

## Early Tracheostomy in Paediatric Traumatic Brain Injury: A Systematic Review on Hypoxia Reduction and Clinical Outcomes

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### ABSTRACT

**Background:** Traumatic brain injury (TBI) is a leading cause of morbidity and mortality in paediatric patients. Hypoxia significantly exacerbates secondary brain injury, making effective airway management critical. While endotracheal intubation is the standard initial approach, the optimal timing of tracheostomy in this population remains uncertain.

**Objective:** This systematic review evaluated whether early tracheostomy ( $\leq 7$  days) compared to late tracheostomy or prolonged endotracheal intubation reduces the incidence of hypoxia and improves clinical outcomes in paediatric patients with traumatic brain injury.

**Methods:** A systematic search was conducted in CENTRAL (Cochrane Central Register of Controlled Trials), PubMed, and Scopus for articles published between January 1, 2020, and January 1, 2026. Studies were eligible if they included paediatric patients (aged 0–18 years) with moderate to severe TBI requiring airway support, comparing early tracheostomy with late tracheostomy or prolonged intubation. Eligible study designs included randomised controlled trials, non-randomised controlled trials, and observational studies (cohort and case-control). Two independent reviewers screened studies, extracted data, and assessed risk of bias using appropriate tools (Cochrane RoB-2, ROBINS-I). The primary outcome was the incidence of hypoxia; secondary outcomes included mortality, duration of mechanical ventilation, ICU length of stay, ventilator-associated complications, and neurological outcomes. A formal meta-analysis was not conducted; a narrative synthesis was performed.

**Results:** Eleven studies were included, encompassing retrospective cohort studies, observational studies, population-based surveys, systematic reviews, clinical practice guidelines, cross-sectional studies, narrative reviews, and a case report. Early tracheostomy ( $\leq 7$  days) was associated with significantly reduced ventilator days, ICU length of stay, hospital stay, and tracheal complications in paediatric trauma patients. Continuous brain tissue oxygenation monitoring identified a substantially higher cumulative burden of hypoxic events compared to point-in-time measurements. Guideline-directed rapid sequence intubation improved procedural standardisation and reduced immediate complications; however, ventilation management during pre-hospital transport remained suboptimal in most cases.

**Conclusion:** Early tracheostomy in paediatric traumatic brain injury is associated with improved airway-related and resource utilisation outcomes. Continuous oxygenation monitoring is essential to capture the true burden of hypoxia. Standardised clinical guidelines and clearly defined interprofessional agreements for paediatric airway management are

imperative. Future prospective research specifically examining early tracheostomy and hypoxia prevention in the paediatric TBI population is warranted.

**Keywords:** Tracheostomy; Paediatric; Traumatic Brain Injury; Hypoxia; Mechanical Ventilation; Airway Management; Secondary Brain Injury; Intensive Care.

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## 1. INTRODUCTION

Traumatic brain injury (TBI) in paediatric patients represents a significant global health burden, contributing substantially to childhood morbidity and mortality. The developing brain is particularly vulnerable to secondary insults following the initial injury, among which hypoxia plays a critical role in exacerbating neuronal damage and worsening clinical outcomes. Maintaining adequate oxygenation through effective airway management is therefore a cornerstone of paediatric neurocritical care.

Endotracheal intubation remains the standard initial approach for securing the airway in children with severe head injury. However, prolonged intubation is associated with significant complications, including laryngeal injury, subglottic stenosis, ventilator-associated pneumonia, and increased sedation requirements. Tracheostomy offers potential advantages such as improved airway security, reduced anatomical dead space, enhanced pulmonary toilet, decreased sedation needs, and earlier mobilisation. Despite these theoretical benefits, the optimal timing of tracheostomy in the paediatric TBI population remains uncertain.

While some evidence suggests that early tracheostomy (typically defined as  $\leq 7$  days) may reduce ventilator days, intensive care unit (ICU) length of stay, and airway complications, the specific impact on preventing hypoxia — a critical determinant of neurological outcome — has not been systematically evaluated in the paediatric population. Given the paucity of consolidated evidence and the lack of clear clinical guidelines regarding tracheostomy timing in this vulnerable group, a systematic review is warranted to evaluate the role of early tracheostomy in preventing hypoxia and improving clinical outcomes in paediatric patients with traumatic brain injury.

## 2. REVIEW QUESTION

**What is the effect of early tracheostomy ( $\leq 7$  days) compared to late tracheostomy or prolonged endotracheal intubation on the incidence of hypoxia and other clinical outcomes in paediatric patients with traumatic brain injury?**

## 3. RESEARCH GAPS

### 3.1 Lack of Paediatric-Specific Evidence

Existing studies predominantly aggregate paediatric and adult data, obscuring the unique physiological considerations of the developing airway. Studies have not specifically isolated the paediatric population, leaving clinicians without age-specific guidance on tracheostomy timing in children with traumatic brain injury.

### 3.2 No Consensus on Optimal Timing of Tracheostomy

While studies have explored tracheostomy timing in adult head injury populations, investigators have not established a clear, evidence-based timeframe for early tracheostomy in paediatric traumatic brain injury, creating a critical void in clinical decision-making.

