored and documented, including pneumothorax/pneumomediastinum, recurrent laryngeal nerve injury, tracheo-esophageal fistula, posterior tracheal wall injury, major hemorrhage, tracheal stenosis, and wound infection.

Statistical Analysis

Data analysis was performed using IBM SPSS 25.0 statistical software (International Business Machines Corporation, Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro–Wilk test. For normally distributed continuous variables, such as age and body mass index (BMI), data are presented as mean ± standard deviation (mean ± standard deviation [SD]), with intergroup comparisons conducted using the t-test. For repeated measures of inflammatory markers (ESR, CRP, PCT) across different time points (preoperative and postoperative), repeated-measures analysis of variance (ANOVA) was used to assess the interaction between group and time. Non-normally distributed continuous variables are expressed as median (M) with interquartile range (Q_1, Q_3), and intergroup comparisons were performed using the Mann–Whitney U test. Categorical variables, including underlying diseases and other count data, are presented as frequency (n) and percentage (%), with intergroup comparisons conducted using the χ^2 test or Fisher's exact test as appropriate. A p-value < 0.05 was considered statistically significant.

Results

Comparison of Baseline Data Between the ST Group and the US-PDT Group

The baseline characteristics of the 278 patients with ARF, divided into the ST group (n = 143) and the US-PDT group (n = 135), are presented in Table 1. There were no statistically significant differences between the two groups in terms of age, BMI, gender distribution, underlying diseases, vital signs, illness severity scores, coagulation parameters, or the causes of ARF (all $p > 0.05$). This indicates that the two groups were well-matched and comparable at baseline.

Comparison of Perioperative Indicators Between the ST Group and the US-PDT Group

Table 2 compares key perioperative indicators between the ST and US-PDT groups. The US-PDT group demonstrated significantly better outcomes across all measures, marked by shorter procedure duration (median 5 vs. 11 minutes, $p < 0.001$), smaller incision length (mean 1.45 vs. 2.72 cm, $p < 0.001$), and lower intraoperative blood loss (median 3 vs. 7 mL, $p < 0.001$). Furthermore, the duration of postoperative mechanical ventilation was significantly shorter in the US-PDT group (median 13 vs. 20 days, $p < 0.001$).

Comparison of Procedural Success and Safety Between the ST Group and the US-PDT Group

Table 3 compares procedural success and safety outcomes between the two groups. The US-PDT group demonstrated a significantly higher single-attempt procedural success rate compared to the ST group (97.78% vs. 72.73%, $p < 0.001$). Furthermore, accidental extubation of the tracheal tube occurred only in the ST group (4.90% vs. 0.00%, $p < 0.001$), indicating a superior safety profile for the US-PDT procedure.

Dynamic Changes in Postoperative Inflammatory Markers Between the ST Group and the US-PDT Group

The dynamic changes in postoperative inflammatory markers (ESR, CRP, and PCT) are shown in Table 4 and Fig. 1. Preoperatively, there were no significant differences in the

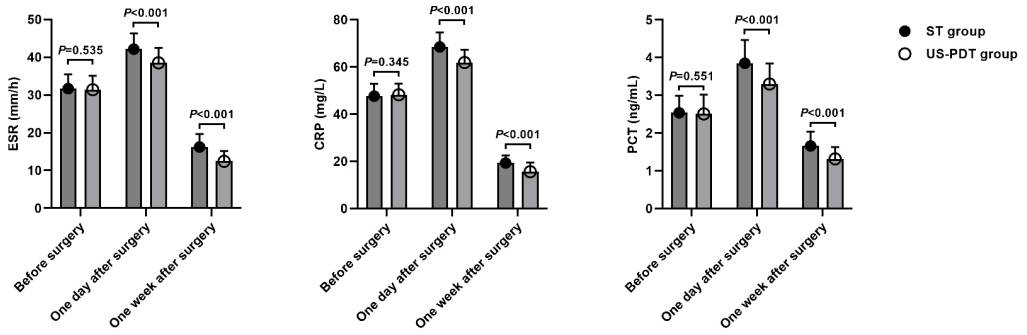

Fig. 1. Comparison of inflammatory markers between the ST group and the US-PDT group. US-PDT, ultrasound-guided percutaneous balloon dilatational tracheotomy; ST, surgical tracheotomy; ESR, erythrocyte sedimentation rate; CRP, C-reactive protein; PCT, procalcitonin.

