Hospital-acquired pneumonia among pediatric trauma patients treated at national trauma centers

Henry W. Ortega, MD, Gretchen Cutler, PhD, Jill Dreyfus, PhD, Andrew Flood, PhD, *and* **Anupam Kharbanda, MD, MSc,** *Minneapolis, Minnesota*

BACKGROUND: Injury is the leading cause of hospitalization in children, and as many as 5% of hospitalized injured children require mechanical ventilation. Despite this, little is known about the complications associated with mechanical ventilation, including pneumonia.

METHODS: This is a retrospective analysis of trauma patients younger than 19 years from the National Trauma Data Bank from 2009 to 2011. Descriptive statistics were used to examine the patient population. Baseline characteristics were compared between subgroups using *t* tests and χ^2 tests. Generalized linear models were used to identify risk factors for hospital-acquired pneumonia adjusting for clustering of patients by hospital.

RESULTS: A total of 252,187 patients were eligible for analysis, and 1,915 patients were diagnosed with pneumonia. Most patients were male (66.3%), were white (54.2%), had no comorbidities (88.9%), and were not considered severely injured (85.5% with an Injury Severity Score [ISS] < 16). The mean (SD) length of stay was 2.9 (5.2) days. Patients who developed pneumonia were older (16–18 years, 61.7% vs. 31.1%, $p < 0.0001$), had an increased length of stay (20.9 days vs. 2.8 days, $p < 0.0001$), more intensive care days (13.9 days vs. 0.7 days, $p < 0.0001$), and more ventilation days (9.5 days vs. 0.3 days, $p < 0.0001$) compared with those who did not develop pneumonia. The rate of pneumonia nearly doubled in patients spending 2 days on a ventilator (odds ratio [OR], 5.52; 95% confidence interval [CI], 3.45–8.84), doubled again for patients spending 3 days (OR, 10.59; 95% CI, 6.38–17.61), and doubled again for patients spending 5 days (OR, 23.72; 95% CI, 13.36–42.15) mechanically ventilated. The presence of two comorbid conditions was associated with twice the odds of developing pneumonia (OR, 2.10; 95% CI, 1.47–1.78).

CONCLUSION: Prolonged mechanical ventilation, increased injury severity, older age, and presence of multiple comorbid conditions all increase the risk of pneumonia in injured children. Preventive measures should be aggressively used in injured children at high risk for the development of pneumonia. (*J Trauma Acute Care Surg*. 2015;78: 1149–1154.

LEVEL OF EVIDENCE: Epidemiologic study, level III.

KEY WORDS: pediatric trauma; mechanical ventilation; pneumonia.

Injuries are the leading cause of emergency department (ED) visits and hospitalizations in the United States. It is estimated that more than 29 million ED visits and 2.6 million hospital admissions occur annually because of injuries.[1] Injury is also the leading cause of death and disability among children.[1] As many as 5% of hospitalized injured children require mechanical ventilation during admission.[2,3] Despite this, little is known about the complications associated with mechanical ventilation, including the development of pneumonia, in children.

Hospital-acquired pneumonia (HAP) is an important and potentially preventable complication in critically ill patients. It is defined as a nosocomial or potentially avoidable infection in patients with mechanical ventilation that is not present at the time of intubation and develops greater than 48 hours after intubation.[3–6] Pneumonia is a significant cause of secondary morbidity in adults, with reported rates between 0.8% and 15% in mechanically ventilated trauma patients.[2–6] Several risk factors have been identified in the adult trauma literature, which may contribute to higher rates of HAP in trauma patients. Head injuries,[3] acuity of illness,[4] and prolonged mechanical ventilation[5] are all associated with higher rates of pneumonia in adult trauma patients.

Despite this research, little is known about the development of HAP in pediatric trauma patients. A non–trauma-specific pediatric study demonstrated that 5.1% of all mechanically ventilated pediatric intensive care unit patients will develop HAP.[7] A study by Taira et al.[8] demonstrated that pediatric trauma patients have a threefold higher risk of developing HAP than nontrauma patients, but the rate of HAP was lower than that reported in adults. Because a nearly 5% of traumatic injuries require mechanical ventilation as part of the acute (or even chronic) treatment plan, larger studies are needed to further elucidate the impact of HAP in the pediatric trauma population. To address this

Submitted: November 17, 2014, Revised: February 17, 2015, Accepted: February 23, 2015.

