ORIGINAL ARTICLE

Inpatient Complications Predict Tracheostomy Better than Admission Variables After Traumatic Brain Injury

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Abstract

Background: Data regarding who will require tracheostomy are lacking which may limit investigations into therapeutic effects of early tracheostomy.

Methods: We performed an observational study of adult traumatic brain injury (TBI) patients requiring intensive care unit (ICU) admission for ≥ 72 h and mechanical ventilation for ≥ 24 h between January 2014 and December 2014 at a level 1 trauma center. Patients who had life-sustaining measures withdrawn were excluded. Multivariable logistic regression analyses were used to assess admission and inpatient factors associated with receiving a tracheostomy and to develop predictive models. Inpatient complications prior to day 7 were used to standardize data collection for patients with and without tracheostomy. Patients who received tracheostomy prior to day 7 were excluded from analysis.

Results: In total, 209 patients (78% men, mean 48 years old, median Glasgow Coma Scale score (GCS) 8) met study criteria with tracheostomy performed in 94 (45%). Admission predictors of tracheostomy included GCS, chest tube, Injury Severity Score, and Marshall score. Inpatient factors associated with tracheostomy included the requirement for an external ventricular drain (EVD), number of operations, inpatient dialysis, aspiration, GCS on day 5, and reintubation. Multiple logistic regression analysis demonstrated that the number of operation room trips (adjusted odds ratio [AOR], 1.75; 95% CI, 1.04–2.97; $P = 0.036$), reintubation (AOR, 8.45; 95% CI, 1.91–37.44; $P = .005$), and placement of an EVD (AOR, 3.48; 95% CI, 1.27–9.58; $P = .016$) were independently associated with patients undergoing tracheostomy. Higher GCS on hospital day 5 (AOR, 0.52; 95% CI, 0.40–0.68; $P < 0.001$) was protective against tracheostomy. A model of inpatient variables only had a stronger association with tracheostomy than one with admission variables only (ROC AUC 0.93 vs 0.72, $P < 0.001$) and did not benefit from the addition of admission variables (ROC AUC 0.93 vs 0.92, $P = 0.78$).

Conclusion: Potentially modifiable inpatient factors have a stronger association with tracheostomy than do admission characteristics. Multicenter studies are needed to validate the results.

Keywords: Tracheostomy, Traumatic brain injury, Head injury, Outcomes

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Introduction

Following traumatic brain injury (TBI), there is a large variation in the rate of tracheostomy with documented rates of 14–47%, and up to 64% following decompressive craniectomy [1–6]. Recently, it has been proposed that earlier tracheostomy may be superior to late tracheostomy by improving patient comfort and facilitating the use of less sedating medications, improved pulmonary toilet, early mobility, and aggressive ventilator weaning [7]. Although large randomized controlled trials are lacking, smaller non-randomized studies have found earlier tracheostomy may at least increase ventilator-free days and decrease intensive care unit length of stay in patients with TBI [7–11]. Earlier tracheostomy, however, comes at the risk of performing the procedure in patients who would have been successfully extubated if given more time [4].

There is a need then to determine whether or not tracheostomy can be accurately predicted early in the hospital stay and if so what the predictors of tracheostomy might be. Previous predictive models aimed at predicting tracheostomy have been developed for stroke patients such as the SET score and TRACH scores [12, 13]. However, predictive models in TBI are lacking. Relatively few studies have attempted to answer these important questions and results have been variable [3–6, 14, 15]. In this study, we aimed to identify the predictors of tracheostomy both present on admission and that developed during the hospital stay and to compare the accuracy of prediction on admission to prediction that incorporates aspects of the hospital course.

Methods

Study Design, Setting, and Population

We performed an observational study of adult TBI patients requiring intensive care unit (ICU) admission for ≥ 72 h and mechanical ventilation for ≥ 24 h between January 2014 and December 2014. Patients were admitted to a 12-bed Neurotrauma Critical Care unit at a single level 1 trauma center, designated as a Primary Adult Resuscitation Center by the American College of Surgeons. The center receives over 7500 trauma patients each year including approximately 400 cases per year of moderate to severe TBI. Data were obtained from the hospital's trauma registry and patient medical records. Patients who had life-sustaining measures withdrawn were excluded from the study.

Standard Protocol Approvals, Registrations, and Patient Consents

This study was performed with the approval of the University of Maryland Institutional Review Board.

