Prediction of tracheostomy in critically ill trauma patients: a systematic review

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ABSTRACT

Background: Tracheostomy is relatively common in mechanically ventilated patients in the intensive care unit (ICU). The prediction of which patients will receive a tracheostomy is crucial to both clinical decision making and the design of targeted interventional trials of its timing.
Objectives: We aimed to systematically review the literature to ascertain whether useful predictors of eventual tracheostomy can be identified, with a particular focus on trauma patients.
Data sources and review methods: We searched three electronic databases to identify all studies of any design evaluating potential predictors of tracheostomy in mechanically ventilated ICU patients. Bias was assessed using the Quality in Prognosis Studies tool.
Results: Of 140 potentially eligible studies, we identified 12 relevant observational studies recruiting a total of 119 945 mechanically ventilated patients, of whom 14 080 (11.7%) received a tracheostomy. Seven studies were performed in trauma populations and included 24 858 patients, of whom 6140 (24.7%) received a tracheostomy. Factors predictive of receiving a tracheostomy in the trauma population included patient factors (age and comorbidities), diagnostic factors (injury type and injury severity score), and intervention factors (craniotomy or laparotomy). Profound clinical and methodological heterogeneity prevented meaningful meta-analysis. Significantly, more predictors were present on the day of admission in trauma populations than in non-trauma patients with brain injury and in other populations (89.7% *v* 73.3% *v* 25.0%).
Conclusion: There are a number of clinical factors associated with subsequent tracheostomy in mechanically ventilated patients, in particular trauma patients. Given the need to prevent patients from receiving an unnecessary tracheostomy, these findings indicate that better predictive models are needed before the conduct of interventional trials.
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Tracheostomy is performed in up to 11% of all mechanically ventilated, critically ill patients[1-3] and in up to 26% of mechanically ventilated patients with moderate to severe traumatic brain injury.[4]

Tracheostomy has been associated with improved patient comfort, reduced use of sedation, and shorter durations of mechanical ventilation and hospital stay.[5-7] However, during insertion, there is the risk of hypoxia; bleeding; damage to the trachea, larynx and oesophagus; and death.[8,9] Tracheostomy may also be associated with serious medium and long term complications, such as accidental decannulation, tracheal stenosis, tracheomalacia and vascular erosion.[10]

Unfortunately, there is limited guidance in the critical care literature about which patients are most likely to benefit from tracheostomy, and whether the timing of tracheostomy insertion affects patient-centred outcomes. At present, early prediction of who will receive a tracheostomy in the intensive care unit (ICU) is based on the clinical judgment of the attending clinicians. Such judgement has been repeatedly shown to be of limited accuracy in randomised controlled trials of early versus late tracheostomy, including in trauma patients (online Appendix, E1, available at cicm.org.au/Resources/Publications/Journal).[5,11-16]Logically, being able to accurately predict who will eventually receive a tracheostomy within the first few days of that ICU admission is an important step toward better randomised controlled trials and may minimise the risk of patients receiving an unnecessary intervention.

Accordingly, we systematically reviewed the literature to ascertain whether useful prediction rules or validated scores to predict eventual tracheostomy can be identified to better inform patient care and clinical trial design. We particularly focused on patients admitted after trauma.

We specifically aimed to identify independent predictors of subsequent tracheostomy in mechanically ventilated, critically ill trauma patients on multivariable regression analysis by identifying and reviewing all studies describing prognostic factors associated with subsequent tracheostomy in this patient population.

Methods

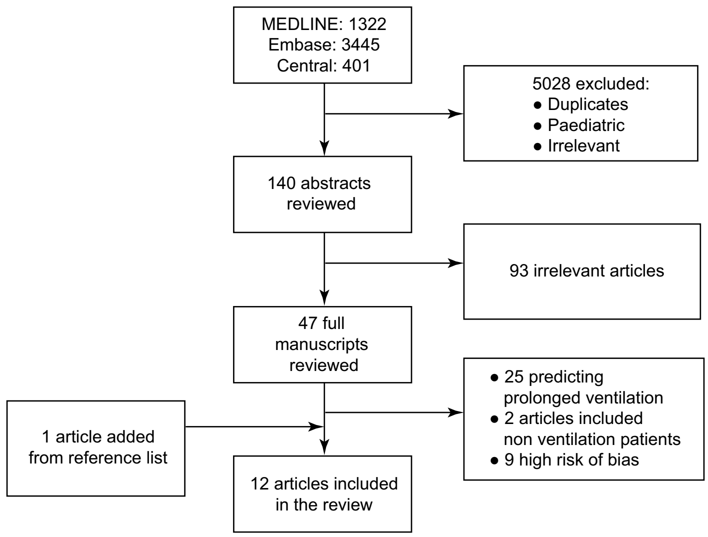
Our systematic review was registered with the PROSPERO International Registry of Systematic Reviews (registration no. CRD42018084987).

Electronic search strategy

We interrogated the MEDLINE, CENTRAL and EMBASE electronic reference databases using a combination of search terms, from 1960 to December 2017 (online Appendix, E2 and E3). In addition, biographies of retrieved articles were examined for references of potential relevance. Results were limited to English language, humans and adults. We included all mechanically ventilated patients in our search to minimise the risk of missing trauma-specific studies.

Two investigators (AJC and BB) carried out the initial search and subsequent study selection. After title screening, we evaluated abstracts for potential relevance. Following this, the manuscripts were retrieved and examined manually in accordance with our inclusion and exclusion criteria. If there was difference in opinion regarding a study's suitability for inclusion, a third investigator (NJG) was consulted and a final decision made. The studies to be included were reviewed to ensure they had not been retracted after their publication.

Figure 1. CONSORT diagram of the study selection



Study inclusion criteria

Studies were eligible if they evaluated potential predictors of tracheostomy in mechanically ventilated ICU patients. There was no restriction on study design. We excluded studies that evaluated predictors of prolonged ventilation as a surrogate for tracheostomy insertion because of variable definitions of "prolonged ventilation" ranging from 24 hours in patients with cardiac surgery to 21 days in other patients.[17-24]

Assessment of risk of bias

Two authors (AJC and BB) assessed the risk of bias independently. Since all the studies were non-randomised and had a cohort design, the Quality in Prognosis Studies (QUIPS) tool was used.[25,26] Articles that had a high risk of bias in any of the domains were not included in the final analysis.[25] Studies that had a low risk of bias in all domains were considered low risk of bias and all other studies were considered intermediate risk of bias and included in the final analysis.

