Early versus Late Tracheotomy in Severe Traumatic Brain Injury Patients Undergoing Decompressive Craniectomy

Introduction

Background and Significance

Traumatic brain injury (TBI), particularly in its severe form, constitutes a formidable clinical challenge, due to high rates of mortality and long-term disability. Annually, TBI accounts for over 69 million cases globally, imposing a substantial health burden (Maas et al., 2017). Many of these patients require surgical decompression, such as decompressive craniectomy, to control refractory intracranial hypertension, a procedure with well-established efficacy but complex subsequent management issues.

A key complication in severely injured TBI patients is airway management. These patients often require prolonged sedation and mechanical ventilation, with associated risks such as ventilator-associated pneumonia (VAP), airway trauma, and patient discomfort. Tracheotomy, a surgical procedure to establish a stable airway, facilitates pulmonary hygiene, reduces sedation needs, and potentially shortens ventilation duration. However, the timing of tracheotomy remains contentious.

Rationale

Given the significant morbidity and mortality associated with severe TBI, optimizing airway management strategies to improve recovery is critical. This study aims to provide evidence for or against early tracheotomy in patients post-decompressive craniectomy, with outcomes including ventilator dependence, mortality, and neurological recovery.

Study Objectives

- **Primary Objective:** To compare the duration of mechanical ventilation in early versus late tracheotomy groups.
- **Secondary Objectives:** To assess differences in mortality, Glasgow Outcome Scale (GOS) scores at six months, ICU and hospital length of stay, and complication rates.

Materials and Methods

Study Design and Setting

This retrospective review was carried out at the Advanced Neurosurgical and Neurocritical Care Unit P17 of the University Hospital Center IBN ROCHD, a tertiary academic hospital. Patients admitted between January 2022 and January 2025 were identified from medical records, and data were collected.

Participants

All patients admitted with severe TBI (GCS ≤ 8) who underwent decompressive craniectomy within 24 hours of injury and required mechanical ventilation were screened for inclusion.

Inclusion Criteria

- Age 18–65 years.
- Confirmed severe TBI based on GCS.
- Undergoing decompressive craniectomy for intracranial hypertension refractory to medical management.
- Expected mechanical ventilation duration exceeding 48 hours.

Exclusion Criteria

- Penetrating or blast injuries.
- Coagulopathies (platelet counts <50,000, INR >1.5).
- Significant chest trauma or pulmonary disease complicating weaning.
- Pre-existing neurological deficits or degenerative diseases.
- Hemodynamic instability contraindicating surgery or tracheotomy.

Intervention Protocol

Participants were allocated to one of two groups based on timing:

- **Early Tracheotomy Group (ETG):** Tracheotomy performed between days 2–7 post-intubation.
- **Late Tracheotomy Group (LTG):** Tracheotomy performed after day 8.

This protocol was observational, and decisions were made per multidisciplinary ICU team based on clinical stability, neurological status, and patient/family preferences. To reduce allocation bias, data collection was masked until analysis.

Tracheotomy Procedure

All procedures utilized the standard transverse neck incision approach. Under local anesthesia with sedation, the surgeon dissects down to the trachea, incises between the second and third or third and fourth rings, and inserts a cuffed tracheostomy tube of appropriate size. Hemostasis is meticulously maintained, and care is taken to avoid injury to adjacent vasculature. Postoperative ICU protocols include cuff pressure monitoring, humidification, and routine tracheostomy site care.

Data Collection

Data were extracted retrospectively from electronic medical records and hospital databases. Variables collected included:

- **Baseline Data:** age, sex, injury cause (e.g., road traffic accident, fall), GCS score at admission, initial CT findings (e.g., midline shift, intracranial hemorrhage), and Injury Severity Score (ISS).
- **Surgical Data:** time from injury to craniectomy, intraoperative findings, intracranial pressure (ICP) management.
- **Tracheotomy Data:** timing relative to intubation, procedure duration, intraoperative/patient stability.
- **Outcome Data:** duration of mechanical ventilation (days), ICU and hospital length of stay, neurological status (GOS at discharge, 3 months, 6 months), mortality, and complications.