Clinical Management

Patient management was consistent with guidelines from the Brain Trauma Foundation. Our practice is to perform daily 60–120-min spontaneous breathing trials (5 cm H₂O of pressure support and 5 cm H₂O of positive end-expiratory pressure) along with a formal assessment in all mechanically ventilated patients that do not have medical contraindications, such as raised intracranial pressure (ICP) or status epilepticus, that require sedation as primary therapy. Formal assessment includes rapid shallow breathing index (RSBI), tidal volume, negative inspiratory force, cuff leak, cough/gag reflexes, level of arousal (including the ability to follow commands), and a qualitative assessment of endotracheal secretions. These results are incorporated into a daily discussion used to determine appropriate timing of patient extubation. Extubation is typically avoided if the patient is not awake enough to follow simple commands, lacks a gag/adequate cough reflex, or frequency of suctioning exceeds every 2 h, or fails the spontaneous breathing trial due to high RSBI, hypoxia, hypercarbia as measured by end-tidal carbon dioxide, tachycardia, or hypo- or hypertension. The decision to pursue tracheostomy is based upon repeated failure by the patient to meet criteria for extubation.

Data Collection

Basic patient and hospital demographics were recorded as well as time-to-hospital arrival, transfer from outside hospital, and mechanism of injury (blunt, penetrating, hanging, burn). Admission vital signs and laboratory values were recorded. Clinical parameters at admission were recorded including admission Glasgow Coma Scale score (GCS), Abbreviated Injury Scale–Head, Marshall score, Rotterdam Score, and Injury Severity Score (ISS) [16–20]. A day 5 GCS was also collected to reflect the post-resuscitation status of the patient. The presence of a pulmonary contusion, pneumothorax, hemothorax, and requirement for chest tube was included as admission variables. Each patient received a non-contrast head computed tomography (CT) on arrival. All CT images were reviewed by two board-certified neurocritical care attendings (N.B. and N.A.M.) to determine Marshall and Rotterdam scores. Initial chest X-rays were reviewed by a neurocritical care attending (N.A.M.) to determine the lung injury score [21]. Additional inpatient complications that were collected included the development of pulmonary complications (aspiration, reintubation, acute respiratory distress syndrome), medical complications (acute kidney injury, dialysis, metabolic acidosis), and hospital-acquired infection (urinary tract infection, pneumonia, bacteremia, surgical site infections) [22, 23]. Furthermore, placement of ICP monitor, craniectomy, and placement of tracheostomy or gastrostomy tube were recorded as well

as surgical site infections and the number of trips to the operating room. Inpatient complications were collected up to hospital day 7.

Statistical Analysis

Complications were assessed prior to day 7 to provide a standardized period of analysis for patients with and without tracheostomy. Patients who received tracheostomy prior to day 7 were excluded from analysis. We compared admission and inpatient factors of patients receiving tracheostomy and those who did not. Variables were presented as mean and standard deviation (SD) and compared using Student's *T* test or as a median and interquartile range (IQR) and compared using Mann-Whitney *U* test. Pearson's Chi-square and Fisher's exact tests were used to assess for a significant difference of frequency distributions between the two groups. Variables were broken into three groups based upon their association with admission, inpatient clinical course or both admission and clinical course. The three groups of variables were then used in a backward stepwise logistic regression analysis to determine factors associated with tracheostomy. ROC curves for the three models were computed and compared to determine which model was more strongly associated with tracheostomy.

Results

There were 209 patients (78% men, mean 48 years old, median GCS 8) meeting study criteria during our study period. (See Fig. 1.) Overall, tracheostomy was performed in 94 (45%) patients after a median of 10 (IQR, 8–14) days. Patients with tracheostomy had significantly longer stays in the ICU (27 ± 16 days vs 10 ± 5 days, $P < 0.00001$) and hospital (32 ± 21 days vs 14 ± 9 days, $P < 0.00001$). Patients with tracheostomy also had significantly more days on mechanical ventilation (21 ± 16 days vs 5 ± 4 days, $P < 0.00001$). There were 75 patients who received a tracheostomy after ≥ 7 days with a median of 11 (IQR, 8–14) days. The remaining 19 patients who received a trach prior to 7 days were excluded from statistical analysis.

