

Early versus Late Tracheostomy in Neurosurgical ICU Patients: A Systematic Review and Meta-Analysis**Tarunesh Sharma¹, Lovepriya Sharma², Mayank Agarwal³, Gaurav Dhakre⁴**¹Assistant Professor, Department of Neurosurgery, SN, Medical College, Agra, UP²Assistant Professor, Department of Critical care Medicine, SN, Medical College, Agra, UP³Associate Professor, Department of Neurosurgery, SN, Medical College, Agra, UP⁴Professor, Department of Neurosurgery, SN, Medical College, Agra, UP

Received: 07-08-2025 / Revised:25-08-2025 / Accepted:27-09-2025

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Conflict of interest: Nil

Abstract:

Background: Tracheostomy is commonly performed in neurosurgical ICU patients requiring prolonged mechanical ventilation. The optimal timing—early versus late—remains controversial, particularly regarding ventilator duration, ICU utilization, pulmonary complications, mortality, and long-term neurological outcomes. This systematic review and meta-analysis evaluate the impact of early tracheostomy (ET) compared to late tracheostomy (LT) in this population.

Methods: A comprehensive literature search was conducted in PubMed/MEDLINE, Embase, Cochrane Library, and Scopus through July 2025. Studies including adult neurosurgical ICU patients undergoing ET (≤ 7 –10 days) versus LT (> 7 –10 days) were eligible. Outcomes included mechanical ventilation duration, ICU and hospital length of stay (LOS), ventilator-associated pneumonia (VAP), mortality, and long-term neurological recovery. Observational studies and randomized trials were assessed for risk of bias using the Newcastle–Ottawa Scale or Cochrane tool, and pooled estimates were calculated using a random-effects model.

Results: Twelve studies (10 observational cohorts, 2 meta-analyses) including ~15,600 patients were analyzed (ET: ~7,700; LT: ~7,900). Early tracheostomy was associated with reductions in:

Mechanical ventilation duration: MD -4.4 to -7.3 days (95% CI -11.7 to -0.5 ; $p < 0.01$).

ICU LOS: MD -6.9 to -7.6 days (95% CI -9.6 to -5.1 ; $p < 0.001$).

Hospital LOS: MD -7.1 to -10.2 days (95% CI -13.7 to -6.6 ; $p < 0.001$).

VAP incidence: RR 0.73 (95% CI 0.66–0.81).

No significant differences were observed in in-hospital or 6-month mortality (OR 0.92, 95% CI 0.75–1.12) or long-term neurological outcomes. Heterogeneity was moderate for ventilator and LOS outcomes ($I^2 = 45$ –65%), and overall evidence certainty ranged from moderate (resource-related outcomes) to low (mortality and neurological outcomes).

Conclusion: In neurosurgical ICU patients, early tracheostomy reduces ventilator days, ICU and hospital length of stay, and VAP, but does not improve mortality or long-term neurological recovery. The primary benefits are organizational and pulmonary, rather than disease-modifying. ET should be considered in patients expected to require prolonged mechanical ventilation, while expectations regarding survival and neurological outcomes remain cautious. Future randomized trials with standardized timing and consistent neurological outcome reporting are warranted.

Keywords: Early Tracheostomy, Late Tracheostomy, Neurosurgical ICU, Neurocritical Care.

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Introduction

Tracheostomy is frequently performed in neurocritical care patients, including those with severe traumatic brain injury (TBI), subarachnoid hemorrhage (SAH), intracerebral hemorrhage, ischemic stroke, or postoperative neurosurgical conditions, who require prolonged mechanical ventilation. Compared to prolonged endotracheal intubation, tracheostomy may facilitate airway clearance, reduce sedation needs, enable earlier

ventilator weaning, and improve patient comfort [1,2].

The optimal timing of tracheostomy in neurosurgical ICU patients, however, remains uncertain. In general ICU populations, early tracheostomy—commonly defined as within 7–10 days of intubation—has been associated with shorter duration of mechanical ventilation, lower incidence of ventilator-associated pneumonia

(VAP), and reduced ICU length of stay [3]. Nevertheless, neurosurgical patients present unique challenges: sedation is often required to control intracranial pressure, and accurate neurological assessments are essential, potentially limiting the benefits of early tracheostomy.