Table 4. Comparison of inflammatory markers between the ST group and the US-PDT group.

Indicators	Group	*n*	Before surgery	One day after surgery	One week after surgery	Statistic	*p*
ESR (mm/h),	ST group	143	31.69 ± 3.79	42.15 ± 4.20	16.22 ± 3.45	F_{group} = 102.143;	$p_{group} < 0.001$;
mean ± SD	US-PDT group	135	31.41 ± 3.65	38.54 ± 3.98	12.45 ± 2.73	F_{time} = 3586.498;	$p_{time} < 0.001$;
Statistic			*t* = 0.621	*t* = 7.341	*t* = 10.127	$F_{group \times time}$ = 19.913	$p_{group \times time} < 0.001$
p			0.535	<0.001	<0.001		
CRP (mg/L),	ST group	143	47.66 ± 5.21	68.51 ± 6.14	19.32 ± 3.22	F_{group} = 87.395;	$p_{group} < 0.001$;
mean ± SD	US-PDT group	135	48.22 ± 4.75	61.88 ± 5.50	15.66 ± 3.89	F_{time} = 6930.269;	$p_{time} < 0.001$;
Statistic			*t* = –0.946	*t* = 9.446	*t* = 8.530	$F_{group \times time}$ = 38.754	$p_{group \times time} < 0.001$
p			0.345	<0.001	<0.001		
PCT (ng/mL),	ST group	143	2.54 ± 0.45	3.85 ± 0.62	1.66 ± 0.38	F_{group} = 99.320;	$p_{group} < 0.001$;
mean ± SD	US-PDT group	135	2.51 ± 0.51	3.30 ± 0.55	1.32 ± 0.31	F_{time} = 1244.510;	$p_{time} < 0.001$;
Statistic			*t* = 0.597	*t* = 7.874	*t* = 8.198	$F_{group \times time}$ = 19.174	$p_{group \times time} < 0.001$
p			0.551	<0.001	<0.001		

Abbreviations: CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; PCT, procalcitonin.

levels of any markers between the two groups (all $p > 0.05$). Compared to those treated with ST, the patients receiving US-PDT showed lower values for ESR (38.54 ± 3.98 vs. 42.15 ± 4.20 mm/h; $p < 0.001$), CRP (61.88 ± 5.50 vs. 68.51 ± 6.14 mg/L; $p < 0.001$), and PCT (3.30 ± 0.55 vs. 3.85 ± 0.62 ng/mL; $p < 0.001$) on postoperative day 1. One week postoperatively, significant differences persisted between the groups for ESR (12.45 ± 2.73 vs. 16.22 ± 3.45 mm/h; $p < 0.001$), CRP (15.66 ± 3.89 vs. 19.32 ± 3.22 mg/L; $p < 0.001$), and PCT (1.32 ± 0.31 vs. 1.66 ± 0.38 ng/mL; $p < 0.001$).

Repeated-measures ANOVA revealed significant effects of both surgical method (Group effect: all $p < 0.001$ for ESR, CRP, and PCT) and time (Time effect: all $p < 0.001$). These findings indicate that postoperative inflammatory markers decreased over time in both patient groups, while those in the US-PDT group remained consistently lower throughout. These results indicate that US-PDT was associated with a markedly attenuated and more rapidly resolving systemic inflammatory response in the early postoperative period.

