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Original Article

Clinical outcomes and safety of percutaneous dilatational tracheostomy in patients with severe traumatic brain injury

Yan Zhu[1], Jun Zheng[2]

[1]*Operating Room, Department of Anesthesiology, West China Hospital, Sichuan University/West China School of Nursing, Sichuan University, Chengdu 610041, Sichuan, China;* [2]*Department of Neurosurgery, West China Hospital, Sichuan University, Chengdu 610041, Sichuan, China*

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Abstract: Objective: To evaluate the therapeutic outcomes of percutaneous dilatational tracheostomy (PDT) and surgical tracheostomy (ST) in patients with severe traumatic brain injury (sTBI). Methods: Clinical records of sTBI patients treated at West China Hospital, Sichuan University, between January 2022 and December 2024 were retrospectively analyzed in this study. A total of 116 patients underwent PDT and 104 underwent ST. Clinical data were compared between groups, including surgical details, perioperative parameters, physiological stability, postoperative inflammatory markers, clinical efficacy, complications, and quality of life. Results: Compared with ST, PDT was associated with shorter operative time, smaller incision, faster wound healing, reduced intraoperative blood loss, shorter ventilation duration, and decreased lengths of ICU and hospital stay ($P < 0.001$). During cannulation, PDT caused smaller fluctuations in physiological parameters ($P < 0.05$). On postoperative day 7, levels of C-reactive protein (CRP), procalcitonin (PCT), erythrocyte sedimentation rate (ESR), white blood cells (WBCs), and neutrophils (NEU) were significantly lower in the PDT group ($P < 0.001$). Moreover, PDT showed fewer complications (7.76% vs. 17.31%, $P < 0.05$), higher clinical response rates (97.41% vs. 91.35%, $P < 0.05$), and improved quality of life scores ($P < 0.001$). Conclusion: In patients with sTBI, PDT offers advantages over ST, including easier operation, less trauma, mild postoperative inflammatory reaction, and faster recovery. It effectively lowers complication rates, enhances clinical efficacy, and improves quality of life, demonstrating high safety and broad applicability.

Keywords: Severe traumatic brain injury, percutaneous dilatational tracheostomy, surgical tracheostomy, clinical outcomes, safety

Introduction

Severe traumatic brain injury (sTBI) is a life-threatening condition characterized by rapid onset, high severity, and poor prognosis. It is associated with substantial mortality and long-term disability, significantly affecting patient survival and quality of life [1]. According to a 2023 report, traumatic brain injuries (TBI) causes more than 1.3 million deaths annually, with traffic accidents, fall from height, and violent injuries being the leading causes [2]. sTBI accounts for a large proportion of these cases, and its incidence continues to rise each year, imposing heavy burdens on healthcare systems and posing significant challenges for society [3]. Huang et al. reported that the annual incidence of TBI was approximately 52.3 per 100,000 people, of which more than 35% were hospitalized patients with sTBI [4]. Compared with mild or moderate cases, sTBI is associated with markedly higher risks of mortality and long-term disability.

In the acute stage, sTBI patients often present with varying levels of impaired consciousness and weakened brainstem reflexes [5]. Respiratory function is usually compromised, with severely reduced airway protective ability. These factors predispose patients to complications like hypoxemia, aspiration-related pneumonia, lung collapse, and even complete airway obstruction. Without timely airway intervention, clinical deterioration can be rapid and