Data collection

We collected data on study type, setting, location and population. We included only factors that were predictive of tracheostomy on multivariable regression analysis; however, we still noted factors present on univariate analysis.

Statistical analysis

We expected heterogeneous results across different patient groups and therefore a meta-analysis approach was not applied. Results are presented in a descriptive manner, with stratification according to patient study group. In particular, we stratified results into trauma patients, patients with non-traumatic neurological injury (hypoxic brain injury, stroke and spontaneous haemorrhage) and all other ICU patients (non-traumatic and no neurological injury).

Odds ratios or relative risk and 95% confidence intervals (CIs) are presented as published in each study. When odds ratios or relative risks were not supplied, they were calculated using data provided and presented as odds ratio or relative risk with 95% CIs.

Results

Electronic search

We identified 5168 articles: 5028 were excluded as duplicates, referent to a paediatric population, or otherwise irrelevant. Of the 140 potentially relevant studies, 12 studies meeting our inclusion criteria were included in the final analysis (Figure 1)[1,27-37] after reviewing 47 studies[1,20-22,27-36,38-70] in full text.

Study details

We included 12 studies reporting on a total of 119 945 mechanically ventilated patients, of whom 14 080 (11.7%) received a tracheostomy. Seven trials involved trauma patients, including one trial focused on patients with cervical spine trauma.[27,29,31-33,36,37] These included 24 858 patients, of which 6140 (24.7%) received a tracheostomy. Ten of the studies were retrospective in nature.[27-34,36,37] Study details and patient demographics are included in Table 1. Risk of bias for each study in each of the six domains is presented in the online Appendix (E4).

Table 1. Description of studies included

Author	Year	Setting	Patients	Study	Study period	*n*	Tracheostomy (%)	Group	Male (%)	Age*	Illness severity*
Kollef et al[1]	1999	University-affiliated urban hospital, US	All ICU patients	Prospective	1996	521	51 (9.7%)	Tracheostomy	64.7%	53.1 ± 20.6	APACHE II: 19.2 ± 6.1
								No tracheostomy	52.3%	57.9 ± 19.7	APACHE II: 17.8 ± 7.2
Gurkin et al[27]	2002	Level I urban hospital, US	Trauma patients with head injury	Retrospective	1994–2000	246	35 (14.2%)	Tracheostomy	74.2%	37.4 ± 18.5	ISS: 30.5 ± 8.6
								No tracheostomy	81.9%	33.9 ± 21.3	ISS: 20.8 ± 9.5
Padia et al[28]	2003	University-affiliated hospital, US	Lung transplant patients	Retrospective	1993–2001	114	16 (14%)	Tracheostomy	56.2%	42 ± 16	na
								No tracheostomy	42.9%	49 ± 14	na
Goettler et al[37]	2006	University-affiliated level I trauma centre, US	Trauma patients	Retrospective	1994–2004	992	430 (43.3%)	Tracheostomy	N/A	45.6 ± 18.8	ISS: 30.3 ± 12.5
								No tracheostomy	N/A	36.7 ± 15.9	ISS: 22 ± 10.3
Nathens et al[29]	2006	National trauma databank, US	Trauma patients	Retrospective	2001–2003	17 523	4146 (23.6%)	Tracheostomy	73.5%	na	na
								No tracheostomy	72.8%	na	na
Szeder et al[30]	2010	University-affiliated tertiary hospital, US	Patients with supratentorial intracranial haemorrhage	Retrospective	1998–2000	41	18 (43.9%)	Tracheostomy	55%	62.4 ± 3.3	na
								No tracheostomy	52%	58.8 ± 3.9	na
Branco et al[31]	2011	National trauma databank, US	Patients with cervical spine injury trauma	Retrospective	2002–2006	5256	1082 (20.5%)	Tracheostomy	79.2%	41.8 ± 20.1	ISS: 33.5 ± 17.7
								No tracheostomy	74.3%	43.7 ± 20.9	ISS: 24.4 ± 16.2
Shamim et al[32]	2011	University-affiliated level I trauma centre, Pakistan	Head injured trauma post-decompressive craniectomy	Retrospective	2004–2009	98	58 (59.1%)	Tracheostomy	na	37.7 ± 17.9	RTS: 9.4 ± 1.5
								No tracheostomy	na	26.8 ± 17	RTS: 9.7 ± 1.6
Huang et al[33]	2013	University-affiliated acute care medical centre, Taiwan	Head injured trauma post-decompressive craniectomy	Retrospective	2006–2008	160	39 (24.3%)	Tracheostomy	63.2%	52 ± 20	ISS: 29 ± 7
								No tracheostomy	73%	42 ± 20	ISS: 26 ± 9
Allareddy et al[34]	2015	National inpatient sample, US	Post in-hospital cardiac arrest with hypoxic brain injury	Retrospective	2004–2010	94 336	7829 (8.3%)	Tracheostomy	na	na	na
								No tracheostomy	na	na	na
Schönenberger et al[35]	2016	University-affiliated hospital, Germany	Patients with ischaemic stroke, intracranial haemorrhage or subarachnoid haemorrhage	Prospective	Unknown	75	26 (34.6%)	Tracheostomy	65.4%	60.3 ± 15.5	NIHSS score: 16.5 ± 12.6
								No tracheostomy	59.2%	66.2 ± 12.6	NIHSS score: 14.9 ± 7.9
Humble et al,[36] median (IQR)	2016	University-affiliated level I trauma centre, US	Trauma patients with severe brain injury	Retrospective	2000–2011	583	350 (60%)	Tracheostomy	73%	37 (24–52)	ISS: 34 (27–41)
								No tracheostomy	76%	36 (24–53)	ISS: 34 (26–41)

APACHE = Acute Physiology and Chronic Health Evaluation. IQR = interquartile range. ISS = Injury Severity Score. RTS = Revised Trauma Score. na = not available. NIHSS = National Institutes of Health Stroke Scale. US = United States. *Results presented are presented in mean ± standard deviation unless otherwise stated.