Comparison of Hospitalization Outcome Indicators Between the ST Group and the US-PDT Group

Table 5 compares key hospitalization outcomes between the ST and US-PDT groups. The US-PDT group demonstrated significantly better results across all measures. The incidence of VAP was lower (38.52% vs. 57.34%; $p = 0.002$) and the weaning success rate was higher (71.85% vs. 53.15%; $p = 0.001$) in the US-PDT group. Both the length of ICU stay (19.18 ± 2.45 vs. 25.45 ± 3.77 days, $p < 0.001$) and the total length of hospital stay (21.26 ± 2.48 vs. 27.52 ± 3.79 days; $p < 0.001$) were significantly shorter for the US-PDT group. Furthermore, both ICU mortality (14.81% vs. 25.17%; $p = 0.031$) and overall hospital mortality (18.52% vs. 30.77%; $p = 0.018$) were significantly lower in the US-PDT group.

Comparison of Operative Complications Between the ST Group and the US-PDT Group

Table 6 compares operative complications between the two groups. Compared to the ST group, a significantly higher proportion of patients in the US-PDT group had no complications (94.07% vs. 78.32%; $p = 0.017$). The ST group reported a higher incidence of individual com-

Table 5. Comparison of hospitalization outcome indicators between the ST group and the US-PDT group.

Variables	Total (n = 278)	ST group (n = 143)	US-PDT group (n = 135)	Statistic	p
VAP incidence rate, n (%)	134 (48.20)	82 (57.34)	52 (38.52)	χ^2 = 9.855	0.002
Weaning success rate, n (%)	173 (62.23)	76 (53.15)	97 (71.85)	χ^2 = 10.337	0.001
Length of ICU stay (days), mean ± SD	22.41 ± 4.48	25.45 ± 3.77	19.18 ± 2.45	t = 16.553	<0.001
Length of hospital stay (days), mean ± SD	24.48 ± 4.49	27.52 ± 3.79	21.26 ± 2.48	t = 16.409	<0.001
ICU mortality, n (%)	56 (20.14)	36 (25.17)	20 (14.81)	χ^2 = 4.633	0.031
Hospital mortality, n (%)	69 (24.82)	44 (30.77)	25 (18.52)	χ^2 = 5.585	0.018

Abbreviations: VAP, ventilator-associated pneumonia; ICU, intensive care unit.

Table 6. Comparison of operative complications between the ST group and the US-PDT group.

Variables	Total (n = 278)	ST group (n = 143)	US-PDT group (n = 135)	Statistic	p
No complications, n (%)	239 (85.97)	112 (78.32)	127 (94.07)		
Pneumothorax or pneumomediastinum, n (%)	6 (2.16)	4 (2.80)	2 (1.48)		
Recurrent laryngeal nerve injury, n (%)	8 (2.88)	6 (4.20)	2 (1.48)		
Tracheo-esophageal fistula, n (%)	1 (0.36)	1 (0.70)	0 (0.00)	-	0.017
Posterior tracheal wall injury, n (%)	6 (2.16)	5 (3.50)	1 (0.74)		
Major hemorrhage, n (%)	8 (2.88)	7 (4.90)	1 (0.74)		
Tracheal stenosis, n (%)	3 (1.08)	3 (2.10)	0 (0.00)		
Wound infection, n (%)	7 (2.52)	5 (3.50)	2 (1.48)		

-, Fisher exact.

plications, including pneumothorax/pneumomediastinum (2.80% vs. 1.48%), recurrent laryngeal nerve injury (4.20% vs. 1.48%), posterior tracheal wall injury (3.50% vs. 0.74%), major hemorrhage (4.90% vs. 0.74%), tracheal stenosis (2.10% vs. 0.00%), and wound infection (3.50% vs. 1.48%). One case of tracheo-esophageal fistula was detected, occurring only in the ST group. Overall, the US-PDT procedure demonstrated a more favorable safety profile with fewer total and specific operative complications.