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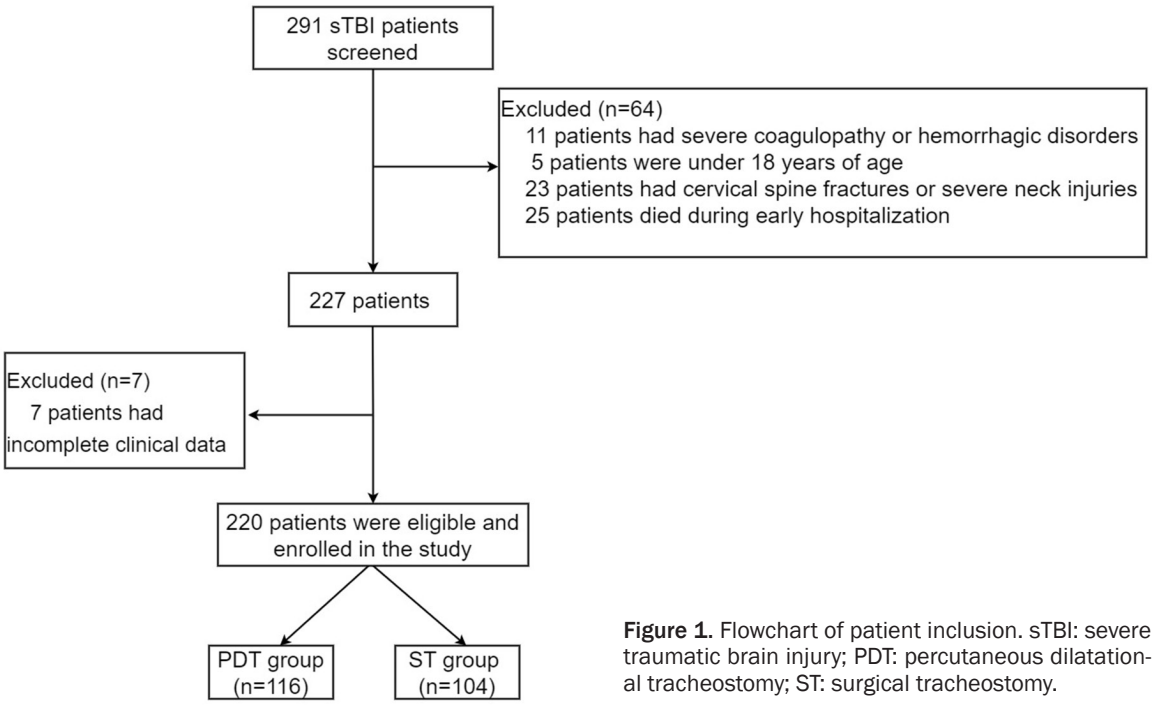

Figure 1. Flowchart of patient inclusion. sTBI: severe traumatic brain injury; PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy.

fatal. Therefore, securing a functional and stable artificial airway is not only necessary but also urgent for sustaining life and supporting recovery.

In clinical settings, surgical tracheostomy (ST) remains a widely used method for airway management in critically ill patients. Its main advantage is the clear surgical field that enables direct visual guidance during the procedure [6]. Surgeons make layered incisions in the neck to expose the trachea and insert the cannula under full visualization. However, ST has several drawbacks, including longer operative time, larger incisions, greater blood loss, and a higher risk of postoperative complications such as wound infections and subcutaneous emphysema [7]. Managing sTBI patients adds additional challenges. These patients are often physiologically fragile, elderly, or present with multiple injuries, particularly thoracic or abdominal trauma. Excessive intraoperative movement must be avoided to prevent dangerous fluctuations in intracranial pressure [8].

With the growing emphasis on minimally invasive techniques in critical care, percutaneous dilatational tracheostomy (PDT) has gained increasing clinical application [9]. It has been shown that the guidewire-guided graded dilatation technique allows for the establishment of a secure airway with shorter operative time, reduced trauma, less intraoperative bleeding, and faster postoperative recovery [10]. Several ICU studies have also supported the safety of this procedure [11, 12]. However, it remains uncertain whether PDT confers systematic advantages over ST in patients with sTBI. To address this gap, this study aimed to compare the clinical outcomes of PDT and ST, with the goal of providing evidence to guide airway management and promote the adoption of less invasive techniques where appropriate.

Materials and methods

Patient population

We retrospectively analyzed the medical records of sTBI patients admitted to West China Hospital, Sichuan University, between January 2022 and December 2024. Based on the tracheostomy method, patients were categorized into the PDT group (n = 116) and the ST group (n = 104). The patient selection process is illustrated in **Figure 1**. Ethical approval was obtained from the Ethics Committee of West China Hospital, Sichuan University.

Inclusion criteria: (1) Age ≥ 18 years; (2) sTBI diagnosis confirmed by computed tomography

(CT) or magnetic resonance imaging (MRI) [13]; (3) Glasgow Coma Scale (GCS) score ≤ 8 at admission; (4) Availability of complete electronic medical records and follow-up data. Exclusion criteria: (1) Presence of severe coagulopathy or bleeding disorders; (2) Traumatic cervical spine fractures or major structural neck injuries; (3) Severe airway obstruction or a history of airway abnormalities; (4) Severe cardiovascular insufficiency, including cardiac arrest or end-stage heart disease; (5) Death within 7 days postoperatively or loss to follow-up due to clinical deterioration.