Table 2. Factors associated with tracheostomy by multivariate analysis for trauma patients

Study	Year published	Group	Risk of bias	Factors multivariate (logistic regression) analysis	Risk (95% CI)	Timing of factor
Gurkin et al[27]	2002	Trauma patients with head injury	Intermediate	Ventilator days > 7	OR 21.45 (7.3–63.5)	After Day 7
				ISS ≥ 25	OR 7.2 (2.9-18.1)	Day 0
				Presenting GCS ≤ 8	OR 3.4 (1.5-7.9)	Day 0
Goettler et al[37]	2006	General trauma patients	Intermediate	Damage control laparotomy	OR 3.8*	Day 0
				Craniotomy	OR 2.6*	Not described
				Older age	OR 2.1, for 18-year increments*	Day 0
				Higher ISS	OR 2.1, for 12-unit increments*	Day 0
				ICP monitor	OR 2.1*	Not described
				Lower Pao_2/Fio_2 ratio at 24 h	OR 0.7, for 138-unit increments*	Day 1
				Lower GCS at 24 h	OR 0.54, for 3-unit increments*	Day 1
Nathens et al[29]	2006	General trauma patients	Low	Higher ISS (*v* < 16)		
				‣ 25–47	RR 1.83 (1.63–2.04)	Day 0
				‣ 48–75	RR 1.69 (1.41–2.03)	Day 0
				‣ 16–24	RR 1.51 (1.35–1.68)	Day 0
				Coronary artery disease	RR 1.64 (1.52–1.78)	Day 0
				Severe spine injury (AIS ≥ 3)	RR 1.42 (1.25–1.61)	Day 0
				Age (*v* 16–24 years)		
				‣ 65–84 years	RR 1.42 (1.26–1.60)	Day 0
				‣ 56–64 years	RR 1.32 (1.16–1.51)	Day 0
				‣ 41–55 years	RR 1.20 (1.08–1.32)	Day 0
				‣ 25–40 years	RR 1.03 (1.03–1.14)	Day 0
				Obesity	RR 1.30 (1.01–1.67)	Day 0
				≥ 3 rib fractures	RR 1.22 (1.12–1.33)	Day 0
				Head injury (AIS ≥ 3)	RR 1.21 (1.11–1.32)	Day 0
				Spinal cord injury	RR 1.18 (1.00–1.41)	Day 0
				Chest injury (AIS ≥ 3)	RR 1.16 (1.07–1.26)	Day 0
				Male gender	RR 1.08 (1.01–1.16)	Day 0
				Abdominal injury (AIS ≥ 3)	RR 0.85 (0.77–0.94)	Day 0
				Brief coma	RR 0.79 (0.72–0.86)	Day 0
				Penetrating trauma *v* blunt	RR 0.73 (0.64–0.82)	Day 0
Branco et al[31]	2011	Trauma patients with cervical spine injury	Intermediate	Intubated in ED	OR 3.9 (3.2–4.8)	Day 0
				C5–C7 complete CSCI	OR 3.1 (2.6–3.8)	Day 0
				Intubated on scene	OR 2.8 (1.7–4.5)	Day 0
				ISS ≥ 16	OR 2.1 (1.5–2.8)	Day 0
				C1–C4 complete CSCI	OR 2.0 (1.6–2.6)	Day 0
				Facial fracture	OR 1.6 (1.3–2.1)	Day 0
				Thoracic injury	OR 1.3 (1.1–1.5)	Day 0

(*continued*)

Table 2. Factors associated with tracheostomy by multivariate analysis for trauma patients (continued)

Study	Year published	Group	Risk of bias	Factors multivariate (logistic regression) analysis	Risk (95% CI)	Timing of factor
Shamim et al[32]	2011	Trauma patients with head injury requiring decompressive craniectomy	Intermediate	≥ 2 comorbidities	OR 24 (10.7–54)	Day 0
				Age 31–50 years (*v* 0–15 years)	OR 16.5 (2.3–114)	Day 0
				Incident to arrival time 1.5–3 h	OR 9.2 (2.2–39)	Day 0
				Incident to arrival time > 3 h	OR 4.8 (1.2–18.9)	Day 0
				Abnormal pupillary response	OR 5.6 (1.84–17.3)	Day 0
				GCS 9–12 (*v* GCS 13–15)	OR 0.01 (0.002–0.4)	Day 0
Huang et al[33]	2013	Trauma patients with head injury requiring decompressive craniectomy	Intermediate	Increasing age (per year increase age)	OR 1.04 (1.02–1.07)	Day 0
				GCS on admission (per unit increase in GCS)	OR 0.73 (0.59–0.91)	Day 0
Humble et al[36]	2016	Trauma patients with severe traumatic brain injury	Intermediate	Age 30 *v* 20 years	OR 1.39 (1.05–1.84)	Day 0
				Age 50 *v* 40 years	OR 0.89 (0.79–1.00)	Day 0
				Age 60 *v* 50 years	OR 0.76 (0.62–0.92)	Day 0
				Age 70 *v* 60 years	OR 0.72 (0.57–0.90)	Day 0
				Age 80 *v* 70	OR 0.72 (0.57–0.90)	Day 0
				Insurance status private *v* none	OR 1.89 (1.09–3.23)	Day 0

AIS = Abbreviated Injury Scale. CSCI = cervical spinal cord injury. Day 0 = intensive care unit admission. ED = emergency department. Fio_2 = fraction of inspired oxygen GCS = Glasgow Coma Scale. ICH = intracerebral haemorrhage. ICP = intracranial pressure. ISS = Injury Severity Scale. OR = odds ratio. Pao_2 = arterial partial pressure of oxygen. RR = relative risk. * 95% CI not provided.

Predictors of tracheostomy

Table 2 and Table 3 list the independent predictors of tracheostomy in trauma patients and patients with non-traumatic neurological injury and their time course. Other ICU patients are presented in the online Appendix (E5). Factors identified as being significantly associated with subsequent tracheostomy on univariate analysis are tabulated in the online Appendix (E6).