Discussion

Acute respiratory failure (ARF) is a common and critical condition in the ICU, where establishing a safe and efficient artificial airway is paramount for successful mechanical ventilation [13]. While ST has a long history of clinical use, its inherent limitations, including significant tissue trauma and a high incidence of perioperative complications, pose challenges for its application in critically ill ARF patients [14]. In recent years, US-PDT has gained increasing attention due to its minimally invasive nature. However, robust evidence directly comparing its efficacy and safety against ST specifically in the high-risk ARF population remains limited. Through a retrospective cohort design involving 278 ARF patients, we systematically compared these two procedures. Our results demonstrate that US-PDT holds significant advantages over ST in perioperative parameters, procedural success, inflammatory response modulation, complication rates, and ultimate hospitalization outcomes.

Optimization of perioperative indicators serves as the primary dimension for evaluating the clinical value of airway establishment techniques, directly reflecting the degree of surgical interference with the patient's physiological status. The results of this study demonstrate that the US-PDT group exhibited significant advantages over the ST group in terms of operative duration, incision size, and intraoperative blood loss. The markedly shorter procedure time in the US-PDT group can be attributed to its minimally invasive nature and streamlined workflow under ultrasound guidance. Unlike ST, which requires extensive tissue dissection and hemostasis, US-PDT utilizes a small incision and achieves tracheal access through a single puncture followed by balloon dilatation, a process that is inherently faster. These findings are highly consistent with the technical principles underlying US-PDT. Kang *et al.* [15] similarly reported a 97.4% success rate for US-PDT, with shorter operative times compared to ST (5.2 ± 3.1 vs. 10.5 ± 5.0 min), confirming its time-saving and safe profile. Conventional ST requires sequential dissection of the skin, subcutaneous tissue, fascia, and anterior tracheal wall, involving cumbersome procedural steps and heightened risk of injury to peritracheal vessels, such as branches of the inferior thyroid artery, leading to increased intraoperative bleeding. In contrast, the Ciaglia–Blue–Dolphin technique employed in this study's US-PDT group enabled tracheal access through a minimal incision (~1.5 cm) under real-time ultrasound guidance. Balloon dilatation facilitated minimally invasive expansion of the anterior tracheal wall without extensive tissue dissection, significantly reducing operative time and vascular injury risk. Furthermore, the visualization advantages of ultrasound guidance allowed clear delineation of tracheal cartilage rings, endotracheal tube positioning, and adjacent critical anatomical structures, mitigating anatomical misidentification risks associated with

conventional ST's reliance on surface landmarks. This provided technical assurance for reducing surgical time and trauma [16].

Procedural success rate serves as a critical metric for evaluating the reliability of airway establishment techniques, particularly in patients with ARF requiring urgent ventilatory support, where single-attempt puncture and cannulation success minimizes tracheal trauma caused by repeated manipulations. In this study, the US-PDT group demonstrated a significantly higher single-attempt procedural success rate compared to the ST group, with no instances of accidental tracheal tube dislodgement. This finding underscores the pivotal role of ultrasound guidance in enhancing procedural precision. The success rate of conventional ST is highly operator-dependent, with increased risks of puncture deviation or cannulation failure in patients with abnormal cervical anatomy or hemodynamic instability. In contrast, US-PDT enables real-time adjustment of puncture angle and depth through dynamic ultrasound imaging, ensuring accurate needle placement into the tracheal lumen. Additionally, the stable tract created by balloon dilatation reduces the risk of catheter dislodgement. Lin *et al*. [17] similarly reported that ultrasound-guided tracheotomy significantly improved first-attempt success rates and reduced complication rates compared to landmark-based tracheotomy, aligning with our findings and further validating the superior operational reliability of US-PDT.