Admission Characteristics

There were no significant differences in admission vital signs including systolic/diastolic blood pressure, heart rate, respiratory rate, and oxygen saturation. In univariate analysis, admission characteristics significantly associated with tracheostomy were found to include admission GCS, Marshall score, ISS, end-stage renal disease, pneumothorax, hemothorax, chest tube, and the lung injury score. (See Table 1.) In a Cox proportional model, the admission GCS (adjusted odds ratio [AOR], 0.90; 95% confidence interval [CI], 0.83–0.98; $P = 0.01$),

Marshall score (AOR, 1.30; 95% CI, 0.97–1.74; $P = 0.074$), placement of a chest tube (AOR, 2.33; 95% CI, 0.88–6.13; $P < 0.088$), and ISS (AOR, 1.04; 95% CI, 0.99–1.08; $P = 0.058$) were independently associated with patients undergoing tracheostomy (see Table 3).

Inpatient Characteristics

Several inpatient events were associated with tracheostomy in univariate analysis. (See Table 2.) In a Cox proportional model, documented aspiration (AOR, 4.96; 95% CI, 0.84–29.34; $P = 0.078$), Acute inpatient dialysis (AOR, 12.81; 95% CI, 1.17–139.78; $P = 0.037$), reintubation (AOR, 6.48; 95% CI, 2.00–20.96; $P = 0.002$), the number of operating room trips (AOR, 1.62; 95% CI, 1.07–2.47; $P = 0.023$), and placement of external ventricular drain (EVD) (AOR, 2.42; 95% CI, 0.95–6.19; $P = 0.066$) were independently associated with patients undergoing tracheostomy (see Table 3). Higher day 5 GCS (AOR, 0.52; 95% CI, 0.4–0.65; $P \leq 0.001$) was protective against tracheostomy.

Admission and Inpatient Characteristics

In a Cox proportional model adjusting for admission GCS, acute inpatient dialysis, chest tube, ISS, and Marshall score; number of operation room trips (AOR, 1.75; 95% CI, 1.04–2.97; $P = 0.036$), reintubation (AOR, 8.45; 95% CI, 1.91–37.44; $P = 0.005$), and placement of EVD (AOR, 2.94; 95% CI, 0.97–8.97; $P = 0.058$) were independently associated with patients undergoing tracheostomy (see Table 3). A higher GCS on hospital day 5 (AOR, 0.52; 95% CI, 0.40–0.68; $P < 0.001$) was protective against tracheostomy. A model of inpatient variables only had a stronger association with tracheostomy than one with admission variables only (ROC AUC 0.93 vs 0.72, $P < 0.001$) and did not benefit from addition of

Table 1 Characteristics of patients with and without tracheostomy

Characteristic ^a	No Tracheostomy (N = 115)	Tracheostomy ^b (N = 75)	P value
Male, gender	88 (76.5)	58 (77.3)	0.74
Age, mean (SD), years	50 (22)	48 (16)	0.63
Body mass index, (SD), kg/m ²	27.7 (6.3)	28.6 (5.3)	0.30
Comorbidity ^c			
Diabetes mellitus	13 (11.3)	14 (18.6)	0.15
Smoker	13 (11.3)	8 (10.7)	0.89
Alcohol abuse	27 (23.3)	17 (22.7)	0.90
End-stage renal disease	1 (.9)	5 (6.7)	0.03
Mechanism ^d			
Blunt	110 (95.7)	69 (92.0)	0.18
Penetrating	4 (3.5)	5 (7.0)	
Admission Characteristics ^e			
Admission GCS (IQR)	11 (6–14)	7 (4–12)	0.006
Marshall score (IQR)	2 (2–2)	2 (2–4)	0.002
# of quadrants with consolidation on chest X-ray (IQR)	0 (0–0)	0 (0–1)	0.01
Injury Severity Score, mean (SD)	27 (9)	33 (8)	<0.001
Pneumothorax	21 (18.3)	28 (37.3)	<0.001
Hemothorax	9 (7.8)	13 (17)	0.045
Chest Tube	15 (13.0)	26 (34.7)	<0.001
Pulmonary Contusions	23 (20.0)	17 (22.7)	0.66
PaO ₂ /FiO ₂ ratio, mean (SD)	375 (152)	314 (117)	0.008

GCS Glasgow Coma Scale score, IQR interquartile range, SD standard deviation

^a Data are presented as number (%) unless otherwise specified^b Patients who received a tracheostomy after ≥ 7 days^c Less than 5% of each group had comorbid IV drug abuse, hepatic failure, congestive heart failure, asthma, or chronic obstructive pulmonary disease^d Alternative mechanisms such as hanging and burns made up < 5% of all patients^e No significant differences in admission vital signs including systolic/diastolic blood pressure, heart rate, respiratory rate, oxygen saturation

admission variables (ROC AUC 0.93 vs 0.92, $P=0.78$). (See Fig. 2.)