Trauma patients

In the studies targeting trauma patients (with or without head injury, but not specifically targeting patients with cervical spine injury),[27,29,32,33,36,37] there were a total of 19 602 patients, of which 5058 (25.8%) required a tracheostomy. Factors that are independently predictive of receipt of a tracheostomy include increasing age, lower Glasgow Coma Scale (GCS) score, abnormal pupillary light response, higher Injury Severity Score (ISS) and medical or surgical comorbidities, such as obesity, significant chest injury, abdominal injury requiring laparotomy, and spinal cord injury (Table 3). Overall, 44/49 (89.7%) of predictive factors for subsequent tracheostomy in this population are present on the day of ICU admission. In a single centre, retrospective study of 992 consecutive admissions of intubated trauma patients, the authors provided those factors and scores associated with a 100%, ≥ 90% or ≥ 80% risk of tracheostomy.[37] These are presented in the online Appendix (E7). We stratified predictors of tracheostomy in trauma patients with head injury and general trauma patients. There was significant heterogeneity of study design and predictive factors, making it impossible to provide pooled data with appropriate statistical analysis (Table 4).

Non-traumatic brain injury

Three studies targeted patients who had non-traumatic brain injury due to stroke, intracranial haemorrhage or hypoxic brain injury after cardiac arrest.[30,34,35] These included 94 452 patients, of which 7873 (8.3%) received a tracheostomy. The first two studies provided measurable scores to predict tracheostomy; the details are presented in the online Appendix (E8 and E9). Factors included admission GCS score, size and site of haemorrhage or ischaemia, hydrocephalus and additional respiratory disease. Increasing age above 50 years had a negative predictive value. Twenty-two of 30 predictive factors (73.3%) were present on the day of admission.

Patients without brain injury

There were only two studies of patients without brain injury including 635 patients, of which 67 (10.6%) received a tracheostomy.[1,28] Only two of eight factors (25%) were present on the day of admission and these were related to surgical issues in the lung transplant group (online Appendix, E5).

Table 3. Factors associated with tracheostomy by multivariate analysis for non-traumatic brain injury

Study	Year published	Group	Risk of bias	Factors multivariate (logistic regression) analysis	Risk (odds ratio; 95% CI)	Timing of factor
Szeder et al[30]	2010	Supratentorial intracranial haemorrhage	Intermediate	GCS < 11 on Day 3	21 (2.3–242)	Day 3
				Hydrocephalus	12.5*	Day 0
				Thalamic haemorrhage	9*	Day 0
				Septum pellucidum shift	9*	Day 0
				Intraventricular haemorrhage	2.5*	Day 0
Allareddy et al[34]	2015	In-hospital cardiac arrest patients with anoxic/hypoxic ischaemic encephalopathy	Low	Race (*v* white)		
				‣ Black	2.05 (1.77–2.37)	Day 0
				‣ Hispanic	1.72 (1.43–2.07)	Day 0
				‣ Asian/Pacific Islander	1.91 (1.45–2.50)	Day 0
				‣ Other races	1.68 (1.21–2.34)	Day 0
				Teaching hospital	1.36 (1.20–1.54)	Day 0
				Comorbid burden (1 unit increase)	1.17 (1.13–1.20)	Day 0
				Hospital site (*v* West)		
				‣ Northeast	1.63 (1.37–1.95)	Day 0
				‣ South	0.85 (0.72–0.99)	Day 0
				Age 60–69 *v* 40–49 years	0.74 (0.62–0.89)	Day 0
				Age > 70 *v* 40–49 years	0.53 (0.45–0.63)	Day 0
Schönenberger et al[35]	2016	Patients with ischaemic stroke, intracranial haemorrhage or subarachnoid haemorrhage		Dysphagia	na†	Varied
				Observed aspiration	na†	Varied
				GCS on admission < 10	na†	Day 0
				Brainstem lesion	na†	Day 0
				Space occupying cerebellar lesion	na†	Day 0
				Ischaemic infarct > 2/3 MCA territory	na†	Day 0
				ICH volume > 25 mL	na†	Day 0
				Diffuse lesion	na†	Day 0
				Hydrocephalus	na†	Day 0
				Neurosurgical intervention	na†	Varied
				Additional respiratory disease	na†	Day 0
				Pao_2/Fio_2 < 150	na†	Varied
				APS (of APACHE II) > 20	na†	Day 1
				LIS > 1	na†	Varied
				Sepsis	na†	Varied

APACHE = Acute Physiology and Chronic Health Evaluation. APS = Acute Physiology Score. Day 0 = intensive care unit admission. Fio_2 = fraction of inspired oxygen. GCS = Glasgow Coma Scale. ICH = intracerebral haemorrhage. MCA = middle cerebral artery. Pao_2 = arterial partial pressure of oxygen. RR = relative risk. * 95% CI not provided; † Used to calculate the Stroke related Early Trachesotomy (SET) score.

Table 4. Factors stratified according to diagnostic group

Group	Total number	Patients with tracheostomy	Risk factors by multivariate regression analysis
Trauma patients with head injury[27,32,33,36]	1087	482 (44%)	Patient factors
			Age 31–50 years
			Multiple comorbidities
			Increasing age (until peak risk, then decreased risk as age increases)
			Private insurance status
			Clinical/diagnostic factors
			Lower presenting GCS
			Higher ISS
			Longer incident to arrival time
			Normal basal cisterns (negative association)
			Intervention factors
			Longer ventilation time
General trauma patients[29,37]	18 515	4576 (25%)	Patient factors
			Male
			Increasing age
			Pre-existing obesity
			Pre-existing coronary artery disease
			Clinical/diagnostic factors
			Higher ISS
			Severe head injury
			Severe chest injury
			Severe spinal cord injury
			Lower RTS
			Lower Pao_2/Fio_2 ratio
			Lower admission/24 h GCS
			Prolonged coma
			Penetrating trauma (negative association)
			Severe abdominal injury (negative association)
			Intervention factors
			Laparotomy requirement
			Craniotomy requirement
			Need for ICP monitor

Fio_2 = fraction of inspired oxygen. GCS = Glasgow Coma Scale. ICP = intracranial pressure. ISS = Injury Severity Scale. RTS = Revised Trauma Score. Pao_2 = arterial partial pressure of oxygen.

Discussion

Key findings

We performed the first systematic review of predictors of tracheostomy in mechanically ventilated ICU patients. We synthesised data from 12 studies, the majority of which were judged to be of intermediate risk of bias. We made several observations. We found that insufficient data exist in the general ICU population. Moreover, we found that the majority of the data pertain to trauma patients or patients with non-traumatic brain injury, with only a single study examining an undifferentiated ICU population. Finally, we found that, while a wide variety of factors on multivariable analysis were identified as being associated with tracheostomy, most were specific to trauma patients.