Standard preoperative management

All patients received standard preoperative care, including vital sign monitoring, supplemental oxygen therapy, hemostatic measures, clearance of oral secretions, and gastric mucosal protection.

ST group

Patients in the ST group underwent conventional open tracheostomy. Under local anesthesia, with the patient in a supine position and the head extended, a vertical incision was made between the inferior margin of the cricoid cartilage and the suprasternal notch following routine skin disinfection and draping. The tissues were dissected layer by layer until the trachea was exposed, and a tracheal incision was made, typically between the second and third rings. A tracheostomy tube was then inserted and secured.

PDT group

In the PDT group, patients were first positioned either flat or in a neutral posture. After skin disinfection and local anesthesia, a puncture was carefully made between the first and second tracheal rings. A needle was then introduced into the trachea, and its position was confirmed by either aspiration or endoscopic visualization. A guidewire was then advanced through the needle, followed by progressive dilation of the airway. After insertion and fixation of the tracheostomy tube, the guidewire was removed, and the tube was connected to an appropriate respiratory device according to the patient's ventilatory status.

Postoperative management

Patients in both groups received routine postoperative airway care, which included continuous administration of humidified oxygen, regular suctioning of secretions, oral hygiene maintenance, and close monitoring of airway patency and potential complications.

Observation indicators

Baseline data were collected for both groups, including sex, age, body mass index (BMI), and Glasgow Coma Scale (GCS) scores at admission. Injury type and cause were recorded, along with laboratory parameters such as D-dimer, prothrombin time (PT), and fibrinogen (FIB). Several procedural indicators were evaluated to compare the practicality and invasiveness of the two tracheostomy techniques. These included incision length, success rate of first-attempt cannulation, occurrence of balloon rupture, and duration of postoperative wound healing. Operative time, intraoperative blood loss, duration of mechanical ventilation, length of ICU stay, total hospitalization days, and Glasgow Outcome Scale (GOS) score at discharge were also documented [14].

During the tracheostomy procedure, bedside monitoring was used to track hemodynamic and respiratory stability. Key indicators such as peripheral oxygen saturation (SpO_2), heart rate (HR), mean arterial pressure (MAP), norepinephrine adrenaline, intracranial pressure (ICP), and cerebral perfusion pressure (CPP) were recorded at two key time points: immediately before tracheostomy and at cannula insertion. To assess systemic inflammation, 10 mL of peripheral venous blood was collected from each patient preoperatively and on postoperative day 7. Samples were centrifuged at 3000 rpm for 10 min to separate serum and plasma, then stored at -80°C until analysis. Inflammatory markers included C-reactive protein (CRP), procalcitonin (PCT), erythrocyte sedimentation rate (ESR), white blood cell (WBC) count, and neutrophil (NEU) percentage. Laboratory analyses were conducted using a fully automated blood analyzer (RT7200, Rayto, Shenzhen, China) and a fully automated biochemical analyzer (AU2700, Olympus, Tokyo, Japan). Postoperative complications, including pulmonary infection, subcutaneous emphyse-

ma, incisional infection, tracheal hemorrhage and tracheal stenosis, were also recorded.

Clinical efficacy was evaluated according to airway patency and improvement in respiratory function. Outcomes were classified into three categories: markedly effective, defined as successful tracheal intubation with restoration of airway patency and maintenance of normal respiratory function; effective, referring to successful intubation accompanied by mild respiratory difficulty or postoperative complications requiring additional management; and ineffective, defined as failed intubation or inadequate ventilation necessitating alternative airway interventions. The total effectiveness rate was calculated as:

Total effectiveness rate (%) = (Markedly effective cases + Effective cases)/total cases ×100%

Quality of life was assessed using the short form-36 health survey (SF-36), which covers eight domains: physical functioning (PF), role-physical (RP), bodily pain (BP), general health (GH), vitality (VT), social functioning (SF), role emotional (RE), and mental health (MH). These domains were further summarized into the physical component summary (PCS) and mental component summary (MCS). Assessments were performed on postoperative day 7 to provide an early assessment of recovery. Each domain was scored from 0 to 100, with higher scores reflecting better health-related quality of life [15].

Statistical analysis

Statistical analyses were performed using SPSS version 22.0. The Kolmogorov-Smirnov test was used to assess the normality of continuous variables. Data conforming to a normal distribution were expressed as ($\bar{x} \pm s$) and compared using the independent-samples t-test. Non-normally distributed data were presented as [M (P25, P75)] and analyzed using the Mann-Whitney U test. Categorical variables were expressed as counts and percentages [n (%)] and compared using the chi-square (χ^2) test or Fisher's exact test where appropriate. Graphpad software was used for plot drawing. A P value of < 0.05 was considered statistically significant.