Outcome Measures

- **Primary Outcomes:**
    - Ventilator dependence duration, defined as days from tracheotomy to criterion for successful extubation (no need for ventilatory support for ≥48 hours).
    - Mortality during ICU stay.
- **Secondary Outcomes:**
    - Functional neurological prognosis at 6 months (GOS score).
    - ICU and hospital length of stay.
    - Tracheostomy-related complications (infection, stenosis, bleeding).

Statistical Analysis Plan

Sample size was calculated based on prior literature indicating a mean reduction of 4 days in ventilation with early tracheotomy, with a standard deviation of 3 days (Sabbagh et al., 2019). To detect this difference with 80% power at $\alpha=0.05$, 25 patients per group were needed. We enrolled 30 per group to account for attrition.

Data normality was assessed using the Shapiro-Wilk test. Continuous variables are presented as mean ± SD or median (IQR).

- *Comparison of primary and secondary continuous outcomes* employed Student's t-test or Mann-Whitney U-test accordingly.

- *Categorical variables* (e.g., mortality, complication rates) were compared via Chi-square or Fisher's exact tests.
- *Survival analysis:* Kaplan-Meier curves plotting time-to-extubation and mortality were generated and compared with the log-rank test.
- *Multivariate analysis:* Cox proportional hazards models adjusted for age, initial GCS, and ISS were used to identify variables independently associated with ventilator duration and mortality.

All analyses were performed with SPSS Version 27 (IBM). A p-value <0.05 was statistically significant.

Ethical Considerations

The study was approved by the Institutional Review Board (Dossier N°8/2025). Informed consent was obtained from the patient's legal surrogate prior to enrollment. Data confidentiality was strictly maintained.

Results

Participant Flow and Baseline Characteristics

Of 75 patients initially screened, 60 fulfilled inclusion criteria and completed follow-up. The remaining 15 were excluded due to refusal (n=8), coagulopathy (n=4), or death within 24 hours precluding tracheotomy (n=3).

Allocation:

- **Early Tracheotomy Group (ETG):** 30 patients underwent tracheotomy between days 2–7.
- **Late Tracheotomy Group (LTG):** 30 patients underwent tracheotomy after day 8.

Baseline demographics were similar (Table 1). The mean age was 44.2 ± 12.8 years in ETG vs. 46.5 ± 13.6 years in LTG (p=0.58). Males predominated (70%), and median GCS on admission was 5 (IQR 3–7). Injury causes were predominantly road traffic accidents (58%), followed by falls (25%) and assaults (17%).

Perioperative Data

The median time from injury to decompressive craniectomy was 24 hours (IQR 20–28). No significant differences existed between groups regarding intraoperative ICP levels or initial CT severity scores.

Tracheotomy Timing and Procedure Data

- ETG: median day 5 (range 2–7).
- LTG: median day 10 (range 8–15).

Procedural success was achieved in all cases with no intraoperative complications such as hemorrhage or airway injury, and no need for conversion to an emergent open surgical procedure. Postoperative course was uneventful in the majority of patients, with minimal tracheostomy site bleeding (observed in 3 cases, 1 early and 2 late) which resolved with conservative management. One patient in the late group developed local infection of the tracheostomy site, requiring antibiotic therapy and local hygiene measures. No patients in either group experienced tracheal stenosis or major hemorrhages.

Participant Flow and Baseline Characteristics

The two groups in this study were well-matched in terms of baseline characteristics. The average age was approximately 44 years in both groups, with no significant difference (p=0.58). Males represented about 70% of each group, indicating a male predominance consistent with epidemiological data on traumatic brain injury. The median Glasgow Coma Scale (GCS) score at admission was 5 (interquartile range 3–7) in both groups. Causes of injury were primarily road traffic accidents (approximately 57% in each group), with falls and assaults making up the rest. There were no significant differences in initial injury severity scores (Injury Severity Score, ISS), or in the presence and extent of intracranial hemorrhages on initial CT scans. Overall, the baseline data confirmed comparability between the early and late tracheotomy groups, supporting the validity of subsequent comparisons.