Relationship to previous studies

To our knowledge, this is the first systematic review of possible predictors of tracheostomy in ICU patients. The only directly relevant studies are those used in our systematic review. However, several groups have randomly allocated patients to receive tracheostomies "early" or "late" in their ICU admission, which included significant numbers of trauma patients[5,11-16] (online Appendix, E1). Such studies provide a clinically relevant perspective because they imply that all patients randomly allocated would have been considered by the treating clinicians to be extremely likely to receive a tracheostomy while in the ICU. As such, they provide an estimate of the positive predictive value of clinician judgment. Given that the percentage of patients in the "late" tracheostomy groups who actually received a tracheostomy ranged from 26% to 83%, it is clear that such judgment is imperfect and its positive predictive value is low.

Implications of study findings

Given the poor ability of clinicians to accurately predict who will receive a tracheostomy, the lack of data in the literature to support such clinical decision making, and that more than 10% of mechanically ventilated patients and up to 26% of patients with traumatic brain injury may undergo this procedure, our study suggests the need to develop predictive models for tracheostomy. Moreover, our study implies that different models incorporating different predictive factors will need to be developed depending on the diagnosis of the patient. There is potential to develop a prediction model in trauma patients using data presented in our review. In addition, although representing a different cohort of patients, there is some clinical crossover between patients who have had a traumatic brain injury and a non-traumatic brain injury. It is possible that factors predictive in the latter group can be incorporated into a prediction model for patients with a traumatic brain injury.

Strengths and limitations

This is the first systematic review of clinical factors predictive of tracheostomy. We have included data from almost 120 000 mechanically ventilated patients, of which almost 14 000 had a tracheostomy. We have included almost 25 000 trauma patients, of which about 6000 required a tracheostomy. Our wide search criteria and use of three separate sources minimised the risk of inclusion bias. We synthesised data from across the spectrum of critically ill patient populations to provide the most comprehensive exploration of the topic to date. The outcome we have studied — patients receiving a tracheostomy — is objective, and we used a validated tool to estimate bias in those studies assessed for inclusion in the review.[25,26]

Our study has a number of limitations. First, it is impossible to account for a variety of potential confounders given the heterogeneity of the data reported, the populations studied and the definitions used. The development of a consistent ontology regarding the consideration, initiation, timing and management of patients requiring a tracheostomy will be vital for further progress to be made in this area. Second, studies were excluded if they focused on predictors of prolonged mechanical ventilation as a surrogate for need for tracheostomy. It is possible that those factors or scores predicting prolonged mechanical ventilation will also predict the need for tracheostomy. In the absence of a generally accepted definition of prolonged ventilation, and given that the correlation between need for tracheostomy and such an undefined variable remains undescribed, we reasoned that inclusion of these studies would have made any data synthesis meaningless. Even by only including those studies examining patients receiving a tracheostomy, the methodological and clinical heterogeneity of the included studies made it impossible to combine data and provide an accurate statistical interpretation of factors present. However, we have made an attempt to summarise the data objectively in order to provide a platform for future predictive and intervention work. Finally, we have examined predictive factors for eventual tracheostomy in mechanically ventilated patients, not whether the tracheostomy was needed or provided benefit. However, we argue that this work may be used as a base for development of a predictive model in trauma patients and subsequent assessment of benefit of tracheostomy in this population.

Conclusion

We performed a systematic review of studies reporting on predictors of receiving a tracheostomy in patients who are mechanically ventilated in the ICU, focusing on trauma patients. We identified a number of factors in observational studies of varying quality that predict which patients will receive a tracheostomy, especially in trauma patients. However, we failed to define any validated models in such patient groups. Until work is done in this area to develop robust predictors of who will receive a tracheostomy early in a patient's ICU stay, the need for, effectiveness and optimal timing of tracheostomy will remain very difficult to assess.

Competing interests

None declared.

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Appendix

This appendix was part of the submitted manuscript and has been peer reviewed. It is posted as supplied by the authors.

E1: Description of “early” vs. “late” tracheostomy trials

Author	Year	Setting	Patients	Study Period	Definition "Early" and "Late"	Prediction tool	Group	Total Number Patients	Number with Tracheostomy (%)	Male (%)	Age*	Illness Severity Description *
Rumbak et al.[11]	2004	2 University Affiliated Hospitals, United States	Medical ICU Patients (no trauma patients)	N/A	≤48 hours vs. 14-16 days	Clinician judgment	**Early**	60	60 (100)	31 (52)	63±10.4	APACHE II: 27.4±4.2
							Late	60	50 (83)	34 (57)	63±9.3	APACHE II: 26.3±2.6
Barquist et al. [12]	2006	University Affiliated Level 1 Trauma Centre, United States	Trauma Patients	N/A	<day 8 vs. > day 28	Certain inclusion criteria and clinician judgment	**Early**	29	27 (93)	20 (69)	53.7±21.5	APACHE II: 12.1±3.2
							Late	31	11 (35)	26 (84)	49.9±18.3	APACHE II: 13.1±5.1
Blot et al.[5]	2008	25 ICU's in France	Medical and Surgical ICU Patients (19% Trauma patients)	2002-2004	< day 4 vs. > day 14	Criteria based on previous work[1, 21, 59, 65] but application of these criteria up to treating clinician	**Early**	61	60 (98)	45 (74)	55 (19-88)#	SAPS II: 50 (17-103)#
							Late	62	16 (26)	43 (69)	58 (20-88)#	SAPS II: 50 (15-96)#
Terragni et al.[13]	2010	12 ICU's in Italy	Medical and Surgical ICU Patients (10% Trauma patients)	2004-2008	6-8 days vs. 13-15 days	Clinical parameters and clinician judgment	**Early**	209	145 (69)	138 (66)	61.8±17.4	SAPS II: 51.1±8.7
							Late	210	119 (57)	142 (68)	61.3±16.8	SAPS II: 49.7±8.6
Young et al. [14]	2013	72 ICU's in the United Kingdom	Medical and Surgical ICU Patients (including Cardiothoracic; unknown number trauma patients)	2004-2011	< 4 days vs. > 10 days	Clinician judgment	**Early**	451	420 (93)	263 (58)	63.6 ± 13.7	APACHE II: 19.6±6.5
							Late	448	204 (46)	264 (59)	64.2±13.3	APACHE II: 20.1±6.0
Bösel et al.[15]	2013	University Affiliated Hospital, Germany	Stroke/Spontaneous ICH Patients (no trauma patients)	2009-2011	≤ 3 days vs. 7-14 days	Non-validated in-house assessment score[66] and 2 clinicians’ judgment	**Early**	30	30 (100)	20 (67)	61.0±12.0	APACHE II: 17 (13-19)#
							Late	30	18 (60)	20 (67)	61.0±13.0	APACHE II: 16 (11-19)#
Dunham et al.[16]	2014	University Affiliated Level 1 Trauma Centre, United States	Blunt Head Trauma Patients	N/A	3-5 days vs. 10-14 days	Clinician judgment	**Early**	17	17 (100)	N/A	33±13	ISS: 28±11
							Late	14	11 (79)	N/A	37±16	ISS: 35±9