Results

Baseline characteristics

The baseline characteristics of the two groups were comparable. No significant differences were observed between the PDT and ST groups in terms of sex distribution, age, BMI, GCS scores, injury mechanisms, injury types, D-dimer, PT, or FIB ($P > 0.05$), indicating good comparability between groups (**Table 1**).

Cannulation outcomes

No significant differences were observed between the PDT and ST groups regarding the success rate of first-attempt cannulation or the incidence of balloon rupture ($P > 0.05$). However, the PDT group demonstrated a significantly shorter incision length and faster postoperative wound healing compared to the ST group ($P < 0.001$), as shown in **Table 2**. These findings indicate that PDT may offer advantages in minimizing procedural trauma and accelerating incision recovery.

Perioperative outcomes

Compared to the ST group, patients in the PDT group exhibited significantly shorter operative times, reduced intraoperative blood loss, shorter durations of mechanical ventilation, and decreased ICU and total hospital stays ($P < 0.001$), as shown in **Table 3**. These findings highlight the advantages of the PDT in minimizing surgical trauma and enhancing perioperative recovery efficiency. No significant difference was observed in GOS scores at discharge between the two groups ($P > 0.05$).

Physiological parameters

As shown in **Table 4**, no significant differences were observed between the PDT and ST groups regarding SpO_2, HR, MAP, norepinephrine, adrenaline, ICP or CPP before tracheostomy ($P > 0.05$). During cannula insertion, both groups exhibited significant changes compared to their preoperative values ($P < 0.05$). However, the magnitude of change across all parameters was significantly smaller in the PDT group, indicating greater hemodynamic and respiratory stability during tracheostomy.

Table 1. Baseline characteristics $\bar{x}\pm s$)/[n (%)]/[M (P25, P75)]

	PDT (n = 116)	ST (n = 104)	$t/\chi^2/Z$	*P*
Sex			0.779	0.378
Male	68 (58.62)	67 (64.42)		
Female	48 (41.38)	37 (35.58)		
Age	51.18±14.07	48.56±11.47	1.505	0.134
BMI (kg/m^2)	22.85±2.08	22.40±3.04	1.283	0.201
GCS score	5.92±0.61	6.03±0.74	1.168	0.244
Cause of injury			0.183	0.913
Traffic accident	50 (43.10)	43 (41.35)		
Fall from height	37 (31.90)	36 (34.62)		
Other	29 (25.00)	25 (24.04)		
Type of injury			1.030	0.598
Diffuse contusion	38 (32.76)	36 (34.62)		
Subdural hematoma	43 (37.07)	32 (30.77)		
Epidural hematoma	35 (30.17)	36 (34.62)		
D-dimer (μg/L)	3.30 (1.77, 4.19)	3.31 (2.38, 4.47)	1.368	0.171
PT (s)	12.44 (11.80, 13.46)	12.28 (11.86, 12.95)	1.663	0.096
FIB (g/L)	4.73 (4.34, 5.04)	4.61 (4.36, 4.98)	0.777	0.437

PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy; BMI: body mass index; GCS: Glasgow coma scale; PT: prothrombin time; FIB: Fibrinogen.

Table 2. Cannulation outcomes ($\bar{x}\pm s$)/[n (%)]

	PDT (n = 116)	ST (n = 104)	t/χ^2	*P*
Incision length (cm)	1.57±0.43	2.94±0.71	17.43	< 0.001
First-attempt cannulation success	111 (95.69)	97 (93.27)	0.623	0.430
Balloon rupture	1 (0.86)	1 (0.96)	-	0.723[a]
Postoperative wound healing time (d)	4.36±1.13	6.16±1.38	10.635	< 0.001

a: Fisher's exact tests; PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy.

Table 3. Perioperative outcomes ($\bar{x}\pm s$)

	PDT (n = 116)	ST (n = 104)	*t*	*P*
Operative time (min)	12.36±2.04	18.64±4.45	13.681	< 0.001
Intraoperative blood loss (mL)	10.38±3.12	16.55±4.17	12.521	< 0.001
Mechanical ventilation duration (d)	7.02±1.58	8.24±1.27	6.284	< 0.001
ICU length of stay (d)	16.53±2.87	19.14±3.36	6.230	< 0.001
Total hospital stay (d)	25.73±3.32	29.57±4.61	7.129	< 0.001
GOS score at discharge	3.58±0.63	3.44±0.54	1.697	0.091

PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy; ICU: intensive care unit; GOS: Glasgow Outcome Scale.