Patients with ARF inherently exhibit systemic inflammatory responses due to respiratory dysfunction, and tracheotomy, as an invasive procedure, may further activate inflammatory pathways, exacerbating disease progression. The results of this study demonstrated that levels of inflammatory markers (ESR, CRP, PCT) in the US-PDT group were significantly lower than those in the ST group one week postoperatively, suggesting that US-PDT effectively mitigates postoperative inflammatory responses. Extensive tissue dissection and separation during conventional ST induce local tissue necrosis, releasing substantial amounts of damage-associated molecular patterns (DAMPs), such as high-mobility group box 1 protein (HMGB1) and adenosine triphosphate (ATP). These molecules activate inflammatory cells, including macrophages and neutrophils, triggering the release of pro-inflammatory cytokines like tumor necrosis factor-α (TNF-α) and interleukin-6 (IL-6), thereby initiating systemic inflammatory responses [18–20]. In contrast, the minimal incision and minimally invasive approach of US-PDT reduce tissue trauma, thereby attenuating both local and systemic inflammation. Additionally, ultrasound-guided precision minimizes excessive tracheal wall injury or inadvertent damage to surrounding tissues, which are potential risks inherent in conventional ST, further limiting inflammatory mediator production and release. CRP, an acute-phase reactant, directly reflects the severity of systemic inflammation, while PCT rises significantly during bacterial infections or severe inflammation, closely correlating with the occurrence of infectious complications [21]. In the present study, the lower postoperative PCT levels observed in the US-PDT group not only indicate reduced inflammation but also provide a foundation for lowering the risk of postoperative infectious complications.

Notably, the occurrence of VAP is closely associated with factors such as disruption of airway barrier function, bacterial colonization, and impaired drainage of airway secretions [22]. The larger incision made during conventional ST increases direct communication between the airway and the external environment, while tissue edema and increased secretions around the incision site create favorable conditions for bacterial colonization and infection. In contrast, the minimal incision in US-PDT reduces disruption of the airway barrier, thereby lowering the risk of bacterial invasion. Additionally, the US-PDT group exhibited significantly shorter postoperative mechanical ventilation duration. It is acknowledged, however, that the duration of mechanical ventilation is a complex outcome also influenced by the severity of the underlying disease, standardized weaning protocols, and the occurrence of non-procedure-related complications. Therefore, while the surgical method appears to be a significant contributing factor, future studies incorporating multivariate analysis are warranted to further delineate its independent effect on ventilation time. Studies have identified tracheotomy and an ICU stay exceeding 5 days as independent risk factors for VAP [23], whereas US-PDT directly reduces the likelihood of VAP occurrence [24]. This may be attributed to its ability to mitigate postoperative inflammatory responses, reduce inflammatory damage to the airway mucosa, decrease secretions, and improve airway drainage, thereby further lowering VAP incidence.

Beyond VAP prevention, US-PDT demonstrates advantages in reducing risks of accidental tracheal tube dislodgement, bleeding, pneumothorax, and posterior tracheal wall injury. Conventional ST relies on sutures or adhesive bands for tube fixation, and the larger incision creates a relatively loose fit between the tube and tracheal wall, increasing the likelihood of tube displacement or dislodgement [25]. In contrast, US-PDT establishes a tightly sealed airway tract through balloon dilatation, enhancing tube–tracheal wall adherence. Precise tube placement under ultrasound guidance helps prevent damage to the posterior tracheal wall or pleura, reducing pneumothorax risk. Furthermore, the Ciaglia–Blue–Dolphin technique employs radial balloon expansion, distributing force evenly to minimize direct impact on or laceration of the posterior tracheal wall, significantly lowering injury risk. Repeated dilatation or excessive pressure on tracheal cartilage rings in conventional ST may lead to scar formation or tracheal collapse, resulting in stenosis. The gentler balloon dilatation method in US-PDT minimizes structural damage to the trachea, thereby reducing postoperative tracheal stenosis incidence. Wen *et al*. [26] confirmed that US-PDT significantly reduced compli-

cation rates compared to anatomical landmark-guided approaches, further validating the rationale and advantages of ultrasound guidance employed in this study.