From the Pediatric Emergency Medicine (H.W.O., G.C., A.K.), and Research and Sponsored Programs (J.D., A.F.), Children's Hospitals and Clinics of Minnesota, Minneapolis, Minnesota.

This study was presented as a poster at the Pediatric Academic Societies Annual Meeting on April 28, 2015.

Address for reprints: Henry W. Ortega, MD, Children's Hospitals and Clinics of Minnesota, 2525 Chicago Ave South, Minneapolis, MN 55404; email: Henry.ortega@childrensmn.org.

DOI: 10.1097/TA.0000000000000661

critical issue, we sought to describe the incidence and risk factors of HAP in pediatric trauma patients in the hopes of identifying populations that may be at increased risk.

PATIENTS AND METHODS

Patient Population

This is a retrospective analysis of trauma patients younger than 19 years from the National Trauma Data Bank (NTDB), years 2009 to 2011. The NTDB represents the largest centralized collection of trauma patients in the United States and is sponsored by the American College of Surgeons (ACS). More than 700 US trauma centers and hospitals voluntarily reported deidentified information about trauma patients to the NTDB, including more than 95% of all ACS-verified Level I and Level II trauma centers, which are required to report data as part of their ACS verification requirements.[9] Inclusion criteria, data collection, verification, and cleaning of data are standardized across all trauma centers included in the data set. This study was reviewed and deemed exempt by the institutional review board at Children's Hospitals and Clinics of Minnesota.

Inclusion Criteria

Only patients younger than 19 years were eligible for inclusion in this study. Patients were excluded if they were transferred to the respective trauma center from another hospital, if they presented to the ED "dead on arrival," or if they "died after failed rescue." Patients were also excluded if they were not admitted or if their length of stay was less than 2 days. We defined the term *hospital-acquired pneumonia* to include aspiration pneumonia, ventilator-associated pneumonia, and infectious pneumonia that developed 48 hours after hospital admission as per previous reports using the NTDB.[2,6,10] An injured child was also considered to have a trauma-related pneumonia if pneumonia was listed as a hospital complication in the NTDB database. In addition, we included patients with the following International Classification of Diseases—9th Rev. (ICD-9) codes for ventilator-associated, aspiration or infectious pneumonia: 997.31, 507.0, and 481 to 486. Similar to another study examining pneumonia risk in adults using the NTDB,[10] patients who were on a ventilator for more than 30 days were considered outliers and were excluded from the study population since these patients have an extremely high risk for developing pneumonia.

Covariates

Additional data obtained from the NTDB included age, sex, race/ethnicity, Injury Severity Score (ISS), Glasgow Coma Scale (GCS) score, length of stay (days), intensive care days, day on mechanical ventilation, injury pattern, comorbid conditions, payment method, and hospital number. Race/ethnicity was categorized as follows: white, African American, Hispanic, Asian, other (Native Hawaiian or other Pacific Islander, other race), and unknown. The NTDB categorizes 24 comorbid conditions. Injury pattern (head/neck only, other only, or head/neck and other) was based on ICD-9 body region codes as defined by the Barell Injury Diagnosis Matrix. A patient was considered to have one or more comorbid conditions if he or she had any condition listed in the NTDB database. Insurance status was based on the payment method listed in the NTDB database and was categorized as private (private/commercial, Blue Cross/Blue Shield), public (Medicaid, Medicare, other government), or other (not billed, self-pay, worker's compensation, no fault automobile, unknown).

Statistical Analysis

We used descriptive statistics to characterize the patient population. Baseline characteristics were compared between subgroups using t tests for continuous variables and χ^2 tests for categorical variables. Generalized linear models were used to identify risk factors for HAP adjusting for clustering of patients by hospital. Models were first run without adjustment for confounders to examine associations between potential risk factors and pneumonia. A final generalized linear model was run based on levels of statistical significance ($p < 0.05$) seen in the unadjusted models. The final model included age group (<1, 1–5, 6–10, 11–15, 16–18 years), race/ethnicity (white, African American, Hispanic, Asian, other, unknown), sex (female/male), Injury Severity Scale (ISS), GCS, injury pattern (head/neck only, head/neck and other, other only), number of days on a ventilator, number of days in the intensive care unit, length of stay (days), number of comorbid conditions (0, 1, 2, or ≥3), and insurance status (private, public, other). All analyses were run using the SAS version 9.3 (Cary, NC). All p values were from two-tailed tests and were considered to be statistically significant if <0.05.