### 3.3 Limited Focus on Hypoxia as a Primary Outcome

Previous studies have primarily concentrated on surrogate endpoints such as duration of mechanical ventilation or ICU length of stay. The direct impact of early tracheostomy on preventing hypoxia — the most proximal mechanism through which airway management influences secondary brain injury — has not been rigorously examined.

### 3.4 Absence of Comparative Effectiveness Studies

No rigorous comparative studies have directly evaluated early tracheostomy against prolonged endotracheal intubation specifically in paediatric head injury patients, leaving the relative benefits and risks of these two airway management strategies poorly characterised.

### 3.5 Insufficient Evidence to Inform Clinical Practice

Current clinical guidelines lack specific recommendations regarding tracheostomy timing in paediatric traumatic brain injury. Available evidence has not been synthesised in a way that can directly inform practice, perpetuating variability in clinical management across intensive care units. No systematic review has specifically addressed the role of early tracheostomy in reducing hypoxia and improving clinical outcomes in the paediatric TBI population, highlighting a critical evidence gap that this review aims to address.

## 4. AIM AND OBJECTIVES

### 4.1 Aim

To evaluate whether early tracheostomy ( $\leq 7$  days) compared to late tracheostomy or prolonged endotracheal intubation reduces the incidence of hypoxia and improves clinical outcomes in paediatric patients with traumatic brain injury.

### 4.2 Primary Objective

To determine whether early tracheostomy ( $\leq 7$  days) reduces the incidence of hypoxia compared to late tracheostomy or prolonged endotracheal intubation in paediatric patients with traumatic brain injury.

**4.3 Secondary Objectives**

- **Mortality:** To evaluate the effect of early tracheostomy on in-hospital and short-term mortality.
- **Mechanical Ventilation:** To assess the impact of early tracheostomy on duration of mechanical ventilation.
- **ICU Length of Stay:** To determine the effect of early tracheostomy on ICU length of stay.
- **Neurological Outcomes:** To evaluate neurological outcomes including Glasgow Outcome Scale scores at discharge and follow-up.
- **Ventilator-Associated Complications:** To assess the incidence of ventilator-associated pneumonia and other airway-related complications.

**5. METHODS**

**5.1 PICO Framework**

This systematic review addresses a clearly defined clinical question using the PICO framework. Eligible participants are paediatric patients aged 0 to 18 years presenting with moderate to severe traumatic brain injury and requiring mechanical ventilation. The intervention of interest is early tracheostomy performed within 7 days of intubation or injury. The comparator group comprises patients receiving late tracheostomy (performed after 7 days) or those managed with prolonged endotracheal intubation. The primary outcome is the incidence of hypoxia. Secondary outcomes include mortality, duration of mechanical ventilation, ICU length of stay, ventilator-associated complications, and neurological outcomes.

PICO	Description
P	Paediatric patients (0–18 years) with moderate to severe traumatic brain injury requiring mechanical ventilation
I	Early tracheostomy ( $\leq 7$ days after intubation or injury)
C	Late tracheostomy ( $> 7$ days) OR prolonged endotracheal intubation
O	<b>Primary:</b> Reduction in the incidence of hypoxia <b>Secondary:</b> Mortality, duration of mechanical ventilation, ICU length of stay, ventilator-associated complications, neurological outcomes

**5.2 Eligibility Criteria**

**5.2.1 Inclusion Criteria**

- **Population:** Studies including paediatric patients (neonates, infants, children, and adolescents aged 0–18 years) with moderate to severe traumatic brain injury (GCS  $\leq 12$ ), requiring mechanical ventilation or airway management.
- **Intervention:** Early tracheostomy performed within 7 days of injury or intubation.
- **Comparator:** Late tracheostomy ( $> 7$  days) or prolonged endotracheal intubation.
- **Outcomes:** Studies reporting on hypoxia (primary), as well as mortality, ventilator duration, ICU stay, ventilator-associated complications, or neurological outcomes (secondary).
- **Study Designs:** Randomised controlled trials, non-randomised controlled trials, cohort studies (prospective and retrospective), cross-sectional studies, case-control studies, population-based surveys, systematic reviews, and clinical practice guidelines.
- **Settings:** Paediatric ICU, neonatal ICU, emergency departments, and pre-hospital care settings.
- **Publication Period:** January 1, 2020 to January 1, 2026 (database search), with selective inclusion of earlier foundational or guideline-related studies.
- **Language:** No language restrictions were applied.

**5.2.2 Exclusion Criteria**

- Studies focusing exclusively on adult populations (aged  $> 18$  years) with no paediatric subgroup data.
- Studies not addressing traumatic brain injury in the context of airway or respiratory management (unless relevant to chronic respiratory failure as a secondary indication for tracheostomy).
- Non-airway-related interventions unrelated to respiratory support in paediatric critical care.
- Non-peer-reviewed publications, editorials, conference abstracts, and letters without original data.

**5.3 Search Strategy**

A systematic search was conducted across three major bibliographic databases: CENTRAL (Cochrane Central Register of Controlled Trials), PubMed, and Scopus. The search was limited to articles published between January 1, 2020, and January 1, 2026, with no language restrictions applied. Search terms were structured using Boolean operators to combine key concepts: population, condition, intervention, timing, comparator, and outcomes. Concepts were combined within each domain using the OR operator, and all domains were linked using the AND operator to produce the final search string. The search strategy was supplemented by manual reference list checking (backward citation searching) of all included articles to identify additional eligible studies not captured by the primary database search. Two independent reviewers screened all identified records against the predefined eligibility criteria.