The reduction in complications and alleviation of inflammatory responses directly contributed to improved hospital outcomes in patients undergoing US-PDT. This study demonstrated that the US-PDT group exhibited significantly higher weaning success rates, along with notably shorter ICU stays and overall hospital stays, compared to the ST group. Additionally, both ICU mortality and overall mortality rates were significantly lower in the US-PDT cohort. Firstly, the minimally invasive nature of US-PDT and its low complication rate minimized physiological stress, creating favorable conditions for respiratory function recovery and thereby enhancing weaning success. Secondly, shortened durations of mechanical ventilation and hospitalization reduced patients' exposure to risks in the ICU, lowering the likelihood of secondary complications such as cross-infections and deep vein thrombosis. Furthermore, the attenuated inflammatory response and reduced complications decreased the risk of multi-organ dysfunction, ultimately improving patient prognosis and decreasing mortality rates.

The core value of this study lies in its pioneering systematic comparison of the efficacy and safety between US-PDT and ST, specifically in patients with ARF. Previous research on the Ciaglia–Blue–Dolphin technique has predominantly focused on general ICU populations. However, patients with ARF present unique challenges due to severe respiratory dysfunction, high clinical volatility, and low tolerance to trauma [27], necessitating more cautious selection of airway establishment techniques. Our findings demonstrate that US-PDT not only retains its advantages of minimal invasiveness and procedural efficiency in this high-risk population of ARF but also effectively reduces mortality rates, providing critical evidence to guide clinical practice.

Limitations

Despite the meaningful results obtained in this study, there are still some limitations. Firstly, in this single-center study, the patient population and clinical practices may be specific to our institution, potentially limiting the generalizability of our findings to other centers with different patient demographics or procedural expertise. Secondly, this study is a retrospective cohort study. Although some confounding factors were controlled through the stringent application of inclusion and exclusion criteria, it is still impossible to completely avoid selection bias and information bias. There may be potential differences between the two groups of patients in terms of the severity of underlying diseases and the number of comorbidities, which can affect the accuracy of the results. Thirdly, the follow-up period in this study was relatively short, precluding evaluation of long-term postoperative prognosis and patients' quality of life. Future studies could conduct multicenter, prospective randomized controlled trials to further verify the efficacy and safety of US-PDT in patients with ARF and reduce the impact of bias. Additionally, the follow-up period could be extended to evaluate the impact of the two surgical approaches on patients' long-term prognosis, with particular attention paid to long-term complications.

Conclusions

In summary, the application of US-PDT in patients with ARF demonstrates significant comprehensive advantages: its minimally invasive nature shortens operative time while reducing intraoperative bleeding and tissue damage; ultrasound-guided visualization enhances single-attempt procedural success rate while lowering the risk of catheter dislodgement; effective modulation of inflammatory responses reduces the incidence of postoperative infectious complications; and the combined reduction in complications and inflammation further improves weaning success rates, shortens hospitalization duration, and decreases mortality.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

XFH was primarily responsible for data collection and analysis, and contributed to the drafting of the manuscript. JLW and JFZ contributed to the analysis and interpretation of the data, provided valuable feedback on the methodology and analysis, and participated in writing the manuscript. SCH contributed to the project management and participated in the design and implementation of the study. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The research protocol was reviewed and approved by the Research Ethics Committee of Yangzhong Traditional Chinese Medicine Hospital (Ethical Approval Number: 202501). Participants provided written informed consent prior to taking part in the study. The study conformed to the provisions of the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Fujishima S. Guideline-based management of acute respiratory failure and acute respiratory distress syndrome. Journal of Intensive Care. 2023; 11: 10. https://doi.org/10.1186/s40560-023-00658-3.

[2] Azoulay E, Russell L, Van de Louw A, Metaxa V, Bauer P, Povoa P, *et al*. Diagnosis of severe respiratory infections in immunocompromised patients. Intensive Care Medicine. 2020; 46: 298–314. https://doi.org/10.1007/s00134-019-05906-5.