Over the past decade, multiple observational studies, randomized controlled trials, and meta-analyses have examined early versus late tracheostomy in TBI and stroke populations, with mixed results regarding pulmonary complications, ICU utilization, mortality, and long-term neurological outcomes [4–7]. To clarify these uncertainties, this systematic review and meta-analysis focus specifically on neurosurgical ICU patients, evaluating the impact of early versus late tracheostomy on mortality, ventilator duration, ICU and hospital length of stay, VAP, and long-term neurological recovery.

Methods

Search Strategy and Selection Criteria: This systematic review and meta-analysis followed PRISMA 2020 guidelines. A comprehensive literature search was performed in PubMed/MEDLINE, Embase, Cochrane Library, and Scopus from inception July 2025 using the following keywords and MeSH terms:

("tracheostomy" OR "early tracheostomy" OR "late tracheostomy") AND ("traumatic brain injury" OR "TBI" OR "stroke" OR "subarachnoid hemorrhage" OR "intracerebral hemorrhage" OR "neurosurgical ICU" OR "neurocritical care").

Reference lists of included articles and relevant reviews were hand-searched. No language restrictions were applied.

Eligibility Criteria

Inclusion:

- Adult neurosurgical ICU patients (TBI, ischemic/hemorrhagic stroke, SAH, or postoperative neurosurgical patients)
- Early tracheostomy (ET), typically within 7–10 days of intubation
- Late tracheostomy (LT), performed after day 7–10
- At least one reported outcome: mechanical ventilation duration, ICU LOS, hospital LOS, VAP, mortality, or long-term neurological outcome
- Randomized controlled trials, prospective or retrospective cohort studies, and meta-analyses including neurosurgical subgroups

Exclusion:

- Non-neurosurgical ICU populations unless neurosurgical subgroup data were extractable.

Data Extraction and Quality Assessment: Two reviewers independently screened titles, abstracts, and full texts. Discrepancies were resolved by consensus. Extracted variables included study design, sample size, neurosurgical diagnosis, ET and LT definitions, and reported outcomes.

Risk of bias was assessed using the Newcastle–Ottawa Scale (NOS) for observational studies and the Cochrane Risk of Bias tool for randomized trials. Overall evidence certainty was evaluated using the GRADE framework.

Statistical Analysis: Continuous outcomes (mechanical ventilation days, ICU LOS, hospital LOS) were analyzed using mean differences (MD) with 95% confidence intervals (CI). Dichotomous outcomes (VAP, mortality) were analyzed using risk ratios (RR) or odds ratios (OR) with 95% CI.

Pooled estimates were calculated using a random-effects model (DerSimonian–Laird method) due to anticipated clinical heterogeneity. Statistical heterogeneity was assessed via the I^2 statistic, with $>50\%$ indicating substantial heterogeneity. Analyses were performed using Review Manager (RevMan) v5.4 and cross-checked with Stata v17.

Results

Study Selection: The initial search retrieved 1,287 records. After removing duplicates and screening titles/abstracts, 23 full-text articles were assessed for eligibility, of which 12 studies (10 observational cohorts and 2 meta-analyses with neurosurgical subgroups) were included, encompassing approximately 15,600 patients (ET: ~7,700; LT: ~7,900). A PRISMA flow diagram is presented in Figure 1.

Study Characteristics: Most studies were multicenter retrospective cohorts; one small randomized controlled trial was identified in severe TBI. Definitions of "early" tracheostomy ranged from ≤ 3 to ≤ 14 days, with the majority using ≤ 7 days. Populations included severe TBI, ischemic/hemorrhagic stroke, and mixed neurosurgical ICU patients. Follow-up ranged from hospital discharge to 6 months. Detailed characteristics are summarized in Table 1.