RESULTS

In 2009 to 2011, there were 391,086 pediatric trauma patients in the NTDB database. We excluded 136,814 patients who were transferred from another facility, 1,386 who were dead on arrival or died after failed resuscitation, 69,995 patients who were not admitted to the hospital, 61,724 patients who were admitted less than 2 days, 253 patients who were on a ventilator for more than 30 days, and 446 patients who had missing data, resulting in 120,468 patients eligible for analysis. Of these patients, 1,855 patients were diagnosed with HAP, of whom 97% (n = 1,795) were listed as a complication, while 56 had a diagnosis code for ventilator-associated pneumonia, 172 had a diagnosis of infectious pneumonia, and 76 had a diagnosis of aspiration pneumonia. Thirteen percent (242) of the cases were listed both as a complication and as a secondary diagnosis and were counted only once in our analysis. In total, 11% of the patients (n = 13,670) spent one or more days on mechanical ventilation.

The demographics and clinical characteristics of our study population along with pneumonia cases are provided in Table 1. Most patients were male (67.1%), were white (52.2%), had no comorbidities (86.2%), and were not considered severely injured (77.8% with an ISS < 16). The mean (SD) length of stay was 4.9 (6.7) days. Regarding region of injury, half of the patients did not have a head and neck injury (51.6%), while 24.3% had a head and neck injury only, and 24.1% of patients had both an injury in the head and neck region and in another region. Patients who developed pneumonia were more likely to be in the oldest (16–18 years) age group (62.9%) compared with those who did not develop pneumonia (36.6%,

TABLE 1. Demographic and Clinical Characteristics of Study Population (NTDB Years 2009–2011)

Variable	Overall Population (n = 120,468)	Pneumonia (n = 1,855)	No Pneumonia (n = 118,613)	*p*
Sex (male), n (%)	80,814 (67.1)	1,327 (71.5)	79,487 (67.1)	<0.0001
Age				
<1	7,101 (5.9)	48 (2.6)	7,053 (6.0)	<0.0001
1–5	20,851 (17.3)	174 (9.4)	20,677 (17.4)	
6–10	17,670 (14.7)	144 (7.8)	17,526 (14.8)	
11–15	30,284 (25.1)	322 (17.4)	29,962 (25.3)	
16–18	44,562 (37.0)	1,167 (62.9)	43,395 (36.6)	
ISS				
Mean (SD)	9.4 (8.8)	25.3 (13.3)	9.2 (8.5)	<0.0001
Median (interquartile range [IQR])	5 (4–14)	25 (17–33)	5 (4–13)	
<16, n (%)	87,617 (77.8)	252 (16.5)	87,365 (78.6)	<0.0001
≥16, n (%)	25,009 (22.2)	1,279 (83.5)	23,730 (21.4)	
GCS score				
Mean (SD)	13.9 (3.0)	7.9 (4.9)	14.0 (2.8)	<0.0001
Median (IQR)	15 (15–15)	6 (3–14)	15 (15–15)	
<8, n (%)	6,521 (7.0)	936 (57.2)	5,585 (6.1)	<0.0001
≥8, n (%)	86,596 (93.0)	700 (42.8)	85,896 (93.9)	
Race/ethnicity, n (%)				
White	62,906 (52.2)	1,046 (56.4)	61,860 (52.2)	0.01
African American	25,073 (20 .8)	351 (18.9)	24,722 (20.8)	
Hispanic	20,599 (17.1)	300 (16.2)	20,299 (17.1)	
Asian	2,050 (1.7)	30 (1.6)	2,020 (1.7)	
Other	6,355 (5.3)	84 (4.5)	6,271 (5.3)	
Unknown	3,485 (2.9)	44 (2.4)	3,441 (2.9)	
Length of stay, d				
Mean (SD)	4.9 (6.7)	21.3 (15.1)	4.7 (6.2)	<0.0001
Median (IQR)	3 (2–5)	19 (12–28)	3 (2–5)	
Intensive care days				
Mean (SD)	1.6 (4.1)	14.1 (10.2)	1.3 (3.6)	<0.0001
Median (IQR)	0 (0–2)	13 (7–19)	0 (0–1)	
Ventilation days				
Mean (SD)	0.6 (2.6)	9.7 (7.8)	0.5 (2.1)	<0.0001
Median (IQR)	0 (0–0)	9 (3–15)	0 (0–0)	
Injury pattern, n (%)				
Head/neck and other	28,891 (24.1)	1,170 (63.1)	27,721 (23.5)	<0.0001
Head/neck only	29,113 (24.3)	346 (18.7)	28,767 (24.4)	
Other only	61,913 (51.6)	339 (18.3)	61,574 (52.2)	
Comorbidities				
0	103,887 (86.2)	1,480 (79.8)	102,407 (86.3)	<0.0001
1	14,352 (11.9)	302 (16.3)	14,050 (11.9)	
2	1,953 (1.6)	63 (3.4)	1,890 (1.6)	
3+	276 (0.2)	10 (0.5)	266 (0.2)	
Insurance level				
Private	45,407 (40.9)	672 (38.9)	44,735 (40.9)	<0.0001
Public	42,310 (38.1)	595 (34.5)	41,715 (38.2)	
Other	23,274 (21.0)	460 (26.6)	22,814 (20.9)	