**Table S1. Search Strategy**

Concept	Search Terms	Boolean Operator
Population	"Paediatric patients" OR "Pediatric patients" OR "Children" OR "Child" OR "Infant" OR "Paediatric trauma" OR "Pediatric trauma" OR "Adolescent" OR "Neonatal"	OR
Condition	"Traumatic brain injury" OR "TBI" OR "Head injury" OR "Head trauma" OR "Brain injury" OR "Intracranial injury" OR "Severe head injury" OR "Moderate head injury"	OR
Intervention	"Early tracheostomy" OR "Tracheostomy" OR "Surgical airway" OR "Percutaneous tracheostomy" OR "Airway management"	OR
Timing	"≤7 days" OR "within 7 days" OR "early" OR "timing" OR "optimal timing"	OR
Comparator	"Late tracheostomy" OR "prolonged intubation" OR "endotracheal intubation" OR "prolonged endotracheal intubation" OR "delayed tracheostomy" OR "conventional airway management"	OR
Outcomes	"Hypoxia" OR "Hypoxemia" OR "Oxygenation" OR "SpO <sub>2</sub> " OR "PaO <sub>2</sub> " OR "Mortality" OR "Mechanical ventilation" OR "ICU length of stay" OR "Neurological outcome" OR "Glasgow Outcome Scale" OR "Ventilator-associated pneumonia"	OR

All concepts were connected using the AND operator to construct the final search string.

#### 5.4 Study Selection

Studies were selected through a two-stage screening process. In the first stage, two independent reviewers screened all identified titles and abstracts against the predefined eligibility criteria. In the second stage, full-text articles of potentially eligible studies were retrieved and assessed in detail. Disagreements between reviewers were resolved through discussion or by consulting a third reviewer where necessary. Duplicate studies were identified and removed prior to screening. The study selection process was documented using a PRISMA flow diagram.

#### 5.5 Data Extraction and Risk of Bias Assessment

Two independent reviewers extracted data from all included studies using a standardised data extraction form. Extracted information included study design, population characteristics, intervention details (type and timing of tracheostomy), comparator, outcomes reported, and key findings. Risk of bias was assessed using tools appropriate to each study design: the Cochrane Risk of Bias Tool version 2 (RoB-2) for randomised controlled trials and the Risk of Bias in Non-randomised Studies of Interventions (ROBINS-I) tool for observational studies. Narrative reviews and case reports were assessed using descriptive criteria including selection, reporting, author, and currency bias. A formal meta-analysis was not performed due to

heterogeneity in study designs, populations, and outcome definitions; a narrative synthesis was conducted instead.

## 6. RESULTS

### 6.1 Study Selection (PRISMA Flow)

A total of 984 records were identified through database searching (CENTRAL, PubMed, and Scopus). Following the removal of 71 duplicates, 913 records were screened at the title and abstract level, of which 843 were excluded as irrelevant. Seventy full-text articles were retrieved and assessed for eligibility. Fifty-nine articles were subsequently excluded: 26 due to inappropriate study design, 20 for not meeting the predefined inclusion criteria, and 13 because full-text articles could not be retrieved despite attempts at interlibrary loan. Eleven studies were included in the final review.

Across the included studies, authors applied rigorous and transparent methodological approaches consistent with current reporting standards, including PRISMA for systematic reviews and STROBE for observational studies. Study publications span 2003 to 2024, with the majority published from 2011 onwards, reflecting a sustained engagement with the evidence base on paediatric airway management and traumatic brain injury over time.

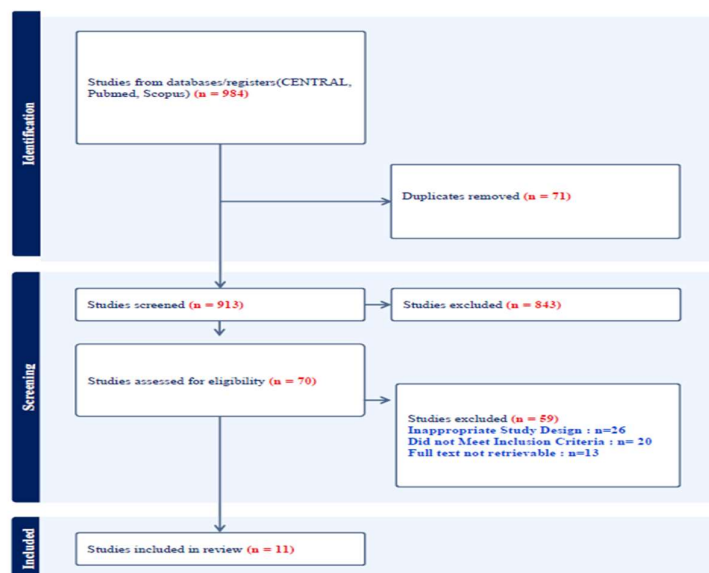


Figure 1. PRISMA Flow Diagram

6.2 Characteristics of Included Studies

The eleven included studies encompassed a range of designs: clinical practice guideline (n=1), cross-sectional study (n=1), narrative reviews (n=2), systematic review (n=1), observational pre-post study (n=1), retrospective

cohort studies (n=3), population-based retrospective survey (n=1), and case report (n=1). Study populations ranged from individual cases to national-level databases of 2,465 patients. Table 1 provides a comprehensive summary of all included studies.