Discussion

In our observational study of 209 intubated TBI patients, a high proportion (45%, $n=94$) of patients received a tracheostomy. The requirement for an EVD, hospital day 5 GCS, reintubation, and the number of operating room trips were identified as predictors of tracheostomy. A model with inpatient variables alone showed the strongest association with tracheostomy when compared to models with admission variables and did not benefit significantly from the addition of admission variables.

Our study builds on sparse literature identifying factors that predict tracheostomy after TBI. A study focused

Table 2 Hospital course of patients with and without tracheostomy

Complications ^a	No Tracheostomy (N = 115)	Tracheostomy ^b (N = 75)	P Value
Seizures	7 (6.1)	13 (17.0)	0.01
Aspiration	4 (3.5)	8 (10.6)	0.046
Reintubated	7 (6.1)	18 (24.0)	<0.001
ARDS	0 (.0)	3 (4.0)	0.06
Pneumonia	0 (.0)	16 (21.0)	<0.001
Craniectomy	35 (30.4)	29 (38.7)	0.24
External Ventricular Drain	26 (22.6)	44 (58.7)	<0.001
Acute Kidney Injury	1 (.9)	11 (14.7)	<0.001
Acute Inpatient Dialysis	1 (.9)	9 (12.0)	0.001
Sepsis	0 (0)	1 (1.1)	0.45
Bacteremia	1 (1.0)	14 (18.7)	<0.001
Urinary Tract Infection	7 (6)	2 (2.2)	0.19
Surgical Site Abscess	0 (.0)	1 (1.3)	0.44
Surgical Site Deep	3 (2.6)	3 (4.0)	0.80
Operating Room trips [IQR]	0 [1–1]	2 [1–3]	<0.001
Day 5 GCS	14 [11–15]	8 [6–10]	<0.001

ARDS acute respiratory distress syndrome, GCS Glasgow Coma Scale score, IQR interquartile range

^a Data are presented as number (%) unless otherwise specified^b Patients who received a tracheostomy after ≥ 7 days**Table 3 Predictors of tracheostomy**

	OR	(95%CI)	P Value
Only admission variables			
Admission GCS	0.90	(0.83–0.98)	0.01
Marshall score	1.30	(0.97–1.74)	0.074
Chest tube	2.33	(0.88–6.13)	0.088
Injury Severity Score	1.04	(0.99–1.08)	0.058
Only clinical variables			
External ventricular drain present	2.42	(0.95–6.19)	0.066
Acute inpatient dialysis	12.81	(1.17–139.78)	0.037
Day 5 GCS	0.52	(0.4–0.65)	<0.001
Reintubated	6.48	(2.00–20.96)	0.002
Documented aspiration	4.96	(0.84–29.34)	0.078
# of operating room trips	1.62	(1.07–2.47)	0.023
Both admission and clinical variables ^a			
External ventricular drain present	2.94	(0.97–8.97)	0.058
Reintubated	8.45	(1.91–37.44)	0.005
# of operating room trips	1.75	(1.04–2.97)	0.036
Day 5 GCS	0.52	(0.4–0.68)	<0.001

GCS Glasgow Coma Scale score, OR Odds Ratio

^a Admission GCS, acute inpatient dialysis, Injury Severity Score, chest tube, and Marshall score were entered into model and fell out after adjustment for EVD, number of operating room trips, reintubation, inpatient dialysis, and day 5 GCS

on emergency room predictors of tracheostomy found that patients requiring cranial decompression, older age, preexisting medical comorbidities, a delay in emergency