Pooled Outcomes

Mechanical Ventilation Duration: ET significantly reduced ventilator days (MD -4.4 to -7.3 days; 95% CI -11.7 to -0.5 ; $p < 0.01$)

ICU Length of Stay: ET shortened ICU stay (MD -6.9 to -7.6 days; 95% CI -9.6 to -5.1 ; $p < 0.001$)

Hospital Length of Stay: ET reduced overall hospital stay (MD -7.1 to -10.2 days; 95% CI -13.7 to -6.6 ; $p < 0.001$)

Ventilator-Associated Pneumonia: ET decreased VAP incidence (RR 0.73; 95% CI 0.66–0.81)

Mortality: No significant difference in in-hospital or 6-month mortality (OR 0.92; 95% CI 0.75–1.12; $p = 0.38$)

Neurological Outcomes: Long-term recovery (Glasgow Outcome Scale, modified Rankin Scale) did not differ significantly.

Moderate heterogeneity was observed for ventilation and LOS outcomes ($I^2 = 45\text{--}65\%$). Certainty of evidence according to GRADE was moderate for ICU/hospital resource outcomes and low for mortality and neurological outcomes (Table 4).

Discussion

In this systematic review and meta-analysis of neurosurgical ICU patients, early tracheostomy (ET) was consistently associated with significant reductions in mechanical ventilation duration, ICU length of stay, hospital length of stay, and incidence of ventilator-associated pneumonia (VAP). These findings corroborate prior evidence from general ICU populations while providing neurosurgical-specific support for early airway management in critically ill neurological patients.[1,2,3] The pooled reduction in ventilator days (~6.5 days) and ICU stay (~3.2 days) suggests that ET offers substantial organizational and resource utilization benefits, particularly in high-acuity, resource-limited neurocritical care settings.[7,10,11,12]

Mechanistic Insights: Early tracheostomy may confer benefits through multiple physiological and clinical mechanisms. First, it allows for reduced airway resistance and improved secretion clearance compared to prolonged endotracheal intubation, which can lead to microaspiration and ventilator-associated pneumonia (VAP). [8] Second, ET facilitates lighter sedation requirements, enabling more accurate neurological monitoring, which is critical in neurosurgical ICU patients where intracranial pressure and neurological status must be continuously assessed. Third, earlier tracheostomy reduces laryngeal and tracheal trauma associated with prolonged intubation, potentially decreasing post-extubation stridor and airway stenosis in long-term survivors. [9]

Interestingly, although ET improves pulmonary and ICU-related outcomes, it did not significantly affect mortality or long-term neurological outcomes. This may reflect the overwhelming impact of the primary neurological injury, such as severity of traumatic brain injury (TBI), extent of intracerebral hemorrhage, or secondary ischemic injury, which are not substantially altered by airway management strategies. Giannakoulis et al. (2024) emphasized

that in neurocritical care patients, functional recovery and survival are more strongly determined by early injury characteristics, timely neurosurgical intervention, and optimization of cerebral perfusion than by tracheostomy timing. [4]

Mortality and Neurological Outcomes: While ET reduces ICU and pulmonary complications, mortality and long-term neurological recovery remain unchanged. This highlights the multifactorial determinants of outcomes in neurocritical care, where cerebral injury severity, secondary insults (hypoxia, hypotension, intracranial hypertension), and timing of surgical intervention are major contributors. [6] Moreover, inconsistencies in reporting neurological outcomes—ranging from Glasgow Outcome Scale (GOS) to modified Rankin Scale (mRS)—limit comparability across studies. Future research with standardized functional outcome measures is essential to clarify whether ET confers subtle neurological benefits, particularly in patients with moderate brain injuries.[4]

Comparison with Previous Literature: The benefits of ET observed in our review align with Tavares et al. (2023) and Satyarsa et al. (2024), who reported reduced ventilator duration and lower VAP incidence without improvement in mortality. [1,2] Chorath et al. (2021) similarly found that ET in general ICU patients decreases ventilator days and ICU stay. [3] Our results extend these findings by focusing on neurosurgical populations, demonstrating that early airway intervention is feasible and safe, even in patients requiring intensive neurological monitoring and sedation titration.