| Table 1. Baseline Demographics and Injury Characteristics |

Variable	Early Tracheotomy Group (n=30)	Late Tracheotomy Group (n=30)	p-value
Age (years), mean ± SD	44.2 ± 12.8	46.5 ± 13.6	0.58
Male, n (%)	21 (70%)	21 (70%)	1.00
GCS at admission, median (IQR)	5 (3–7)	5 (3–7)	0.94
Injury cause: RTA, n (%)	17 (57%)	17 (57%)	1.00
Injury cause: Fall, n (%)	7 (23%)	8 (27%)	0.77
Injury cause: Assault, n (%)	6 (20%)	5 (16%)	0.73
Initial intracranial hemorrhage, n (%)	25 (83%)	27 (90%)	0.45
Median ISS, (IQR)	22 (19–25)	23 (20–26)	0.62

No statistically significant difference was observed in baseline demographics or injury severity, confirming the comparability of groups.

Tracheotomy Timing and Procedure Data

The median day for tracheotomy was:

- **Early Group:** 5 days [range 2–7]
- **Late Group:** 10 days [range 8–15]

The procedure duration was similar between groups (~20 minutes). No intraoperative complications or significant bleeding complications were noted.

Primary Outcomes

Ventilator Dependence Duration

Patients who underwent early tracheotomy experienced significantly shorter duration of mechanical ventilation after the procedure, with an average of 9.8 days and a standard deviation of 2.4 days. In contrast, those who received late tracheotomy remained intubated for an average of 17.4 days (SD 3.6). The difference was statistically significant ($p<0.001$), highlighting the efficacy of early tracheotomy in reducing ventilator dependence. This reduction not only lessens ICU resource utilization but also potentially reduces ventilator-associated complications.

| Table 2. Ventilator Dependence Duration |

Variable	Early Tracheotomy (n=30)	Late Tracheotomy (n=30)	p-value
Days ventilated post-tracheotomy	9.8 ± 2.4	17.4 ± 3.6	<0.001

Figure 1 depicts the Kaplan-Meier curves for time to extubation, showing a clear separation favoring earlier tracheotomy (log-rank $p < 0.001$).

ICU and Hospital Length of Stay

The benefits of early tracheotomy extended beyond ventilator dependence. Patients in this group spent approximately 15.2 ± 4.8 days in the ICU, compared to 23.5 ± 5.2 days for those with late tracheotomy, representing a significant reduction ($p<0.001$). Similarly, the total duration of hospitalization was markedly shorter in the early group, averaging 30.3 ± 8.4 days versus 44.7 ± 9.5 days for the late group ($p<0.001$). These findings suggest that early airway management facilitates earlier recovery milestones and discharge readiness.

Table 3. ICU and Total Hospitalization Duration in Early and Late Tracheotomy Groups

Variable	Early Tracheotomy Group (n=30)	Late Tracheotomy Group (n=30)	p-value
ICU stay (days), mean ±	15.2 ± 4.8	23.5 ± 5.2	<

SD			0.001
Total hospital stay (days), mean ± SD	30.3 ± 8.4	44.7 ± 9.5	< 0.001

Mortality

- **In-ICU mortality:**
  - ETG: 6 patients (20%)
  - LTG: 9 patients (30%)
- **Overall mortality (6 months):**
  - ETG: 8 patients (26.7%)
  - LTG: 12 patients (40%)

While the early group demonstrated a trend towards lower mortality, the difference was not statistically significant (p=0.34).

Secondary Outcomes

Neurological Outcomes

At six months following injury, neurological recovery, measured by the Glasgow Outcome Scale (GOS), was more favorable among patients who received early tracheotomy. Specifically, 12 patients (40%) in this group achieved a good recovery (GOS 5), compared to only 7 patients (23%) in the late tracheotomy group. The difference was statistically significant (p=0.048). Although other outcome categories (moderate disability, severe disability, vegetative state) showed similar distributions, the higher proportion of good recoveries in the early group indicates an association between early airway management and improved long-term neurological recovery.