$p < 0.0001$). Patients who developed pneumonia had an increased length of stay (21.9 days vs. 4.7 days, $p < 0.0001$), more intensive care days (14.1 days vs. 1.3 days, $p < 0.0001$), and more ventilation days (9.5 days vs. 0.3 days, $p < 0.0001$). Patients who developed pneumonia were more likely to have comorbid conditions (20.2%) compared with patients who did not develop pneumonia (13.7%, $p < 0.0001$).

Table 2 shows associations of risk factors with HAP from our fully adjusted model. Patients in the oldest age group (16–18 years) had twice the odds of developing pneumonia compared with children younger than 1 year (odds ratio [OR], 1.99; 95% CI, 1.56–2.55). Odds of developing pneumonia were greater for patients with ISSs of 16 or greater and GCS scores lower than 8 (OR, 5.38; 95% CI, 4.46–6.50; OR, 2.55;

95% CI, 2.11–3.09, respectively). Patients who had an injury in the head/neck region in addition to other regions had higher odds of developing pneumonia compared with patients who only had injuries in non–head/neck regions (OR, 1.27; 95% CI, 1.07–1.51). Each additional day on a ventilator was associated with an 11% increased odds of developing pneumonia (OR, 1.11; 95% CI, 1.08–1.14). Compared with no comorbid conditions, the presence of one comorbid condition was associated with a 49% increased odds of developing pneumonia, and presence of two or more comorbid conditions was associated with twice the odds of developing pneumonia (OR, 1.49; 95% CI, 1.25–1.78; OR, 2.10; 95% CI, 1.47–1.78, respectively). In the adjusted model, sex, race/ethnicity, and insurance type were not associated with a risk of developing pneumonia.

TABLE 2. OR (and 95% CI) of Developing HAP, Mutually Adjusted for All Variables Shown—NTDB Years 2009 to 2011

Variable	OR (95% CI)	*p*
Sex		
Male	Reference	—
Female	0.88 (0.76–1.01)	0.07
Age, y		
<1	Reference	—
1–5	0.88 (0.58–1.34)	0.56
6–10	1.24 (0.93–1.66)	0.14
11–15	1.24 (0.96–1.61)	0.10
16–18	1.99 (1.56–2.55)	<0.0001
ISS		
<16	Reference	—
≥16	5.38 (4.46–6.50)	<0.0001
GCS score		
<8	2.55 (2.11–3.09)	<0.0001
≥8	Reference	—
Race/ethnicity		
White	Reference	—
African American	1.07 (0.88–1.31)	0.50
Hispanic	1.00 (0.79–1.27)	0.99
Asian	1.26 (0.78–2.06)	0.35
Other	0.82 (0.58–1.17)	0.27
Unknown	1.07 (0.61–1.90)	0.81
Ventilation days	1.11 (1.08–1.14)	<0.0001
Length of stay, d	1.02 (1.01–1.14)	<0.0001
Intensive care days	1.06 (1.03–1.08)	<0.0001
Injury pattern		
Other only	Reference	—
Head/neck only	0.85 (0.71–1.03)	0.10
Head/neck and other	1.27 (1.07–1.51)	0.005
Comorbidities		
0	Reference	—
1	1.49 (1.25–1.78)	<0.0001
2	2.10 (1.47–1.78)	<0.0001
3+	1.87 (0.77–4.56)	0.17
Insurance level		
Private	Reference	—
Public	0.98 (0.83–1.16)	0.78
Other	0.83 (0.68–1.02)	0.08