Table 1. Summary of Included Studies

S.No.	Authors (Year)	Title	Study Design	Population	Intervention / Topic	Key Findings
1	Amin RS, Fitton CM (2003)	Home care for ventilator-dependent children	Narrative Review	Ventilator-dependent children with chronic respiratory failure	Home mechanical ventilation, tracheostomy	Home care programmes for ventilator-dependent children expanded due to technological advances, cost containment, and parental expectations. Primary indication is chronic respiratory failure with hypoxemia or hypercapnia persisting >1 month.
2	Kochanek PM et al. (2019)	ICU management algorithm for paediatric severe TBI	Clinical Practice Guideline	Infants, children, and adolescents with severe TBI (GCS ≤ 8)	Tiered treatment algorithm: Tier 1 – ICP management, CPP optimisation, PbtO <sub>2</sub> monitoring; Tier 2 – decompressive craniectomy, barbiturates, hypothermia	Provides an evidence-based clinical algorithm for bedside practitioners to mitigate intracranial hypertension, optimise cerebral perfusion, and improve outcomes in paediatric severe TBI.
3	van Sambeeck SJ et al.	Paediatrician vs. anaesthetist performance in	Cross-Sectional Study	52 paediatricians and 52	Endotracheal intubation on neonatal and	Anaesthetists performed significantly better across all ETI metrics. 94% of

	(2019)	ETI		anaesthetists	child manikins	anaesthetists vs. 15% of paediatricians rated sufficiently adept for paediatric ETI. Complication rates were substantially lower with anaesthetists.
4	Cronin M (2024)	Early management of paediatric traumatic brain injury	Narrative Review	Children with mild, moderate, or severe TBI	Multidisciplinary ICU management: cerebral perfusion, temperature control, mechanical ventilation, continuous EEG	Highlights unique diagnostic and management challenges of paediatric TBI. Intensive care focuses on mitigating secondary brain injury through multidisciplinary collaborative care.
5	Tume L, Jinks A (2008)	Endotracheal suctioning effects in severe TBI	Systematic Review	Children and adults with severe TBI (433 patients across 21 papers)	Endotracheal suctioning (ETS) effects on ICP and CPP	Majority of papers demonstrated increased ICP following ETS. Paediatric-specific evidence was extremely limited, dated, and inconclusive. Further research is needed on ETS effects in children with severe TBI.
6	Martinon C et al. (2011)	Scene emergency intubation in paediatric TBI	Observational Study (Pre-Post)	296 children aged 2–15 years with severe TBI (GCS ≤ 8)	Scene RSI, guideline implementation, ventilation control	Guideline implementation increased RSI standardisation and reduced immediate complications from 25% to 8%. However, 70% of patients arrived with PaCO <sub>2</sub> outside the target range of 35–40 torr, indicating persistent challenges in transport ventilation.
7	Jeong J et al. (2020)	Modified ivy loop for ET tube securing in facial burns	Case Report / Technical Note	Child with facial burn	Modified ivy loop method for endotracheal tube stabilisation	Describes a practical, rapid method to secure an endotracheal tube using a modified ivy loop when traditional tape-based methods are unsuitable due to facial wounds or burns.
8	Holscher CM et al. (2014)	Early vs. late tracheostomy in paediatric trauma	Retrospective Cohort Study	91 paediatric trauma patients undergoing tracheostomy	Early tracheostomy (≤7 days post-injury) vs. late tracheostomy (>7 days)	Early tracheostomy was associated with significantly fewer ventilator days (p=0.003), ICU days (p=0.003), hospital days (p=0.046), and tracheal complications (p=0.03). No significant difference in pneumonia rates between groups (p=0.48).
9	Kang KT et al. (2024)	Trends in paediatric tracheostomy in Taiwan	Population-Based Retrospective	2,465 paediatric patients (<18 years)	Paediatric tracheostomy trends, indications,	Incidence decreased from 3.3 to 2.1 per 100,000. Infant proportion increased (22.8% to 32.5%). ICU stays

			Survey	undergoing tracheostomy (2000–2019)	and outcomes	increased from 30 to 50 days. Five-year mortality declined from 38.0% to 31.0%.
10	Eskildsen SJ et al. (2024)	Factors affecting time to decannulation after TBI	Retrospective Registry Cohort Study	324 subjects with moderate/severe TBI and tracheostomy	Time to decannulation, swallowing ability, sensorimotor and cognitive function	Improved swallowing ability during initial 4 weeks was associated with an 8.2-day reduction in time to decannulation. Pneumonia was associated with a 24.4-day increase. Cognitive improvement did not significantly affect decannulation timing.
11	Padayachy LC et al. (2012)	Point prevalence vs. cumulative burden of reduced PbtO <sub>2</sub> in paediatric TBI	Retrospective Cohort Study	87 children with severe TBI receiving PbtO <sub>2</sub> monitoring	Brain tissue oxygenation (PbtO <sub>2</sub> ) monitoring — point prevalence vs. cumulative burden	Point prevalence of reduced PbtO <sub>2</sub> (<10 mmHg) at 24 h was 10%; at 72 h was 0%. Cumulative burden analysis revealed that 50% of patients experienced PbtO <sub>2</sub> episodes <10 mmHg, and 88% experienced episodes <20 mmHg. Point-in-time monitoring substantially underestimates hypoxic burden.