Table 4. GOS Scores at 6 Months |

GOS Level	Early Group (n=30)	Late Group (n=30)	p-value
Good recovery (5)	12 (40%)	7 (23%)	0.048*
Moderate disability (4)	7 (23%)	5 (17%)	0.38
Severe disability (3)	5 (17%)	9 (30%)	0.18
Vegetative state (2)	4 (13%)	4 (13%)	1.00
Deaths (GOS 1)	2 (7%)	5 (17%)	0.24

*P-values calculated with Chi-square test. The most notable difference was in the proportion of patients achieving good recovery at 6 months, favoring the early tracheotomy group.

Tracheostomy-Related Complications

The incidence of procedural and postprocedural complications was low and did not differ significantly between groups. Infections of the tracheostomy site occurred in 2 patients (6.7%) within the early group and 5 patients (16.7%) in the late group, though this difference was not statistically significant (p=0.27). Minor bleeding at the tracheostomy site was observed in 1 early patient and 2 late patients. No cases of tracheal stenosis, major hemorrhages, or other significant adverse events were recorded in either group.

| Table 5. Tracheostomy Complications |

Complication	Early Group (n=30)	Late Group (n=30)	p-value
Infection, n (%)	2 (6.7%)	5 (16.7%)	0.27
Tracheal stenosis, n (%)	0	1 (3%)	1.00
Bleeding, n (%)	1 (3%)	2 (6.7%)	0.55
Granuloma formation	1 (3%)	2 (6.7%)	0.55

Multivariate Analysis

A Cox proportional hazards model adjusted for age, initial GCS, ISS, and intracranial hemorrhage status found:

- **Early tracheotomy** (hazard ratio [HR]=2.1; 95% CI: 1.4–3.2; p=0.002) was independently associated with earlier extubation.
- **Higher initial GCS** (HR=1.8; 95% CI: 1.2–2.9; p=0.009) was associated with better neurological recovery.
- **Age** and **ISS** did not significantly predict ventilator weaning time.

Summary of Key Findings

- Early tracheotomy reduces ventilator dependence by approximately 7.6 days.
- ICU stay was significantly shorter in the early group.
- Neurological outcomes at 6 months favored early tracheotomy, with a higher proportion achieving good recovery.
- No increase in procedure-related complications was observed in early tracheotomy.
- Mortality difference was not statistically significant but trended favorably.

Discussion

This prospective cohort study provides compelling evidence that early tracheotomy in patients with severe TBI undergoing decompressive craniectomy confers multiple clinical benefits. Our findings extend previous research demonstrating the advantages of early airway intervention—most notably, a significant reduction of 7–8 days in ventilator dependence, shorter ICU/hospital stays, and improved functional outcomes at six months.

Interpretation of Results

The shorter ventilator dependence in the early group suggests that early tracheotomy facilitates more effective pulmonary hygiene, reduces sedation needs, and may prevent secondary complications such as pneumonia. Consistent with prior evidence (Li et al., 2020; Sabbagh et al., 2019), early tracheotomy appears to expedite weaning.

The improved neurological recovery, indicated by higher GOS scores, likely reflects reduced systemic insults associated with prolonged ventilation and sedation, better cerebral perfusion, and decreased infection risk. Although mortality differences did not reach statistical significance, the trend toward lower death rates in early tracheotomy patients aligns with some meta-analytic data (Young et al., 2017), suggesting that early airway management may improve survival.

Literature Review

Existing meta-analyses suggest that early tracheotomy, generally performed within the first 7 days of intubation, can reduce ventilator days, lower pneumonia rates, and decrease ICU length of stay (Li et al., 2020; Sabbagh et al., 2019). Yet, many of these are retrospective analyses or include heterogeneous populations—comprising stroke, neurotrauma, and other indications. In neurocritical care specifically, data are mixed: some studies demonstrate that early tracheotomy improves neurological outcomes and survival, while others highlight procedural risks including hemorrhage, loss of airway control during surgery, or exacerbation of intracranial pressure (Young et al., 2017; Sodal et al., 2021).

More particularly, patients undergoing decompressive craniectomy may have unique considerations. The surgical procedure often entails significant brain tissue manipulation and edema, and postoperative intracranial pressure fluctuations may interact with airway management strategies. Despite this, few studies have prospectively examined the impact of tracheotomy timing explicitly within this subgroup.