Inflammatory marker levels

Preoperative levels of CRP, PCT, ESR, WBC count and NEU percentage were comparable between groups ($P > 0.05$), indicating no significant differences in baseline inflammatory status. By postoperative day 7, all five inflammatory markers had declined in both groups. However, the PDT group demonstrated significantly lower levels of CRP, PCT, ESR, WBC count and NEU percentage compared to the ST group ($P < 0.001$), as shown in **Table 5**. These findings suggest that PDT may offer superior control of postoperative systemic inflammatory response.

Table 4. Physiological parameters ($\bar{x}\pm s$)

	PDT (n = 116)	ST (n = 104)	*t*	*P*
SpO_2 (%)				
Before tracheostomy	96.61±1.56	96.87±1.81	1.107	0.269
At cannula insertion	95.54±1.98[a]	94.87±2.90[a]	2.003	0.047
HR (bpm)				
Before tracheostomy	79.51±6.05	79.24±5.57	0.341	0.734
At cannula insertion	85.11±7.54[a]	91.67±8.82[a]	5.947	< 0.001
MAP (mmHg)				
Before tracheostomy	83.31±6.55	83.93±7.26	0.668	0.505
At cannula insertion	86.17±6.83[a]	90.40±7.94[a]	4.248	< 0.001
Norepinephrine				
Before tracheostomy	319.57±10.24	321.75±11.06	1.518	0.131
At cannula insertion	652.30±35.89[a]	705.64±32.71[a]	11.474	< 0.001
Adrenaline				
Before tracheostomy	42.65±5.34	44.10±9.22	1.445	0.150
At cannula insertion	108.72±26.53[a]	136.47±18.96[a]	8.834	< 0.001
ICP (mmHg)				
Before tracheostomy	17.33±3.12	17.74±3.34	0.941	0.348
At cannula insertion	22.08±2.05[a]	28.91±2.11[a]	24.333	< 0.001
CPP (mmHg)				
Before tracheostomy	65.99±7.06	66.20±8.15	0.205	0.838
At cannula insertion	64.10±6.89[a]	61.49±8.25[a]	2.555	0.011

a: $P < 0.05$ compared with before tracheostomy in the same group. 1 mmHg = 0.133 kPa. PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy; SpO_2: peripheral capillary oxygen saturation; HR: heart rate; MAP: mean arterial pressure; ICP: intracranial pressure; CPP: cerebral perfusion pressure.

Table 5. Inflammatory marker levels [M (P25, P75)]

	PDT (n = 116)	ST (n = 104)	*Z*	*P*
CRP (mg/L)				
Preoperative	35.30 (32.92, 38.61)	36.47 (33.26, 39.60)	1.709	0.089
Postoperative day 7	16.20 (14.66, 18.62)	20.12 (18.46, 21.70)	8.418	< 0.001
PCT (μg/L)				
Preoperative	2.04 (1.90, 2.26)	2.13 (1.94, 2.29)	1.354	0.176
Postoperative day 7	0.81 (0.68, 0.91)	1.18 (1.05, 1.33)	10.646	< 0.001
ESR (mm/h)				
Preoperative	30.33 (27.52, 32.78)	31.70 (27.71, 34.25)	1.279	0.201
Postoperative day 7	12.55 (10.54, 13.99)	14.73 (13.60, 16.86)	7.197	< 0.001
WBC count ($\times 10^9$/L)				
Preoperative	11.20 (10.81, 11.58)	11.17 (10.81, 11.49)	0.256	0.798
Postoperative day 7	6.34 (6.09, 6.61)	6.78 (6.51, 7.05)	7.113	< 0.001
NEU (%)				
Preoperative	76.90 (72.99, 80.42)	77.44 (73.97, 81.80)	1.261	0.207
Postoperative day 7	56.22 (52.38, 60.44)	62.23 (58.71, 63.78)	6.978	< 0.001

PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy; CRP: C-reactive protein; PCT: procalcitonin; ESR: erythrocyte sedimentation rate; WBC: white blood cell; NEU: Neutrophil.