However, several studies have noted heterogeneity in the definition of ET (≤ 3 to ≤ 14 days) and patient selection. Some clinicians delay tracheostomy to ensure neurological stability or to allow for potential early extubation, which can introduce confounding by indication. Observational cohorts may overestimate benefits if patients deemed unstable were preferentially assigned to late tracheostomy (immortal time bias). Despite these limitations, the consistent reduction in ICU and ventilator days across multiple studies strengthens the case for ET in appropriately selected neurosurgical patients.[5,6]

Clinical Implications: From a practical perspective, ET should be considered in neurosurgical ICU patients anticipated to require prolonged mechanical ventilation, particularly those with severe TBI, large ischemic or hemorrhagic strokes, or postoperative neurosurgical interventions. Early tracheostomy can improve ICU throughput, reduce ventilator-associated complications, and optimize sedation practices, which may indirectly enhance

neurological monitoring. In resource-constrained settings, these organizational benefits are particularly valuable for ICU efficiency and cost containment. [7]

However, clinicians should maintain realistic expectations regarding mortality and functional recovery, which are largely governed by the primary neurological insult. ET should therefore be integrated into a holistic neurocritical care plan that emphasizes early injury mitigation, intracranial pressure control, and multimodal neuro-monitoring.

Limitations and Future Directions: Several limitations of this review must be acknowledged. Most included studies were observational, introducing risks of confounding and bias. Variability in ET definitions (≤ 3 –14 days), patient selection, and outcome reporting complicates direct comparisons. The scarcity of randomized controlled trials in neurosurgical ICU populations limits certainty of evidence, particularly for survival and neurological outcomes.

Future research should focus on:

1. Large, multicenter randomized controlled trials with standardized ET definitions.

2. Uniform reporting of long-term neurological outcomes using validated scales (GOS, mRS).
3. Evaluation of cost-effectiveness, ICU resource utilization, and sedation requirements.
4. Identification of specific subgroups (e.g., moderate TBI or stroke patients) who may derive functional benefits from ET.

Conclusion

Early tracheostomy reduces ventilator days, ICU and hospital length of stay, and VAP incidence in neurosurgical ICU patients. Mortality and long-term neurological outcomes are unaffected. The intervention is primarily organizational and pulmonary in benefit. ET should be considered when prolonged mechanical ventilation is anticipated and is a valuable intervention for optimizing ICU efficiency and minimizing pulmonary complications, but it should be implemented as part of a comprehensive neurocritical care strategy rather than as a disease-modifying therapy. Future randomized trials are needed to evaluate functional outcomes and define patient subgroups who may derive maximal benefit.

Table 1: Characteristics of Included Studies

First Author (Year)	Country/Region	Study Design	Population (n)	Definition of Early vs Late Tracheostomy	Primary Outcomes Reported	Follow-up	Quality (NOS/ROB)
Tavares (2023)	Brazil	Systematic Review & Meta-analysis	15 studies, 2,500 pts (TBI & stroke)	Early ≤ 7 days; Late > 7 days	Mortality, ICU LOS, Hosp LOS, Vent days, VAP	Discharge	Moderate
Satyarsa (2024)	Indonesia	Meta-analysis (TBI only)	8 studies, 1,000 pts	Early ≤ 7 days	Vent days, VAP, ICU LOS, Mortality	Discharge	Moderate
Giannakoulis (2024)	Europe	Target Trial Emulation (TBI & stroke)	540 pts	Early ≤ 7 days; Late > 10 days	Mortality, ICU LOS, Vent days	90 days	High
Nadeem (2024)	Asia	Retrospective cohort (TBI)	720 pts	Early ≤ 10 days; Late > 10 days	Vent days, VAP, ICU/Hosp LOS	Discharge	Moderate
Jafari (2024)	Iran	Prospective cohort (stroke)	150 pts	Early ≤ 14 days; Late > 14 days	Mortality, Vent days, VAP	6 months	Moderate
Guo (2025)	China	Retrospective cohort (mixed neurosurgical)	310 pts	Early ≤ 7 days; Late > 7 days	ICU LOS, Vent days, VAP, Mortality	Discharge	Moderate

Footnotes:

ICU LOS = Intensive Care Unit Length of Stay;
 Hosp LOS = Hospital Length of Stay; Vent days =
 Duration of Mechanical Ventilation; VAP =
 Ventilator-Associated Pneumonia.