Gaps in Current Evidence:

- Lack of randomized controlled trials (RCTs) focused on decompressive craniectomy patients.
- Inconsistent definitions of 'early' and 'late' tracheotomy.
- Unclear impact on neurofunctional outcomes and mortality specific to this population.

Comparison with Existing Literature

Our results concur with systematic reviews (Sabbagh et al., 2019), affirming that early tracheotomy (within 7 days) shortens ventilation and ICU stays. Specifically, in neurotrauma populations, prior smaller studies (Sodal et al., 2021) have highlighted that early tracheotomy might reduce secondary brain insults by minimizing hypoxia and systemic inflammation. However, some recent RCTs (e.g., the Tracheotomy in Neurocritical Care [TINC] trial) have yielded mixed results, emphasizing the importance of patient selection.

Pathophysiological Considerations

Early tracheotomy may mitigate systemic inflammatory responses by reducing ventilator-associated pulmonary infections, which are known to exacerbate neuroinflammation and intracranial hypertension (Khan et al., 2022). Improved pulmonary hygiene and reduced sedation facilitate early mobilization and participation in neurorehabilitation, which are associated with better functional outcomes (Chang et al., 2020). Additionally, early tracheotomy allows for more comfortable airway management, decreasing the need for continuous sedation and enabling better neurological assessments, critical for optimizing neurointensive care trajectories.

Limitations

Despite the promising findings, several limitations must be acknowledged:

- **Non-randomized design:** Allocation based on clinical judgment may introduce selection bias. Randomized controlled trials (RCTs) are needed to confirm causal relationships.
- **Sample size:** While adequately powered for primary outcomes, the sample remains modest, particularly for secondary endpoints such as mortality and long-term neurological recovery.
- **Single-center setting:** Results may not be generalizable across varied healthcare settings with differing protocols and resources.
- **Potential confounders:** Factors such as variations in sedation strategies, rehabilitation services, and unmeasured comorbidities could influence outcomes.
- **Follow-up duration:** Six-month follow-up, although standard, may not capture all long-term neurological and functional changes.

Clinical Implications

Our findings support integrating early tracheotomy into neurocritical care protocols for severe TBI patients undergoing decompressive craniectomy. Rapid airway stabilization appears to confer benefits in ventilator weaning, ICU resource utilization, and neurological recovery without increasing procedural risks.

Future Directions

To definitively establish optimal tracheotomy timing, well-designed multicenter RCTs are essential. These should stratify patients based on injury severity, neuroimaging findings, and intraoperative variables. Additionally, exploring biomarkers linked to neuroinflammation and secondary injury could clarify mechanistic pathways by which airway management influences recovery.

Conclusion

This prospective study provides compelling evidence supporting the early implementation of tracheotomy in patients with severe traumatic brain injury undergoing decompressive craniectomy. The data demonstrate that performing tracheotomy within the first week post-intubation significantly reduces ventilator dependence, ICU stay duration, and overall hospitalization days, thereby potentially decreasing healthcare costs and resource utilization. Importantly, early tracheotomy was associated with improved functional outcomes at six months, as evidenced by a higher proportion of patients achieving good recovery (GOS 5), highlighting the potential neuroprotective effects related to reduced systemic and intracranial complications associated with prolonged ventilation. Moreover, the safety profile of early tracheotomy was comparable to that of late procedures, with no significant increase in procedural or infectious complications. These findings align with and augment the current body of literature advocating for early airway management in neurocritical care, yet they also underline the importance of careful patient selection and timing to maximize benefits. Nonetheless, the study's limitations—including its non-randomized, single-center design and modest sample size—warrant cautious interpretation. Larger, multicenter randomized controlled trials are needed to confirm these results, explore long-term cognitive and quality-of-life outcomes, and refine guidelines for tracheotomy timing specifically tailored to neurotrauma patients. Meanwhile, clinicians should consider early tracheotomy as a viable strategy within the context of multidisciplinary neurocritical care, balancing the potential benefits against individual patient conditions and prognostic factors. Overall, adopting early tracheotomy protocols could significantly improve patient outcomes, optimize ICU resources, and advance the standards of neurotrauma management worldwide.