Table 6. Postoperative complications [n (%)]

	PDT (n = 116)	ST (n = 104)	χ^2	*P*
Pulmonary infection	6 (5.17)	10 (9.62)	1.605	0.205
Subcutaneous emphysema	1 (0.86)	2 (1.92)	0.009	0.924
Incisional infection	1 (0.86)	3 (2.88)	0.379	0.538
Tracheal hemorrhage	1 (0.86)	2 (1.92)	0.009	0.924
Tracheal stenosis	0	1 (0.96)	-	0.473[a]
Total complications	9 (7.76)	18 (17.31)	4.644	0.031

a: Fisher's exact tests; PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy.

Table 7. Clinical efficacy outcomes [n (%)]

	PDT (n = 116)	ST (n = 104)	χ^2	*P*
Markedly effective	59 (50.86)	51 (49.04)	0.073	0.787
Effective	54 (46.55)	44 (42.31)	0.400	0.527
Ineffective	3 (2.59)	9 (8.65)	3.915	0.048
Total effective rate	113 (97.41)	95 (91.35)	3.915	0.048

PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy.

Postoperative complications

All patients who developed postoperative complications responded well to symptomatic and supportive management, including antimicrobial therapy and fluid-electrolyte regulation, with no severe adverse outcomes observed. As shown in **Table 6**, there were no significant differences between the two groups in the incidence of individual complications ($P > 0.05$). However, the overall complication rate was significantly lower in the PDT group (7.76%) compared to the ST group (17.31%) ($P < 0.05$), suggesting a potential advantage of PDT in mitigating postoperative morbidity.

Clinical efficacy outcomes

No significant differences were observed between the two groups in the proportions of patients achieving markedly effective or effective outcomes ($P > 0.05$). However, the proportion of ineffective cases was significantly lower in the PDT group (2.59%) than in the ST group (8.65%) ($P < 0.05$). As a result, the total effective rate was notably higher in the PDT group compared with the ST group (97.41 vs. 91.35%, $P < 0.05$) (**Table 7**), suggesting a potential advantage of PDT in improving overall clinical effectiveness.

Postoperative quality of life

On postoperative day 7, patients in the PDT group demonstrated significantly higher scores in several domains of the physical component summary (PCS) - including PF, RP, BP, and GH - compared with the ST group ($P < 0.001$), indicating superior physical recovery. Additionally, the PDT group outperformed the ST group in multiple mental component summary (MCS) domains, including VT, RE, MH, and SF (all $P < 0.05$). These findings suggest that PDT may offer greater clinical benefit in enhancing patients' overall postoperative quality of life (**Figure 2**).

Discussion

Patients with severe traumatic brain injury (sTBI) typically show impaired consciousness and diminished neurological reflexes, leading to compromised respiratory function and prolonged dependence on mechanical ventilation. These factors make airway management in this population one of the greatest challenges in neurocritical care [16]. Establishing a safe and stable airway while minimizing intraoperative and postoperative complications is therefore essential [17]. In this study, we systematically compared the efficacy of PDT and ST in patients with sTBI, evaluating not only perioperative outcomes but also postoperative complications and multidimensional recovery, including quality of life. Compared with ST, PDT offered distinct advantages of reduced surgical trauma, shorter hospitalization, better systemic inflammation control, fewer complications, and improved overall outcomes.

Compared with ST, PDT showed clear advantages in several perioperative parameters, including shorter operative time, less intraoperative bleeding, reduced duration of mechanical ventilation, and shorter ICU stay. These findings are consistent with those reported by Kumar, who noted that PDT, as a minimally invasive technique, simplifies procedural path-