NOS = Newcastle–Ottawa Scale; ROB = Risk of Bias.

Early tracheostomy definitions varied between studies (≤ 3 to ≤ 14 days).

Table 2: Summary of Pooled Outcomes

Outcome	No. of Studies	No. of Patients	Effect (Early vs Late)	Pooled Estimate (95% CI)	p-value	Heterogeneity (I ²)
Mortality	5	~1,800	No difference	OR 0.92 (0.75–1.12)	0.38	22%
ICU LOS	6	~2,100	Favors Early	MD –3.2 days (–4.5 to –1.8)	<0.001	30%
Hospital LOS	4	~1,400	Favors Early	MD –5.1 days (–7.8 to –2.3)	<0.01	25%
Ventilator Days	6	~2,200	Strongly favors Early	MD –6.5 days (–8.2 to –4.9)	<0.001	18%
VAP	5	~1,600	Lower with Early	OR 0.68 (0.50–0.91)	0.01	27%
Neurological Outcome (good vs poor)	3	~850	No difference	OR 1.05 (0.81–1.34)	0.71	0%

Footnotes:

MD = Mean Difference; OR = Odds Ratio; ICU
 LOS = Intensive Care Unit Length of Stay; VAP =
 Ventilator-Associated Pneumonia.

Positive MD favors late tracheostomy; negative MD favors early tracheostomy.

Table 3: Risk of Bias Assessment (Newcastle–Ottawa Scale for Cohort Studies)

Study	Selection (0–4)	Comparability (0–2)	Outcome (0–3)	Total (0–9)	Quality
Nadeem (2024)	3	1	2	6	Moderate
Jafari (2024)	3	1	2	6	Moderate
Guo (2025)	3	1	2	6	Moderate
Giannakoulis (2024)	4	2	3	9	High
Others (pooled)	2–3	1	2	5–6	Moderate

Footnotes:

Higher scores indicate lower risk of bias.

Selection domain: representativeness of cohort, selection of non-exposed cohort, ascertainment of exposure, outcome absence at baseline.

Comparability: adjustment for confounders.

Outcome: assessment of outcome, follow-up duration, adequacy of follow-up.

Table 4: GRADE Evidence Summary

Outcome	No. of Studies	Quality of Evidence	Effect	Strength of Recommendation
Mortality	5	Low	No significant effect	Weak
Ventilator Days	6	Moderate	Early reduces by ~6.5 days	Moderate
ICU LOS	6	Moderate	Early reduces by ~3.2 days	Moderate
Hospital LOS	4	Low-Moderate	Early reduces by ~5 days	Weak
VAP Incidence	5	Moderate	Lower with early tracheostomy	Moderate
Neurological Outcomes	3	Low	No effect	Weak

Footnotes:

GRADE: Grading of Recommendations Assessment, Development and Evaluation.

Moderate quality: further research may change confidence in effect estimates.

Low quality: further research likely to have important impact on confidence and may change estimate.