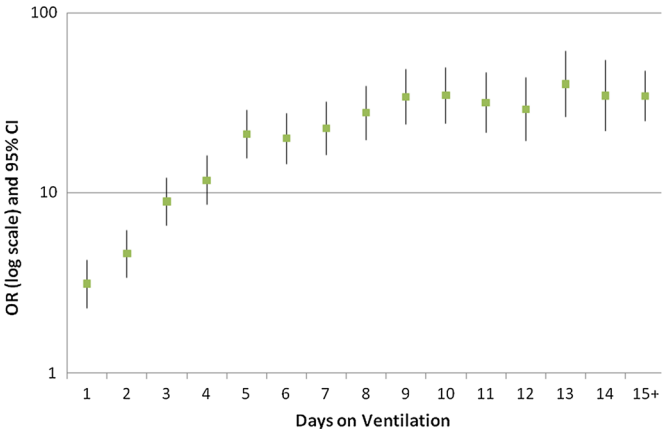

Figure 1. OR with 95% CIs of developing HAP by days on mechanical ventilation. Graphed on a log scale and adjusted for all covariates.

We further examined the relationship between mechanical ventilation and risk of developing HAP by calculating the increase in odds for each additional day on a ventilator (Fig. 1). In the fully adjusted model, we found that spending just 1 day on a ventilator was associated with three times the odds of developing pneumonia compared with no days on a ventilator (OR, 3.21; 95% CI, 2.00–5.15). The odds of developing pneumonia nearly doubled from the baseline rate for patients spending 2 days on a ventilator (OR, 5.52; 95% CI, 3.45–8.84), doubled again for patients spending 3 days (OR, 10.59; 95% CI, 6.38–17.61), and doubled again for patients spending 5 days on a ventilator (OR, 23.72; 95% CI, 13.36–42.15). As shown in Figure 1, there was an exponential increase in the odds of developing pneumonia for patients on mechanical ventilation up to 5 days, after which the odds of developing pneumonia seemed to plateau.

DISCUSSION

We report that HAP is a significant cause of morbidity in pediatric trauma patients, with nearly 1% of the patients treated at a trauma center during the study period developing HAP. To our knowledge, this is the first study to report on the incidence and risk factors of HAP in children using a large, national database. We recommend that preventive measures be implemented early in all pediatric trauma patients requiring mechanical ventilation.

In our study, similar to studies in adults,[11,12] the number of days on mechanical ventilation was strongly predictive of developing HAP in children. Several risk factors for the development of HAP have been described in adult trauma patients.[2–4] We report that pediatric patients on mechanical ventilation have an exponential increase in the odds of developing pneumonia up to 5 days, after which the odds seems to plateau. Our findings differ from those by Taira et al.[8] who reported the mean number of days from admission to diagnosis of pneumonia was 10. However, Taira et al.[8] examined a small population of regional trauma patients, and the rate of pneumonia was 0.2% overall. In

contrast, our study reports trends in a national database over a multiyear period.

We report that the severity of patient injury also significantly affected the risk of HAP. This is in agreement with previous studies in both adults and children.[8,10] Children with an ISS of 16 or greater had a threefold increase in the risk of developing HAP in our study. There are likely many reasons for this. Higher ISSs often are associated with multisystem or polytrauma. Injuries to multiple body areas may result in increased or prolonged mechanical ventilation, thereby increasing the risk of developing HAP. Even after adjustment for ventilator days in our model, higher injury severity was still independently associated with HAP. While it is possible that injury mechanism itself contributes to the development of HAP, we did not specifically address this in our study. This is an area of importance and the subject of future work by our research team.

We found that children with injuries to multiple body regions (including the head and neck) were more likely to develop HAP than children with injuries to non–head/neck regions only. These results suggest that the addition of a head and neck injury to injuries in other regions may increase risk for developing HAP. However, children with isolated head and neck injuries did not have an increased risk of pneumonia in our study, in contrast to what has been reported in adult studies.[2,3,12] We also report that children 16 years to 18 years old have a significantly higher risk of developing pneumonia than younger children. This is consistent with a previous study,[8] which reported that injured adolescents were more likely to develop HAP compared with younger children. While the reasons for this are likely numerous, one plausible explanation is that injury patterns is adolescent patients are similar to adults. Further research is needed to examine how injury patterns differ in children by age group and whether this may help explain the relationship between age and risk of developing HAP.