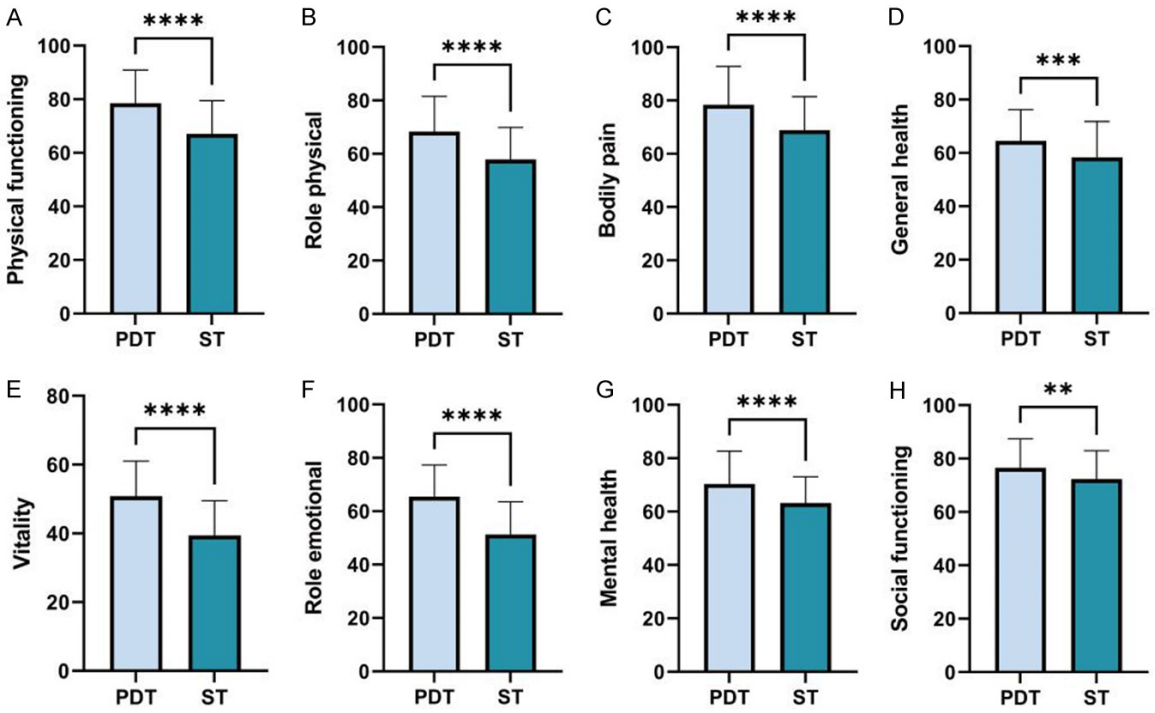

Figure 2. Postoperative quality of life in PDT vs. ST groups. A. Physical functioning; B. Role physical; C. Bodily pain; D. General health; E. Vitality; F. Role emotional; G. Mental health; H. Social functioning. PDT: percutaneous dilatational tracheostomy; ST: surgical tracheostomy. $^{**}P < 0.01$, $^{***}P < 0.001$, $^{****}P < 0.0001$.

ways, minimizes dissection of anterior cervical soft tissues, reduces intraoperative hemorrhage, and shortens operative duration [18]. Moreover, PDT can be performed at the bedside in ICU, avoiding interdepartmental transfer and thereby enhancing procedural safety [19]. Our study also indicated that patients undergoing PDT showed milder fluctuations in key physiological parameters compared with those receiving ST. Although both groups exhibited significant changes from baseline, the magnitude of these changes was notably smaller in the PDT group, indicating greater respiratory and circulatory stability during airway tracheostomy. These findings are consistent with previous studies that highlighted the procedural simplicity and safety of PDT in neurocritical care. Temel et al. reported that PDT minimized physiological disturbances, thereby promoting hemodynamic and neurological stability in critically ill patients [20]. Similarly, Li et al. observed lower infection rates and more stable airway management following PDT [21]. Notably, although PDT demonstrated significant advantages in perioperative outcomes, there were no significant differences between the two groups regarding first-attempt cannulation success, balloon rupture rates, or GOS scores at discharge. This suggests comparable technical feasibility and procedural maturity under current clinical standards. Moreover, as GOS primarily reflects neurological recovery, outcomes are likely influenced more by the severity of primary brain injury and secondary neurological complications rather than the tracheostomy technique alone [22].

Postoperative inflammatory responses are a major concern in sTBI patients, not only representing common physiological stress reactions but also contributing directly to secondary brain injury [23]. Excessive surgical stress responses may exacerbate cerebral edema, promote neuronal apoptosis, and hinder central nervous system recovery [24]. Owing to autonomic dysfunction and dysregulation of the hypothalamic-pituitary-adrenal axis, sTBI patients are particularly prone to exaggerated systemic inflammatory responses following surgery [25]. In this study, patients in the PDT group exhibited significantly lower inflammatory biomarker levels one week postoperatively compared with those in the ST group, suggesting better postoperative inflammation control. This advantage likely

stems from the minimally invasive nature of PDT, reduced mechanical ventilation duration, and decreased risk of airway microbial colonization [26]. Kreitmann et al. highlighted that prolonged mechanical ventilation and invasive airway procedures are major risk factors for ICU-acquired infections [27]. By contrast, PDT, with its shorter airway conduit and better catheter stability, may improve pulmonary ventilation and oxygenation, thereby mitigating hypoxia-driven immune activation. Furthermore, the accelerated postoperative recovery associated with PDT reduces antibiotic consumption, thereby lowering the risk of resistant bacterial colonization and subsequent inflammatory complications [28].