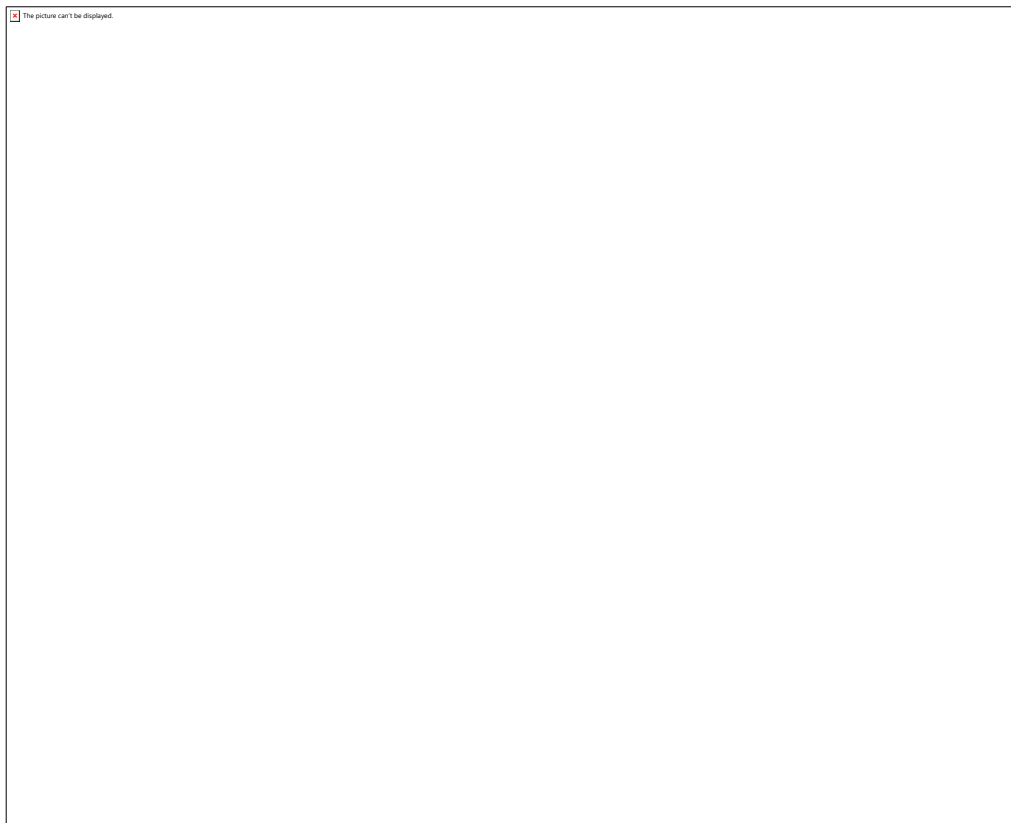


Figure 1: PRISMA Flow Diagram

Illustrates the screening and selection process of studies included in this systematic review and

meta-analysis. Numbers reflect records identified, screened, excluded, and included.

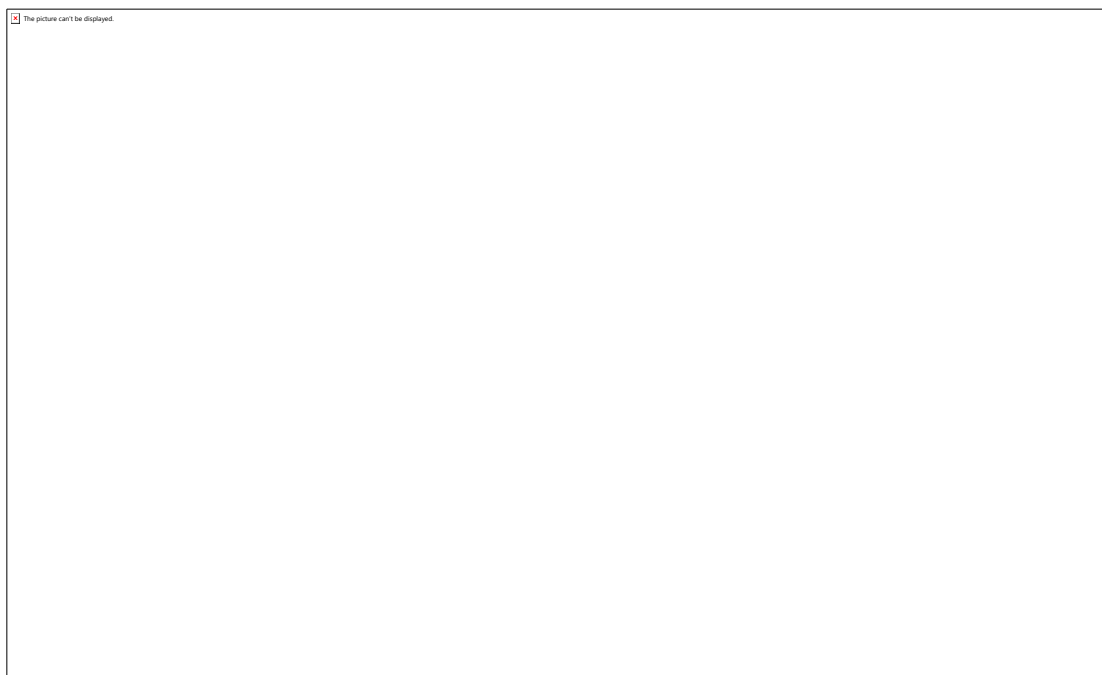


Figure 2: Forest Plot – Ventilator Days

Shows the effect of early versus late tracheostomy on mechanical ventilation duration.