**6.3 Risk of Bias Assessment**

Risk of bias was assessed for each included study across relevant domains according to study design. Table 2 summarises the risk of bias ratings by domain and overall assessment. The majority of included studies demonstrated a moderate risk of bias, primarily due to retrospective designs, reliance on administrative data, single-centre recruitment, and insufficient control for confounding

variables. The clinical practice guideline (Kochanek et al., 2019) received the lowest overall risk of bias rating due to its transparent methodology, multi-institutional development, and evidence-based consensus approach. The case report (Jeong et al., 2020) received the highest risk of bias rating owing to its single-patient design, purely descriptive nature, and limited generalisability.

**Table 2. Risk of Bias Assessment by Study Domain**

Authors (Year)	Study Design	Domain 1	Domain 2	Domain 3	Domain 4	Domain 5	Domain 6	Overall Risk
Amin & Fitton (2003)	Narrative Review	Selection: N/A	Reporting: Low	Publication: Unclear	Author: Low	Currency: High (dated 2003)	N/A	Moderate
Kochanek et al. (2019)	Clinical Guideline	Evidence selection: Low	Consensus process: Low	Transparency: Low	COI: Low	Applicability: Low	N/A	Low
van Sambeek et al. (2019)	Cross-Sectional	Selection: Low	Performance: Low	Detection: Low	Attrition: Low	Confounding: Moderate	Measurement: Low	Low–Moderate
Cronin (2024)	Narrative Review	Selection: N/A	Reporting: Moderate	Publication: Unclear	Author: Low	Currency: Low	N/A	Moderate
Tume & Jinks (2008)	Systematic Review	Search: Low	Selection: Low	Quality assessment: High	Publication: Unclear	Synthesis: Moderate	Currency: High	Moderate–High
Martino et al.	Observational (Pre-	Selection:	Performance: Low	Detection: Low	Attrition: Low	Confounding:	Measurement: Low	Moderate

(2011)	Post)	Moderate				Moderate		
Jeong et al. (2020)	Case Report	Selection: High	Reporting: High	Publication: Unclear	Author: Moderate	Applicability: High	N/A	<b>High</b>
Holscher et al. (2014)	Retrospective Cohort	Selection: Moderate	Performance: Low	Detection: Low	Attrition: Low	Confounding: Moderate	Measurement: Low	<b>Moderate</b>
Kang et al. (2024)	Population-Based Retrospective	Selection: Low	Performance: N/A	Detection: Moderate	Attrition: Low	Confounding: Low	Measurement: Moderate	<b>Moderate</b>
Eskildsen et al. (2024)	Registry Cohort	Selection: Low	Performance: Low	Detection: Low	Attrition: Low	Confounding: Moderate	Measurement: Low	<b>Low-Moderate</b>
Padayachy et al. (2012)	Retrospective Cohort	Selection: Moderate	Performance: Low	Detection: Low	Attrition: Moderate	Confounding: Moderate	Measurement: Low	<b>Moderate</b>

Colour key: Green = Low / Low-Moderate risk; Yellow = Moderate risk; Red = Moderate-High / High risk

**Table 3. Risk of Bias Summary by Study Design**

Study Design	n	Low	Low-Moderate	Moderate	Moderate-High	High	Ref(s)
Clinical Practice Guideline	1	1	0	0	0	0	2
Cross-Sectional Study	1	0	1	0	0	0	3
Narrative Review	2	0	0	2	0	0	1, 4
Systematic Review	1	0	0	0	1	0	5
Observational (Pre-Post)	1	0	0	1	0	0	6
Retrospective Cohort	3	0	0	3	0	0	8, 11
Registry-Based Cohort	1	0	1	0	0	0	10
Population-Based Retrospective	1	0	0	1	0	0	9
Case Report / Technical Note	1	0	0	0	0	1	7

**6.4 Key Findings by Theme**

**6.4.1 Provider Competence in Endotracheal Intubation**

van Sambeek and colleagues (2019) compared the endotracheal intubation performance of 52 paediatricians and 52 anaesthetists on simulated neonatal and paediatric manikins. Anaesthetists achieved significantly superior outcomes across nearly all metrics, including time to successful intubation, number of attempts, and complication rate. For neonatal intubation, 100% of anaesthetists were rated as sufficiently adept compared to 65% of paediatricians. The performance gap widened substantially for paediatric intubation: only 15% of paediatricians achieved sufficient ability ratings versus 94% of anaesthetists. Of note, 29% of paediatricians overestimated their performance, while 33% of anaesthetists underestimated their own proficiency.

**6.4.2 Guideline Implementation and Emergency Intubation**

Martinon and colleagues (2011) evaluated scene emergency tracheal intubation in 296 children with severe TBI (GCS ≤ 8) before and after national guideline implementation. Guideline implementation increased scene intubation rates from 88% to 100% and drove significant changes in rapid

sequence intubation practice: succinylcholine use rose from 10% to 80%, while opioid use decreased from 70% to 36% and nondepolarising muscle relaxant use fell from 20% to 0%. The recommended protocol of etomidate and succinylcholine was applied in 64% of cases following guideline implementation, compared to 2.8% prior. Immediate complications upon tube insertion decreased from 25% to 8% (p=0.0015). Despite these improvements, 70% of patients arrived with PaCO<sub>2</sub> outside the target range of 35–40 torr, indicating persistent challenges in ventilation management during pre-hospital transport.