Consistent with these observations, this study demonstrated a significantly lower overall complication rate in the PDT group (7.76%) compared to the ST group (17.31%). Due to impaired consciousness, weakened cough reflexes, and respiratory insufficiency, sTBI patients are particularly prone to postoperative airway complications, including infection, bleeding, and catheter-related issues [29]. ST, which involves larger incisions and broader tissue dissection, has been associated with higher risks of wound oozing, subcutaneous emphysema, and surgical site infections [30]. In contrast, PDT establishes airway access through blunt dilation, resulting in reduced tissue trauma and improved catheter stability, which facilitates standardized airway management, reduces secretion retention and aspiration risk, and ultimately lowers the incidence of pulmonary infections [31]. Nevertheless, regardless of the tracheostomy technique used, routine postoperative bronchoscopic assessment remains essential for evaluating local airway conditions, enabling early detection of potential complications such as tracheoesophageal fistula, and ensuring procedural safety [32].

The total effective rate of the PDT group was significantly higher than that in the ST group, and patients achieved higher scores in several domains of quality of life, suggesting that PDT not only improves short-term clinical outcomes but may also facilitate functional recovery and overall rehabilitation. In sTBI, intracranial lesions are often accompanied by complex systemic stress responses, including autonomic dysregulation, hypermetabolism, and respiratory instability [33]. Within this pathophysiological context, the reduced physiological disturbance associated with PDT may contribute to better control of intracranial pressure and maintenance of cerebral perfusion. This is supported by a recent study by Godoy et al., which emphasized that maintaining hemodynamic stability during PDT can help optimize cerebral perfusion in patients with severe brain injury, thereby potentially improving neurological recovery [34]. Furthermore, PDT's ability to reduce postoperative infection and respiratory complications is particularly critical given the fragile immune status and prolonged recovery trajectory characteristic of sTBI patients [21]. Importantly, PDT provides a more stable and durable airway, creating a favorable environment for early respiratory training, sedation adjustment, and subsequent rehabilitation interventions [35]. Cohen et al. emphasized that performing PDT at the bedside enables patients to remain under the continuous care by their original monitoring teams, ensuring uninterrupted neurological surveillance and rehabilitation [36]. In addition, studies in critically ill populations have shown that patients undergoing PDT achieve better postoperative physical function, emotional well-being, and role functioning compared to those undergoing ST. These improvements are likely attributable to earlier initiation of rehabilitation, decreased analgesic requirements, and enhanced patient engagement [37]. These findings collectively suggest that integrating earlier and more continuous rehabilitation pathways following PDT may be crucial to maximizing neurological recovery and improving long-term quality of life in sTBI patients.

In conclusion, this study systematically compared the clinical outcomes of PDT and ST in sTBI patients and demonstrated that PDT offers clear advantages in terms of procedural simplicity, reduced tissue trauma, better postoperative inflammatory control, lower perioperative complication rates, and improved quality of life, with a favorable safety profile and strong clinical applicability. Nonetheless, several limitations should be acknowledged. First, this was a single-center study, and potential selection bias may limit the generalizability of the findings. Future multicenter studies with larger sample sizes are warranted to validate these results. Second, advanced neurological assess-

ment tools, such as neuroimaging, electrophysiological testing, or detailed consciousness recovery scoring, were not incorporated, which may limit the comprehensiveness of the evaluation. Future research should integrate broader neurofunctional assessments to further refine individualized airway management strategies for sTBI patients. Third, the follow-up period was relatively short, focusing only on early postoperative recovery, failing to capture long-term neurological outcomes or overall prognosis. Extended follow-up is required to fully assess the long-term effects of different tracheostomy techniques on neurological recovery and survival.

Disclosure of conflict of interest

None.

Address correspondence to: Jun Zheng, Department of Neurosurgery, West China Hospital, Sichuan University, No. 37, Guoxue Lane, Chengdu 610041, Sichuan, China. Tel: +86-028-85422488; E-mail: zjmed0514@163.com

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