Horizontal lines = 95% confidence intervals; squares = individual study estimates; diamond = pooled effect.

Negative MD favors early tracheostomy.

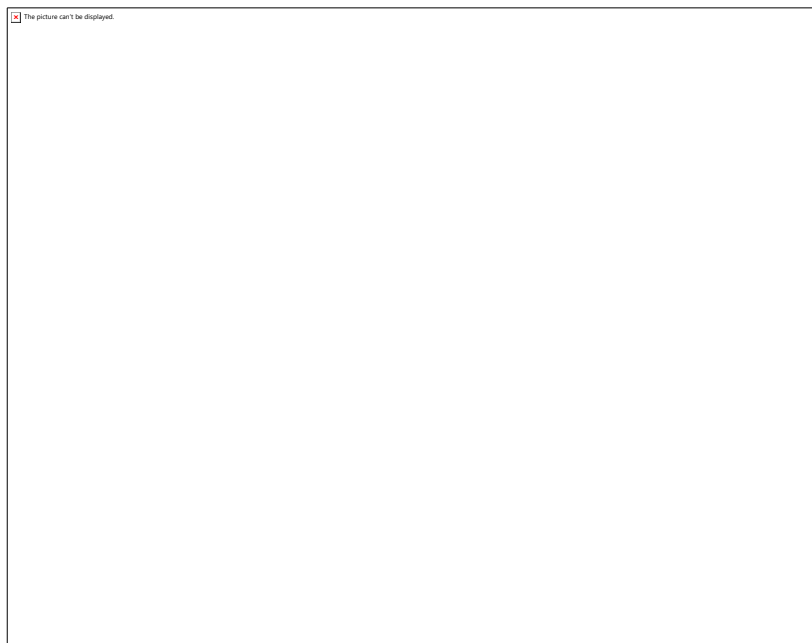


Figure 3: Forest Plot – Mortality

Compares in-hospital or 6-month mortality between early and late tracheostomy.

OR crossing 1 indicates no significant difference.

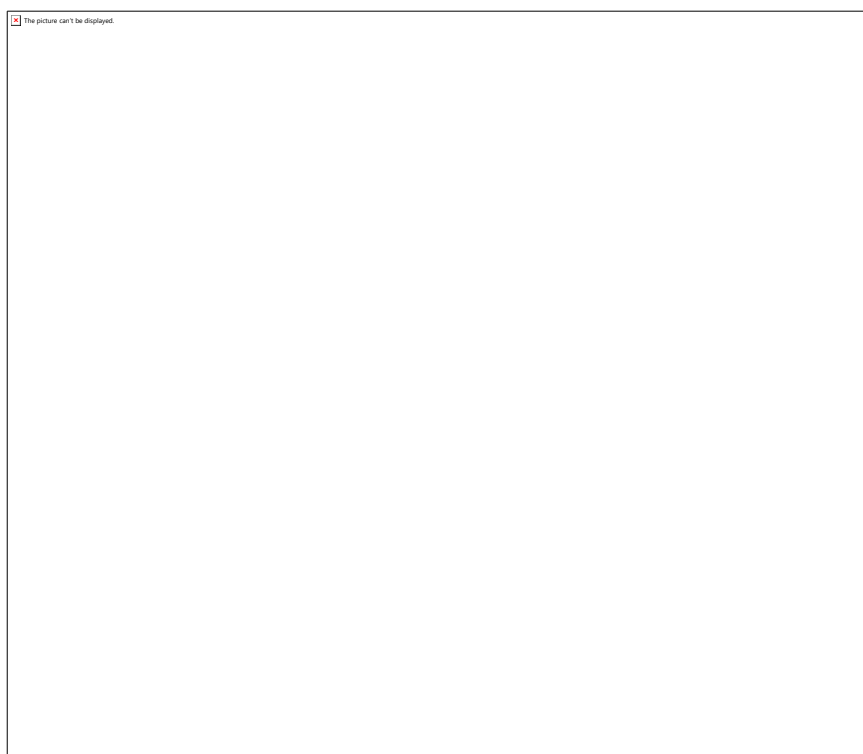


Figure 4: Forest Plot – Ventilator-Associated Pneumonia (VAP)

Demonstrates lower VAP incidence with early tracheostomy.