[3] Vega ML, Pisani L. Nasal high flow oxygen in acute respiratory failure. Pulmonology. 2021; 27: 240–247. https://doi.org/10.1016/j.pulmoe.2021.01.005.

[4] Toker A, Hayanga JA, Dhamija A, Herron R, Abbas G. Tracheotomy, closure of long-term tracheostomy and standard tracheal segmental resections. Journal of Thoracic Disease. 2020; 12: 6185–6197. https://doi.org/10.21037/jtd.2020.02.41.

[5] Soliman SI, Panuganti BA, Francis DO, Pang J, Klebaner D, Asturias A, *et al*. Factors Associated With Otolaryngologists Performing Tracheotomy. JAMA Otolaryngology–Head & Neck Surgery. 2023; 149: 1066–1073. https://doi.org/10.1001/jamaoto.2023.2698.

[6] Eriksson SE, Jobe BA, Ayazi S. Chevalier Jackson: father of endoscopic surgery, and champion of women in medicine, social justice, and public health. Surgical Endoscopy. 2023; 37: 6660–6671. https://doi.org/10.1007/s00464-023-10256-x.

[7] Jotic AD, Milovanovic JP, Trivic AS, Folic MM, Krejovic-Trivic SB, Radin ZZ, *et al*. Predictors of Complications Occurrence Associated With Emergency Surgical Tracheotomy. Otolaryngology–Head and Neck Surgery. 2021; 164: 346–352. https://doi.org/10.1177/0194599820947001.

[8] Bianchini A, Pintus L, Vitale G, Mazzotta E, Felicani C, Zangheri E, *et al*. Lung Ultrasound in Mechanical Ventilation: A Purposive Review. Diagnostics. 2025; 15: 870. https://doi.org/10.3390/diagnostics15070870.

[9] Kim SY, Lee SW, Baek A, Park KN. Comparison between Real-Time Ultrasound-guided Percutaneous Dilatational Tracheostomy and Surgical Tracheostomy in critically ill Patients: A Randomized Controlled Trial. Clinical and Experimental Otorhinolaryngology. 2023; 16: 388–394. https://doi.org/10.21053/ceo.2023.01088.

[10] Fiorelli A, Bove M, Noro A, Iuorio A, Santini M, Ferraro F. Dilation of tracheal stenosis below tracheostomy tube with Dolphin percutaneous tracheostomy kit: Tracheal stenosis treated with Dolphin PDT. General Thoracic and Cardiovascular Surgery. 2020; 68: 655–658. https://doi.org/10.1007/s11748-020-01311-8.

[11] Lagina M, Valley TS. Diagnosis and Management of Acute Respiratory Failure. Critical Care Clinics. 2024; 40: 235–253. https://doi.org/10.1016/j.ccc.2024.01.002.

[12] Wen B, Zhang G, Zhan C, Chen C, Yi H. The 2024 revision of the Declaration of Helsinki: a modern ethical framework for medical research. Postgraduate Medical Journal. 2025; 101: 371–382. https://doi.org/10.1093/postmj/qgae181.

[13] Ervin JN, Rentes VC, Dibble ER, Sjoding MW, Iwashyna TJ, Hough CL, *et al*. Evidence-Based Practices for Acute Respiratory Failure and Acute Respiratory Distress Syndrome: A Systematic Review of Reviews. Chest. 2020; 158: 2381–2393. https://doi.org/10.1016/j.chest.2020.06.080.

[14] Murray M, Shen C, Massey B, Stadler M, Zenga J. Retrospective analysis of post-tracheostomy complications. American Journal of Otolaryngology. 2022; 43: 103350. https://doi.org/10.1016/j.amjoto.2021.103350.

[15] Kang HT, Kim SY, Lee MK, Lee SW, Baek A, Park KN. Comparison Between Real-Time Ultrasound-Guided Percutaneous Tracheostomy and Surgical Tracheostomy in Critically Ill Patients. Critical Care Research and Practice. 2022; 2022: 1388225. https://doi.org/10.1155/2022/1388225.