* - mean ± Standard deviation; # - median (interquartile range);ICU – Intensive Care Unite; N/A - not available; APACHE II – Acute Physiology and Chronic Health Evaluation II score; SAPS – Simplified Acute Physiology Score; ISS – Injury severity score

E2: Search Criteria

Medline Search

1. exp tracheostomy/
2. exp tracheotomy/
3. percutaneous tracheostomy.mp.
4. percutaneous tracheotomy.mp.
5. 1 or 2 or 3 or 4
6. exp Intensive Care Units/or exp Critical Care/or critical care medicine.mp.
7. exp Intensive Care Units/or exp Critical Care/or intensive care medicine.mp.
8. mechanical ventilation.mp or exp Respiration, Artificial/
9. prolonged ventilation.mp.
10. 6 or 7 or 8 or 9
11. 5 and 10
12. limit 11 to (English language and humans and yr=”1960-2017” and “all adult (19 plus years)”)

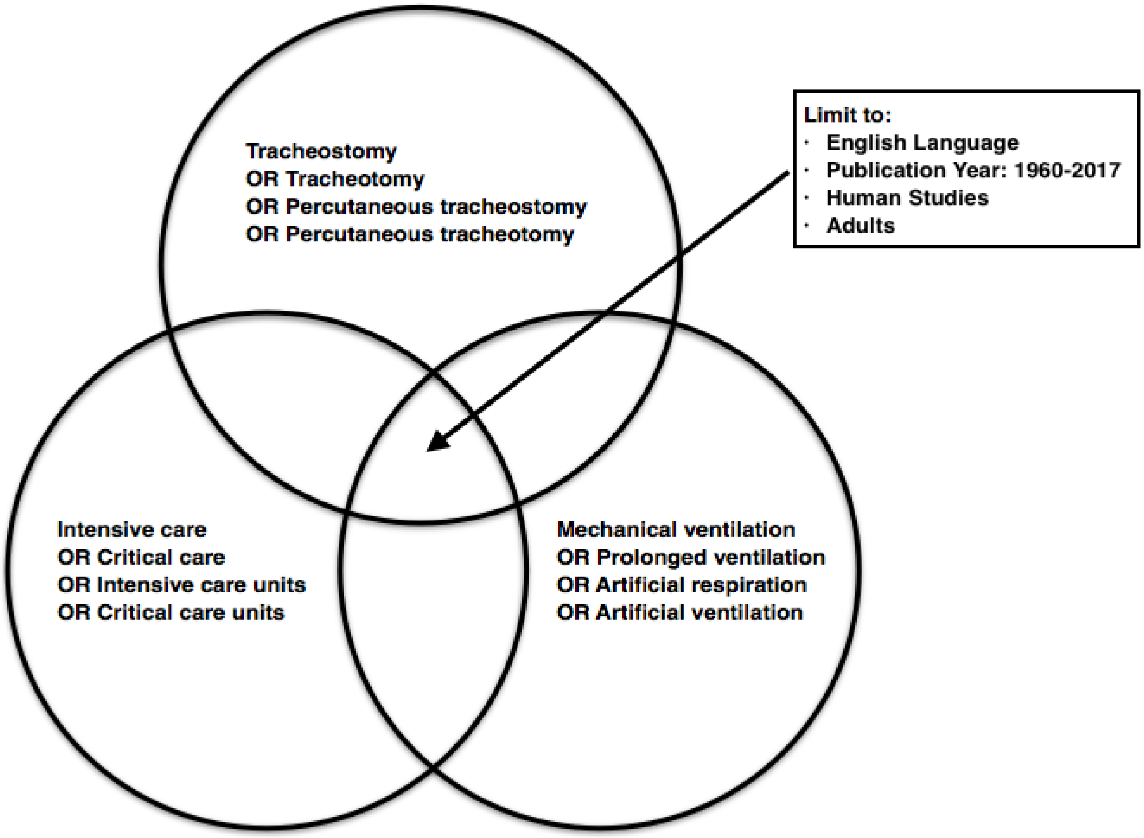
Embase Search

1. exp tracheostomy/
2. exp tracheotomy
3. percutaneous tracheostomy.mp.
4. percutaneous tracheotomy.mp.
5. 1 or 2 or 3 or 4
6. exp intensive care/
7. critical care.mp.
8. prolonged ventilation.mp.
9. mechanical ventilation.mp. or exp artificial ventilation/
10. 6 or 7 or 8 or 9
11. 5 and 10
12. limit 11 to (human and English language and yr=”1960 –2017” and adult <18 to 64 years>)

CENTRAL Evidence Based Medicine Reviews

1. tracheostomy.mp
2. tracheotomy.mp
3. percutaneous tracheostomy.mp
4. percutaneous tracheotomy.mp
5. 1 or 2 or 3 or 4
6. intensive care.mp
7. critical care.mp
8. mechanical ventilation.mp
9. prolonged ventilation.mp
10. 6 or 7 or 8 or 9
11. 5 and 10
12. limit 11 to “all adult (19 plus years)”
13. limit 12 to English language
14. limit 13 to yr=”1960-2017”
15. limit 14 to humans