**6.4.3 Tracheostomy Timing and Clinical Outcomes**

Holscher and colleagues (2014) conducted a retrospective review of 91 paediatric trauma patients undergoing tracheostomy at a single centre over a 10-year period (2002–2012). Early tracheostomy was defined as occurring on or before post-injury day 7. Among patients under 12 years of age, 38% received early tracheostomy; among those aged 13–18 years, 52% underwent early tracheostomy. Patients in the early tracheostomy group experienced significantly fewer ventilator days (p=0.003), ICU days (p=0.003), hospital days (p=0.046), and tracheal complications (p=0.03) compared to the late tracheostomy group. There

was no significant difference in pneumonia rates between groups ( $p=0.48$ ). These findings provide the most direct evidence supporting early tracheostomy in the paediatric trauma population.

#### 6.4.4 Population-Level Trends in Paediatric Tracheostomy

Kang and colleagues (2024) analysed 2,465 paediatric patients who underwent tracheostomy in Taiwan between 2000 and 2019 using a national health insurance database. The overall incidence of paediatric tracheostomy declined from 3.3 to 2.1 per 100,000 individuals ( $p$  for trend  $<0.001$ ). The proportion of infants receiving tracheostomy increased from 22.8% in 2000–2004 to 32.5% in 2015–2019 ( $p$  for trend  $=0.06$ ). Tracheostomy procedures were increasingly performed at tertiary medical centres, rising from 74.7% to 81.0% of cases ( $p$  for trend  $=0.003$ ). Trauma or brain injury as a surgical indication decreased from 36.6% to 28.7% over the study period ( $p$  for trend  $=0.001$ ). ICU length of stay increased from a median of 30 days to 50 days ( $p$  for trend  $<0.001$ ), and total hospital stay increased from 58 to 71 days ( $p$  for trend  $=0.001$ ). Five-year mortality declined modestly from 38.0% in 2000–2004 to 31.0% in 2010–2014 ( $p$  for trend  $=0.006$ ).

#### 6.4.5 Factors Affecting Decannulation

Eskildsen and colleagues (2024) performed a registry-based retrospective cohort study of 324 subjects with moderate or severe TBI and tracheostomy from the Danish Head Trauma Database. The median time to decannulation was 44 days. Improvement in swallowing ability during the first four weeks of rehabilitation was associated with an 8.2-day reduction in time to decannulation (95% CI  $-12.3$  to  $-4.2$ ;  $p<0.001$ ). Improvement in sensorimotor ability was associated with a 0.94-day reduction in decannulation time (95% CI  $-0.78$  to  $-0.10$ ;  $p=0.03$ ). Pneumonia was associated with the most substantial delay, adding 24.4 days to decannulation time (95% CI  $15.9$ – $32.9$ ;  $p<0.001$ ). Change in cognitive abilities during rehabilitation did not significantly affect time to decannulation ( $p=0.66$ ).

#### 6.4.6 Brain Tissue Oxygenation Monitoring

Padayachy and colleagues (2012) examined the frequency of reduced brain tissue oxygenation ( $PbtO_2$ ) in 87 children with severe TBI at a single tertiary neurosurgical centre. Using hourly  $PbtO_2$  recordings with a critical threshold of 10 mmHg, they compared point-prevalence estimates at fixed time points with cumulative burden measured over the entire monitoring period. Point prevalence of reduced  $PbtO_2$  at 24 hours post-injury was 10%, declining to 0% at 72 hours. However, cumulative burden analysis revealed a substantially different picture: 50% of patients experienced at least one episode of  $PbtO_2$  below 10 mmHg, and 88% experienced episodes below 20 mmHg during the monitoring period. These findings demonstrate that point-in-time measurements significantly underestimate the true

frequency and duration of hypoxic events in paediatric TBI, underscoring the necessity of continuous oxygenation monitoring.

#### 6.4.7 Effects of Endotracheal Suctioning

Tume and Jinks (2008) conducted a systematic review of 21 papers encompassing 433 patients examining the effects of endotracheal suctioning on intracranial pressure and cerebral perfusion pressure in severe TBI. The majority of studies demonstrated transient increases in intracranial pressure following endotracheal suctioning. However, paediatric-specific evidence was extremely limited, largely dated, and inconclusive, with contradictory findings across studies regarding recovery trajectories. The authors identified significant gaps in the evidence, particularly regarding the impact of confounding variables such as sedation protocols, suctioning technique, and catheter type in the paediatric context.

#### 6.4.8 Clinical Guidelines and ICU Management Algorithms

Kochanek and colleagues (2019) formulated an evidence-based treatment algorithm for the ICU management of paediatric severe TBI based on the 2019 guidelines and expert consensus. The first-tier interventions focus on preventing and treating intracranial hypertension, optimising cerebral perfusion pressure, and monitoring brain tissue oxygenation. When first-tier measures are insufficient, second-tier interventions are escalated, including decompressive craniectomy, barbiturate infusion, late hypothermia, induced hyperventilation, and hyperosmolar therapies. This tiered algorithm provides a structured, evidence-grounded framework for bedside practitioners managing children with severe TBI. Cronin (2024) further emphasised the multidisciplinary nature of effective paediatric TBI management, including mechanical ventilation strategy, temperature control, continuous EEG monitoring, and long-term rehabilitation.