Fig. 2 ROC curve comparison. A comparison of ROC curves generated by differing models based upon admission, inpatient, and a combination of admission and inpatient variables

department arrival, abnormal admission pupil response, and a preoperative neurological worsening during hospital stay were independent predictors of tracheostomy [6]. Previous inpatient studies have identified increased age, admission GCS, the presence of hydrocephalus, Simplified Acute Physiology Scores and Sequential Organ Failure Assessment, ISS, Abbreviated Injury Scale-Head, and increased number of ventilator days as predictive of tracheostomy [3–5, 14, 15, 24, 25]. Our univariate analysis similarly found that admission GCS and ISS were significantly associated with tracheostomy; however, these markers of injury severity were no longer significant in the final model of admission and inpatient characteristics. Our analysis identified a higher GCS on day 5 to be protective of tracheostomy. Similarly, studies on blunt and isolated TBI found a poor GCS ≤ 8 on day 3 and 5 to be significantly associated with tracheostomy [4, 24]. This may suggest that patients with the potential to improve should be monitored for neurological progression until day 5 before pursuing early tracheostomy.

Our study stands out from previous in the granularity of its data collection, particularly regarding inpatient complications. The strongest risk factors in our study for tracheostomy were reintubation, placement of an EVD and number of operation room trips. A failed extubation leading to reintubation may be the most cogent mechanism for identifying patients that require tracheostomy and as such was a strong factor for tracheostomy in our study. While the number of operating room trips may simply represent injury severity, it may also provide reason to study the effects surgical procedures have on a patient's respiratory status.

Acute inpatient dialysis was found to be an inpatient variable predictive of tracheostomy and may serve as a marker of severity for non-neurological

injuries. Although effects on tracheostomy have not been reported, acute kidney injury is a common complication in TBI patients with rates ranging from 9.2 to 23% [26–29]. Further work is needed to elucidate the relationship between the requirement for dialysis and tracheostomy, but fluid overload may play an important role.

Early tracheostomy may benefit patients with severe TBI as it facilitates oral hygiene and pulmonary toilet, improves patient comfort, reduces sedation requirements, accommodates early mobility, and eases ventilator weaning. Results from studies of early versus late tracheostomy have been inconsistent [30, 31]. Paramount to future inquiry is developing a validated clinical tool to predict tracheostomy, such as the SET score which predicts tracheostomy in cerebrovascular neurocritical care patients and is being utilized to guide the SETPOINT2 study of early versus late tracheostomy after stroke [13, 32]. Given the important contributions of inpatient factors, developing and validating such a tool for patients with TBI may be difficult, but our work suggests that hospital-acquired infections and other inpatient factors should play a prominent role.

There were several limitations to this study. First, our study was limited to an observational review of a small sample of patients at a single center, limiting its generalizability. Given the limited data available to clinicians and variability in ventilator liberation assessment, the decision to proceed to tracheostomy is subjective and may vary from clinician to clinician and institution to institution. Nonetheless, our tracheostomy rate was similar to those at other institutions [5, 14]. Cannulation times were highly variable among previous research studies with differing definitions of early trach ranging from ≤ 3 to ≤ 10 days [33]. Our median time to tracheostomy was 10 days for the overall population and 11 days for those who received a trach after ≥ 7 days. Both of which have been defined as intermediate tracheostomy in previous multi-institutional studies [34]. Second, a small portion of our initial population had life-sustaining measures withdrawn and was excluded from our analyses which could have biased our results, especially if care was withdrawn specifically to avoid tracheostomy per patient or surrogate preference. Third, we did not assess physician biases toward tracheostomy requirements and therefore cannot comment on whether or not a self-fulfilling prophecy may have led a certain risk factor to be associated with tracheostomy simply because physicians believe that patients with that risk factor will require tracheostomy. Finally, we were not able to determine which inpatient factors were present prior to the decision to proceed to tracheostomy and thus could be incorporated into clinical decision making.

Conclusions

Inpatient factors may have a stronger association with tracheostomy than admission characteristics. Physicians should proceed with caution in recommending very early tracheostomy as the hospital complications such as reintubations or hospital-acquired infections may have strong influence on the need for tracheostomy. In addition, some of these variables are potentially modifiable and clinical improvements may ultimately lower the need for tracheostomy.

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Author's Contributions

N.B., N.M., and R.J. contributed to the conception and design of the research. B.H., D.S., G.P., G.S., N.B., N.M., R.J., R.V.B., and W.C. contributed to the acquisition and analysis of data. N.M. and R.J. drafted the article. B.H., D.S., G.P., G.S., N.B., N.M., R.J., R.V.B., and W.C. revised the article critically for important intellectual content. N.M. and R.J. contributed equally to the manuscript.

Source of support

No funding.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

Published online: 17 October 2018

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