E3: Diagrammatic representation of the search strategy



E4: Risk of bias in each of the domains of the QUIPS tool described in text

Study	Study Participation	Study Attrition	Prognostic Factor Measurement	Outcome Measurement	Study Confounding	Statistical Analysis and Reporting
Kollef et al[1]	Low	Low	Low	Low	Moderate	Low
Gurkin et al.[27]	Moderate	Moderate	Low	Low	Moderate	Low
Padia et al.[28]	Low	Low	Low	Low	Moderate	Low
Goettler et al.[37]	Moderate	Low	Moderate	Low	Moderate	Moderate
Nathens et al.[29]	Low	Low	Low	Low	Low	Low
Szeder et al.[30]	Moderate	Low	Low	Low	Moderate	Low
Branco et al.[31]	Moderate	Low	Moderate	Low	Moderate	Low
Shamim et al.[32]	Moderate	Moderate	Moderate	Low	Moderate	Low
Huang et al.[33]	Low	Low	Moderate	Low	Moderate	Low
Rampa et al.[34]	Low	Low	Low	Low	Low	Low
Schönenberger et al.[35]	Low	Low	Moderate	Low	Low	Low
Humble et al.[36]	Low	Low	Moderate	Low	Moderate	Moderate

E5: Factors associated with tracheostomy by multivariate analysis for non brain injured patients

Study	Year published	Group	Risk of bias	Factors multivariate (logistic regression) analysis	Risk (OR or RR (95% CI))	Timing of factor
Kollef et al[1]	1999	All ICU patients	Intermediate	Nosocomial pneumonia	4.72 (3.24-6.87)	Varied
				Witnessed aspiration	3.79 (1.54-3.18)	Varied
				Receiving aerosol treatment	3.00 (2.18-4.13)	Varied
				Reintubation	2.21 (1.54-3.18)	Varied
Padia et al.[28]	2003	Lung transplant recipients	Intermediate	Pneumonia	16.7 (3.6-78)	Varied
				Double lung transplant	12.4 (2.2-29)	Day 0
				Reintubation	5.7 (1.9-17.3)	Varied
				Cardiopulmonary bypass	5 (1.5-16.5)	Day 0

Day 0 = ICU admission

E6: Factors associated with tracheostomy by univariate analysis.

Study	Year published	Group	Factors Univariate analysis	OR (95% CI)
Kollef et al[1]	1999	All ICU patients	Received aerosol therapy	24.79 (12.33-49.83)
			Developed VAP	6.21 (3.16-12.22)
			Witnessed aspiration	3.79 (1.59-9.02)
			Re-intubation	3.70 (1.94-7.05)
			Required fibre optic intubation	3.09 (1.26-7.61)
			Bone marrow organ-system derangement	2.38 (1.24-4.58)
			Lung organ system derangement	2.05 (1.14-3.7)
Gurkin et al.[27]	2002	Head Injured Trauma Patients	Pneumonia	23.43 (6.93-79.28)
			ISS	20.8±9.5 vs. 30.5±8.6**
			GCS on presentation	9.7±4.3 vs. 6.5±4.0**
Padia et al.[28]	2003	Lung transplant recipients	Pneumonia	16.66 (3.56-77.99)
			Double lung transplant	8.54 (2.27-32.06)
			Re-intubated	5.71 (1.88-17.38)
			Cardiopulmonary bypass	4.95 (1.49-16.47)
			Single lung transplant	0.08 (0.02-0.37)
Goettler et al.[37]	2006	General trauma patients	N/A	
Nathens et al.[29]	2006	General trauma patients	Spinal cord injury	RR 2.90 (1.95-2.26)
			ISS (cf. 9-15)	
			≥48	RR 2.28 (1.95-2.67)
			25-47	RR 2.19 (1.99-2.41)
			16-24	RR 1.62 (1.46-1.79)

Maximum AIS score (cf. 3)	
6	RR 2.02 (1.51-2.36)
5	RR 1.56 (1.45-1.69)
4	RR 1.46 (1.35-1.56)
Co-morbidities	
Neurologic pre-existing disease (stroke/dementia)	RR 1.88 (1.75-2.02)
Coronary Artery disease	RR 1.67 (1.58-1.76)
Obesity	RR 1.46 (1.20-1.77)
Diabetes	RR 1.29 (1.15-1.46)
COPD	RR 1.20 (1.04-1.39)
None	RR 0.58 (0.55-0.61)
Rib fractures (cf. none)	
≥ 3	RR 1.61 (1.50-1.72)
1-2	RR 1.16 (1.04-1.29)
Age (cf.16-24 years)	
65-84	RR 1.46 (1.31-1.63)
56-64	RR 1.44 (1.27-1.62)
41-55	RR 1.29 (1.18-1.42)
Chest injury AIS ≥ 3	RR 1.43 (1.34-1.52)
Coma (cf. none)	
Prolonged	RR 1.23 (1.14-1.32)
Brief	RR 0.88 (0.82-0.95)
Hospital beds available (cf. lowest quartile (125-290)	
Third quartile (375-519)	RR 1.22 (1.06-1.41)
Highest quartile (520-908)	RR 1.18 (1.02-1.35)
University Teaching Hospital (cf. non teaching)	RR 1.21 (1.07-1.44)
Head injury AIS ≥3	RR 1.20 (1.14-1.28)

			ICU beds available (cf. lowest quartile (9-15)	
			Highest quartile (21-122)	RR 1.17 (1.08-1.27)
			Third quartile (21-30)	RR 1.12 (1.02-1.24)
			Trauma centre designation level (cf. level 1)	
			Level 3	RR 0.89 (0.81-0.96)
			Level 2	RR 0.87 (0.80-0.94)
			Penetrating trauma	RR 0.65 (0.59-0.72)
Szeder et al.[30]	2010	Supratentorial intracranial haemorrhage	GCS on day 3 (Median < 11))	21.0 (2.3-242.3)
			Thalamic haemorrhage	11.0 (1.2-102.4)
			Hydrocephalus	8.4 (1.5-47.0)
			IVH grade (mean ± SD)	3.57±1.21 vs. 8.05±1.72**
			Pineal shift (mm) (mean ± SD)	0.78±0.37 vs. 2.33±0.64**
			Septum pellucidum shift (mm) (mean ± SD)	1.74±0.69 vs. 4.22±0.68**
Branco et al.[31]	2011	Cervical spine Injury trauma patients	Intubated in ED	5.25 (4.43-6.23)
			ISS ≥ 16	4.39 (3.41-5.65)
			Complete C5-C7 level	2.98 (2.57-3.45)
			Intubated on Scene	2.95 (2.01-4.41)
			GCS ≤ 8 on admission	2.57 (2.20-3.01)
			Complete CI-C4 level	2.42 (2.00-2.92)
			Thoracic injury	1.84 (1.60-2.12)
			SBP < 90mmHg on admission	1.84 (1.53-2.22)
			Facial fracture	1.81 (1.48-2.21)
			RR < 10 or > 24 on admission	1.70 (1.44-2.01)
			Male	1.32 (1.12-1.55)
			Abdominal injury	1.31 (1.07-1.57)
			Pelvic/extremity injury	1.28 (1.09-1.49)