[16] Topcu H, Ozçiftçi S, Şahiner Y. Comparative effectiveness of real-time ultrasound-guided tracheostomy and anatomic landmark percutaneous dilatational tracheostomy: a retrospective cohort study. European Review for Medical and Pharmacological Sciences. 2022; 26: 7883–7891. https://doi.org/10.26355/eurrev_202211_30139.

[17] Lin KT, Kao YS, Chiu CW, Lin CH, Chou CC, Hsieh PY, *et al*. Comparative effectiveness of ultrasound-guided and anatomic landmark percutaneous dilatational tracheostomy: A systematic review and meta-analysis. PLoS ONE. 2021; 16: e0258972. https://doi.org/10.1371/journal.pone.0258972.

[18] Bezu L, Akçal Öksüz D, Bell M, Buggy D, Diaz-Cambronero O, Enlund M, *et al*. Perioperative Immunosuppressive Factors during Cancer Surgery: An Updated Review. Cancers. 2024; 16: 2304. https://doi.org/10.3390/cancers16132304.

[19] Sikora JP, Karawani J, Sobczak J. Neutrophils and the Systemic Inflammatory Response Syndrome (SIRS). International Journal of Molecular Sciences. 2023; 24: 13469. https://doi.org/10.3390/ijms241713469.

[20] Relja B, Land WG. Damage-associated molecular patterns in trauma. European Journal of Trauma and Emergency Surgery. 2020; 46: 751–775. https://doi.org/10.1007/s00068-019-01235-w.

[21] Li Y, Min L, Zhang X. Usefulness of procalcitonin (PCT), C-reactive protein (CRP), and white blood cell (WBC) levels in the differential diagnosis of acute bacterial, viral, and mycoplasmal respiratory tract infections in children. BMC Pulmonary Medicine. 2021; 21: 386. https://doi.org/10.1186/s12890-021-01756-4.

[22] Modi AR, Kovacs CS. Hospital-acquired and ventilator-associated pneumonia: Diagnosis, management, and prevention. Cleveland Clinic Journal of Medicine. 2020; 87: 633–639. https://doi.org/10.3949/ccjm.87a.19117.

[23] Pawlik J, Tomaszek L, Mazurek H, Mędrzycka-Dąbrowska W. Risk Factors and Protective Factors against Ventilator-Associated Pneumonia-A Single-Center Mixed Prospective and Retrospective Cohort Study. Journal of Personalized Medicine. 2022; 12: 597. https://doi.org/10.3390/jpm12040597.

[24] Gobatto ALN, Besen BAMP, Cestari M, Pelosi P, Malbouisson LMS. Ultrasound-Guided Percutaneous Dilational Tracheostomy: A Systematic Review of Randomized Controlled Trials and Meta-Analysis. Journal of Intensive Care Medicine. 2020; 35: 445–452. https://doi.org/10.1177/0885066618755334.

[25] Rosero EB, Corbett J, Mau T, Joshi GP. Intraoperative Airway Management Considerations for Adult Patients Presenting With Tracheostomy: A Narrative Review. Anesthesia and Analgesia. 2021; 132: 1003–1011. https://doi.org/10.1213/ANE.0000000000005330.

[26] Wen D, Yang X, Liang Z, Hu Y, Wang S, Zhang D, *et al*. Effectiveness of ultrasound-guided versus anatomical landmark-guided percutaneous dilatational tracheostomy: a systematic review and meta-analysis. BMC Anesthesiology. 2025; 25: 211. https://doi.org/10.1186/s12871-025-03085-z.

[27] Heunks L, Duiverman ML. New insights into acute and chronic respiratory failure: highlights from the Respiratory Failure and Mechanical Ventilation Conference 2022. European Respiratory Review. 2023; 32: 230027. https://doi.org/10.1183/16000617.0027-2023.