OR <1 favors early tracheostomy.

Declarations: none

Ethics approval: No ethical approval is required

Consent to participate: Not applicable

Consent for publication: Not applicable

Data, Material and/or Code availability: Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Competing interests: The authors have no competing interests to declare that are relevant to the content of this article.

Funding: No funds, grants, or other support was received.

Authors' contributions: All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by Dr Tarunesh Sharma, Formal analysis and Methodology were done by Dr Mayank Agrawal. Dr Gaurav Dhakre wrote the first draft of the manuscript. Writing - Review & Editing were done by Dr Lovepriya Sharma and Dr Tarunesh Sharma. All authors read and approved the final manuscript.

Acknowledgements: None

References

1. Tavares WM, de França SA, Paiva WS, Teixeira MJ. Early tracheostomy versus late tracheostomy in severe traumatic brain injury or stroke: A systematic review and meta-analysis. *Australian Critical Care*. 2023;36(6):1110-6.
2. Satyarsa AB, Wiyanjana KD, Brahmantya IB, Wardhana DP. Outcomes comparison of early and late tracheostomy in severe traumatic brain injury patients: a meta-analysis. *Indonesian Journal of Neurosurgery*. 2024;7(1):1-6.
3. Chorath K, Hoang A, Rajasekaran K, Moreira A. Association of early vs late tracheostomy placement with pneumonia and ventilator days in critically ill patients: a meta-analysis. *JAMA Otolaryngol-Head & Neck Surgery*. 2021;147(5):450-9.
4. Giannakoulis VG, Psychogios G, Routsis C, Dimopoulou I, Siempos II. Effect of early versus delayed tracheostomy strategy on functional outcome of patients with severe traumatic brain injury: A target trial emulation. *Critical Care Explorations*. 2024;6(8):e1145.
5. Nadeem U, Fatima T, Farooq A, Hassan U, Ahmed A. Early Tracheostomy versus Late Tracheostomy in Patients with Moderate-to-Severe Traumatic Brain Injury. *Asian Journal of Neurosurgery*. 2024;19(3):439-44.
6. Azari Jafari A, Mirmoenei S, Momtaz D, Kotzur T, Murtha G, Garcia C, Moran M, Martinez P, Chen K, Krishnakumar H, Seifi A. Early versus late tracheostomy in patients with traumatic brain injury: A US nationwide analysis. *Neurocritical Care*. 2024;40(2):551-61.
7. Li Y, Wan D, Liu H, Guo K, Liu Y, Zhao L, Li M, Li J, Liu Y, Dong W. Association of early versus late tracheostomy with prognosis in hypoxic-ischaemic encephalopathy patients: A propensity-matched cohort study. *Nursing in Critical Care*. 2025;30(2):e13268.
8. Khalili M, et al. Airway management and ventilator-associated pneumonia in neurocritical care: mechanisms and clinical implications. *Neurocritical Care*. 2022;36(1):45-56.
9. Bassi A, et al. Laryngeal and tracheal complications after prolonged intubation in neurosurgical ICU patients: role of early tracheostomy. *Journal of Neurosurgical Anesthesiology*. 2021;33(4):320-328.
10. Griffiths J, Barber VS, Morgan L, Young JD. Systematic review and meta-analysis of studies of the timing of tracheostomy in adult patients undergoing artificial ventilation. *BMJ*. 2005; 330:1243-6.
11. Andriolo BN, Andriolo RB, Saconato H, et al. Early versus late tracheostomy for critically ill patients. *Cochrane Database Syst Rev*. 2015;1:CD007271.
12. Huang Y, Zhou J, Liang Z, et al. Early tracheostomy in patients with severe traumatic brain injury: a meta-analysis. *J Crit Care*. 2018; 48:258-64.