#### 6.4.9 Home Mechanical Ventilation for Chronic Respiratory Failure

Amin and Fitton (2003) traced the historical evolution of home mechanical ventilation for ventilator-dependent children, identifying chronic respiratory failure — defined by hypoxemia or hypercapnia persisting for more than one month — as the primary indication. The review highlighted the critical role of multidisciplinary care teams, encompassing physicians, nurses, respiratory therapists, and social workers, in supporting families managing ventilated children at home. Although this review predates many technological and clinical advances, it establishes an important foundational context for understanding long-term airway management needs in children who do not achieve decannulation following critical illness.

## 6.5 Summary of Key Quantitative Findings

**Table 4. Summary of Key Quantitative Results**

Study	Key Finding	Effect Size / Proportion	p-value
van Sambeek et al. (2019)	Anaesthetists sufficiently adept for paediatric ETI	94% vs. 15%	NR
van Sambeek et al. (2019)	Anaesthetists sufficiently adept for neonatal ETI	100% vs. 65%	NR
Martinon et al. (2011)	Immediate complications – after vs. before guideline implementation	8% vs. 25%	0.0015
Holscher et al. (2014)	Early tracheostomy – reduction in ventilator days	Significant reduction	0.003
Holscher et al. (2014)	Early tracheostomy – reduction in ICU days	Significant reduction	0.003
Holscher et al. (2014)	Early tracheostomy – reduction in hospital days	Significant reduction	0.046
Holscher et al. (2014)	Early tracheostomy – reduction in tracheal complications	Significant reduction	0.030
Kang et al. (2024)	Paediatric tracheostomy incidence change (2000–2019)	3.3 → 2.1 per 100,000	<0.001
Kang et al. (2024)	Five-year mortality reduction	38.0% → 31.0%	0.006
Eskildsen et al. (2024)	Swallowing improvement – reduction in decannulation time	8.2 days	<0.001
Eskildsen et al. (2024)	Pneumonia – delay in decannulation time	+24.4 days	<0.001
Padayachy et al. (2012)	Patients with PbtO <sub>2</sub> <10 mmHg (cumulative burden)	50%	NR
Padayachy et al. (2012)	Patients with PbtO <sub>2</sub> <20 mmHg (cumulative burden)	88%	NR

## 7. DISCUSSION

This systematic review synthesises evidence from eleven studies examining paediatric airway management across acute, intensive care, pre-hospital, rehabilitative, and home care settings. Although the heterogeneity of included study designs and outcome definitions precluded formal meta-analysis, the narrative synthesis reveals several clinically meaningful patterns that carry important implications for practice and future research.

### Provider Expertise and Airway Management Proficiency

The findings of van Sambeek and colleagues (2019) present a compelling and concerning disparity in endotracheal intubation competence between paediatricians and anaesthetists in simulated settings. With only 15% of paediatricians demonstrating sufficient proficiency for paediatric intubation compared to 94% of anaesthetists, the data strongly support the need for clearly defined interprofessional agreements regarding paediatric airway management responsibilities in acute care settings. The finding that nearly one-third of paediatricians overestimated their own performance further highlights the importance of simulation-based training and objective competency assessment.

### Impact of Standardised Guidelines on Emergency Intubation

The pre-post study by Martinon and colleagues (2011) demonstrates that the implementation of national guidelines substantially improved the standardisation of rapid sequence intubation practice in the pre-hospital setting, reducing immediate procedural complications from 25% to 8%. However, the observation that 70% of patients arrived at hospital with PaCO<sub>2</sub> values outside the target range reveals a critical unmet need in transport ventilation management. These findings suggest that while guideline

implementation can effectively standardise procedural practice, the more dynamic aspect of ongoing ventilation management during transport requires dedicated monitoring tools and additional training. This aligns with broader evidence that protocol adherence and real-time feedback mechanisms are necessary adjuncts to guideline implementation alone.

### Early Tracheostomy and Clinical Benefits

The retrospective cohort study by Holscher and colleagues (2014) provides the most direct evidence regarding tracheostomy timing in paediatric trauma patients. Early tracheostomy was associated with significant reductions in ventilator days, ICU length of stay, hospital stay, and tracheal complications, without an increase in pneumonia rates. These findings are broadly consistent with evidence from adult TBI populations supporting early tracheostomy. The absence of a statistically significant difference in pneumonia rates between early and late tracheostomy groups is noteworthy, as pneumonia prevention is often cited as a potential benefit of earlier airway securing. The retrospective single-centre design limits the generalisability of these findings, and the study did not directly measure hypoxia as an outcome. Nonetheless, the reduction in ventilator duration and tracheal complications associated with early tracheostomy supports its consideration as a standard component of the airway management algorithm for children likely to require prolonged ventilatory support.