			Thoraco-lumbar fracture	1.19 (1.01-1.41)
			Age ≥ 55	0.84 (0.72-0.98)
			Blunt trauma	0.62 (0.45-0.84)
			Incomplete C1-C4 level	0.59 (0.50-0.69)
			Incomplete C5-C7 level	0.44 (0.38-0.51)
Shamim et al.[32]	2011	Head Injured Trauma patients requiring decompressive craniectomy	Age (cf. 0-15)	
			>51	11.9*
			31-50	7.3*
			16-30	5.3*
			Co morbidities (cf. none)	
			≥2	3.7*
			1	1.3*
			Incident to arrival time (cf. 0-1.5hrs)	
			> 3 hours	4.2*
			1.5-3 hours	3.16*
			Arrival abnormal pupil response	3.4*
			Arrival GCS score (cf. 13-15)	
			3-4	0.57*
			5-8	0.25*
			9-12	0.08*
Huang et al.[33]	2013	Head Injured Trauma patients requiring decompressive craniectomy	Pupil reactivity at presentation	
			One or both not reacting	4.61 (2.11-10.09)
			Both reacting	0.22 (0.10-0.47)
			Interval from Head Injury to DC	
			≤ 24 hours	3.97 (1.14-13.84)

			> 24 hours	0.25 (0.07-0.88)
			Absent basal cisterns on CT brain	2.19 (1.01-4.75)
			Mean age (years) (±SD)	42±20 vs. 52±20**
			Mead head AIS (±SD)	5±0 vs. 5±0**
			Mean ISS (±SD)	26±9 vs. 29±7**
			Mean GCS at presentation (±SD)	9±3 vs. 6±3**
			Midline shift on CT (mm) (mean ± SD)	7±5 vs. 10±7**
Rampa et al.[34]	2015	In-hospital cardiac arrest patients with anoxic/hypoxic ischaemic encephalopathy	N/A	
Schönenberger et al.[35]	2016	Patients with ischaemic stroke, intracranial haemorrhage or subarachnoid haemorrhage	Ischaemic stroke	69.4% vs. 26.9% **
			Hemorrhagic stroke	30.6% vs. 73.1%
			SET score	6.9±3.7 vs. 9.7±3.2
Humble et al.[36]	2016	Trauma patients with severe traumatic brain injury	N/A	

* 95% CI not provided; ** for non tracheostomy patients vs. tracheostomy patients; N/A - not available; VAP – Ventilator Associated Pneumonia; ISS – Injury Severity Score; GCS – Glasgow Coma Scale; AIS - Abbreviated Injury Scale; ICU – Intensive Care Unit; IVH – Intraventricular Haemorrhage; SBP – Systolic Blood Pressure; RR – Respiratory Rate; DC – Decompressive Craniectomy; CT – Computed Tomography; COPD – Chronic obstructive pulmonary disease; SET – Stroke related Early Tracheostomy

E7: Tracheostomy risk factors in Goettler et al.[37]

100% Tracheostomy rate (3% of patients studied)	≥ 90% Tracheostomy Rate (10.6% of patients studied)	≥ 80% Tracheostomy Rate (25% patients studied)
ISS = 75	ISS ≥ 54	ISS ≥ 38
ISS ≥ 50 & age ≥ 55	ISS ≥ 40 & age ≥ 40	Age ≥ 80
Admit/24 hr GCS = 3 & age ≥ 70	Admit/24 hr GCS = 3 & age ≥ 55	Admit/24 hr GCS = 3 & age ≥ 45
AIS abdomen, chest or extremities ≥ 5 and age ≥60	Paralysis (any level) & age ≥ 40	Damage control laparotomy & age ≥ 50
Bilateral pulmonary contusions & ≥ 8 rib fractures	Bilateral pulmonary contusions & age ≥ 55	Bilateral pulmonary contusions & age ≥ 50
Craniotomy and age ≥ 50		Aspiration & age ≥ 55
Craniotomy, ICP Monitor and age ≥ 40		Craniotomy & ICP monitor
Craniotomy & GCS ≤ 4 at 24 hours		Craniotomy & GCS ≤ 9 at 24 hours

ISS – Injury severity score; GCS – Glasgow Coma Scale; ICP – Intracranial Pressure

E8: Details of Stroke related Early Tracheostomy Score in Schönenberger et al.[35]

Area of assessment	Situation	Points
Neurological function	Dysphagia	4
	Observed aspiration	3
	GCS on admission < 10	3
Neurological Lesion	Brainstem	4
	Space-occupying cerebellar	3
	Ischaemic infarct > 2/3 MCA territory	4
	ICH volume > 25ml	4
	Diffuse lesion	3
	Hydrocephalus	4
General organ function/procedure	(Neuro)surgical intervention	2
	Additional respiratory disease	3
	$PaO_2/FiO_2 < 150$	2
	APS (of APACHEII) > 20	4
	LIS > 1	2
	Sepsis	3

GCS – Glasgow coma scale; MCA – middle cerebral artery; ICH – intracerebral haemorrhage; PaO_2 – arterial partial pressure of oxygen; FiO_2 – fractional inspired oxygen; APS – acute physiology score; APACHEII – acute physiology and chronic health evaluation II; LIS – lung injury score.

E9: Details of TRACH score in Szeder et al. [30]

TRACH Score = 3 + (1 x RScale) – (0.5 x GCS)

RScale = Radiological Scale

Radiological scale = sum of points of significant predictors: Location, Hydrocephalus, Septum Pellucidum shift (L + H + S)

- Location: Thalamus = 2 points; Other = 0 points
- Hydrocephalus: Present = 1.5 points; Absent = 0 points
- Septum Pellucidum shift: Present = 3 points; Absent = 0 points

All patients with a score < 0.7 were extubated and all patients with a score > 2.0 received a trachesotomy.

The TRACH Score had a reported ROC of 0.92, with a sensitivity to predict extubation of 94%, a specificity of 83%, a positive predictive value of 83% and a negative predictive value of 95%.