### Population-Level Trends and Changing Indications

The national data from Kang and colleagues (2024) document a shifting epidemiological landscape of paediatric tracheostomy in Taiwan over two decades. The declining overall incidence alongside an increasing proportion of infants undergoing tracheostomy reflects a changing case mix, with a trend away from trauma-related indications (36.6% to 28.7%) towards chronic conditions and

neurodevelopmental diagnoses. The modest reduction in five-year mortality (38.0% to 31.0%) despite longer ICU and hospital stays suggests improved survival but increased complexity and acuity of patients receiving tracheostomy. These trends have important implications for resource allocation, caregiver training, and the infrastructure needed to support long-term ventilation management in the paediatric population.

#### **Decannulation and Rehabilitation Outcomes**

The registry-based study by Eskildsen and colleagues (2024) identifies swallowing ability and pneumonia as the most significant modifiable determinants of time to decannulation following TBI. The association between swallowing improvement during early rehabilitation and an 8.2-day reduction in decannulation time highlights the importance of early, targeted dysphagia rehabilitation. Conversely, pneumonia — a known complication of prolonged intubation — added over three weeks to decannulation time, further reinforcing the potential benefit of early tracheostomy in facilitating airway management and reducing infection risk. These findings underscore the value of multidisciplinary rehabilitation teams that prioritise swallowing assessment and targeted dysphagia intervention in the post-acute period.

#### **Hypoxia Monitoring and the Limitation of Point-in-Time Assessment**

Padayachy and colleagues (2012) provide a particularly compelling insight into the underestimation of hypoxic burden when relying on point-in-time PbtO<sub>2</sub> measurements. The marked discrepancy between point prevalence (10% at 24 hours) and cumulative burden (50% of patients experiencing PbtO<sub>2</sub> <10 mmHg over the full monitoring period) demonstrates that standard measurement practices may substantially obscure the frequency and clinical significance of cerebral hypoxic events in paediatric TBI. This finding reinforces the importance of continuous, rather than intermittent, brain tissue oxygenation monitoring in this population and provides a methodological caution for the design and interpretation of future studies.

#### **Home Ventilation and Long-Term Considerations**

The foundational review by Amin and Fitton (2003), while dated, contextualises the trajectory of long-term ventilation in children and underscores the importance of considering the post-acute care continuum when making airway management decisions in the acute setting. Children who do not achieve decannulation following TBI-related critical illness may transition to long-term home mechanical ventilation, a pathway that carries significant implications for family burden, healthcare utilisation, and quality of life.

#### **Limitations**

This review has several limitations that must be acknowledged. First, the heterogeneity of included study designs, populations, and outcome definitions precluded formal meta-analysis and limits the strength of pooled conclusions. Second, the majority of included studies are

retrospective in design, with associated risks of selection bias and unmeasured confounding. Third, no included study directly compared early tracheostomy with late tracheostomy or prolonged intubation using hypoxia as the primary outcome in an exclusively paediatric TBI population, which represents the central gap this review sought to address. Fourth, while the search was conducted across three major databases with supplementary reference searching, the restriction to a specific date range may have excluded relevant earlier studies. These limitations highlight the urgent need for prospective, adequately powered studies with standardised outcome definitions in this population.

#### **8. CONCLUSION**

This systematic review synthesises evidence from eleven studies examining paediatric airway management in the context of traumatic brain injury, and yields several conclusions with direct implications for clinical practice and future research.

#### **Provider expertise critically determines patient safety during airway procedures**

The substantial gap in endotracheal intubation proficiency between anaesthetists and paediatricians in simulated settings underscores the need for clearly defined interprofessional protocols designating the most qualified providers for paediatric and neonatal intubation in acute and emergency care settings.

#### **Early tracheostomy (≤7 days) offers meaningful clinical benefits in paediatric trauma patients**

Evidence from the included retrospective cohort study indicates that early tracheostomy significantly reduces ventilator days, ICU stay, hospital stay, and tracheal complications without increasing the risk of pneumonia. Clinicians should consider early tracheostomy as a standard element of the airway management algorithm for paediatric patients with severe TBI anticipated to require prolonged mechanical ventilation.

#### **Continuous brain tissue oxygenation monitoring is essential to capture the true burden of hypoxia**

Point-in-time measurements substantially underestimate the frequency and duration of hypoxic events in paediatric TBI. Continuous PbtO<sub>2</sub> monitoring should be integrated into standard neurocritical care protocols to ensure timely identification and management of cerebral hypoxia.

#### **Guideline implementation improves procedural standardisation but is insufficient alone**

National guideline implementation significantly improved rapid sequence intubation practice and reduced procedural complications in the pre-hospital setting. However, ventilation management during transport remains suboptimal, suggesting that guideline adherence must be accompanied by real-time monitoring and targeted training to achieve optimal outcomes.

**Swallowing rehabilitation and pneumonia prevention are key determinants of decannulation**

Early dysphagia assessment and intervention, combined with proactive pneumonia prevention strategies, should be prioritised in the post-acute rehabilitation of paediatric patients with tracheostomy following TBI to facilitate safe and timely decannulation.

**Significant evidence gaps remain**

No included study directly examined the effect of early tracheostomy on hypoxia as the primary outcome in an exclusively paediatric TBI population. Future prospective, multicentre studies with standardised outcome definitions — specifically incorporating hypoxia as a primary outcome — are essential to establish definitive evidence-based guidance on tracheostomy timing in this vulnerable population. Such studies should include diverse age groups, injury severity strata, and long-term follow-up measures of neurological outcome to comprehensively characterise the benefits and risks of early airway intervention in paediatric traumatic brain injury.

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