Comorbid conditions were also associated with increased risk of pneumonia in injured children. We report a nearly twofold increase in the risk of pneumonia in children with multiple comorbid conditions, which is similar to previous studies in both adults and children.[10,13] These results are not surprising given that some comorbid conditions (such as obesity) are associated with systemic inflammation, leading to an immune-deficient state. Clearly, this is not as dramatic as one would expect in a patient receiving chemotherapy for a malignancy, but alterations in metabolism have been shown to affect morbidity and mortality in pediatric trauma patients.[14]

We did not address any specific hospital-based preventive measures in this study because of the nature of the NTDB data. We do report that children requiring prolonged mechanical ventilation have a significantly high risk of pneumonia. Children ventilated in 3 days have a nearly 10-fold increase in the risk of pneumonia, and the risk increased to more than 20-fold by Day 5 compared with those children who were not ventilated. We strongly recommend early and aggressive use of prophylactic measures in those children requiring mechanical ventilation greater than 72 hours. A number of evidence-based prophylactic measures to reduce the risk of HAP, which are commonly used in adult trauma patients, should be considered in children. These include elevating the head of the hospital bed to 30 degrees,[15] antacid use for gastric reflux,[16] regular suctioning of oral secretions,[17] using endotracheal tubes lined with antimicrobials,[18] and minimizing patient sedation when possible.[19] The use of a "Quality Rounds Checklist" to increase compliance with evidence-based prophylactic measures has been shown to reduce the rate of pneumonia in ventilated patients.[20] However, even with these preventive measures in place, extended ventilator time has been shown to be associated with an increased risk of pneumonia.[10]

In 2008, the Centers for Medicare and Medicaid Services developed a list of "never events" and have proposed to include HAP on the list of completely preventable hospital adverse events.[21–23] Assuming that hospitals reporting to the NTDB use some form of prevention measure to avoid the development of HAP, our data suggest that pneumonia may not be entirely preventable in injured children. Injured children may require mechanical ventilation for days to weeks, which is different from children who require mechanical ventilation for a shorter, more defined period, such as children undergoing general surgical or even cardiac operative procedures.[24] Although it is desirable to extubate traumatically injured children as soon as possible, this may not always be a viable clinical option, thus calling into question the of labeling HAP as a "never event."

Our study is subject to limitations. While the NTDB provides a unique opportunity to examine a large number of trauma patient visits, the database has many limitations as stated by Hui et al.[10] The NTDB provides no follow-up patient data, and time-specific information about the initiation of mechanical ventilation and development of pneumonia is not reported. As such, long-term outcomes and temporal effects cannot be fully determined.[10] Missing data are a concern with the NTDB data and may affect our results.[10] However, NTDB inclusion criteria and data collection procedures have been standardized with the implementation of the National Trauma Standard,[9] improving the quality and consistency of the data. Inconsistent reporting by trauma centers would almost certainly result in underreporting pneumonia cases because hospitals are less likely to inaccurately report a complication in care such as pneumonia. If this is true, our findings represent the lower range of the estimates on the true incidence of HAP. Finally, because of the large, multicenter-generated database, there is the potential that confounders not reported by the NTDB contribute to the conclusions in this study.[10]

CONCLUSION

Similar to adults, injured children admitted to the hospital are at risk for HAP. Prolonged mechanical ventilation, increased injury severity, older age, and presence of multiple comorbid conditions all increase the risk of pneumonia. Preventive measures should be used early and aggressively in injured children at high risk for the development of HAP.

AUTHORSHIP

H.W.O. conceptualized and designed the study, interpreted the data, drafted the article, and approved the final version of the article as submitted. G.C. conceptualized and designed the study, analyzed and interpreted the data, drafted the article, and approved the final version of the article as submitted. J.D. provided methodological advice, revised the article, and approved the final version as submitted. A.F. provided methodological advice, reviewed the statistical analysis, revised the

article, and approved the final article as submitted. A.K. assisted with the study design, reviewed the statistical analyses, revised the article, and approved the final article as submitted.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Burt CW. *Injury-Related Visits to Hospital Emergency Departments*. Atlanta, GA: National Center for Injury Prevention and Control; 2012. Available at: http://webappa.cdc.gov/sasweb/ncipc/nfilead2001.html. Accessed February 2014.
2. Kallel H, Chelly H, Bahloul M, Ksibi H, Dammak H, Chaari A, Ben Hamida C, Rekik N, Bouaziz M. The effect of ventilator-associated pneumonia and the progress of head trauma patients. *J Trauma*. 2005;59:705–710.
3. Zygun DA, Zuege DJ, Boiteau PJ, Laupland KB, Henderson EA, Kortbeek JB, Doig CJ. Ventilator-associated pneumonia in severe traumatic brain injury. *Neurocrit Care*. 2006;5:108–114.
4. Hyllienmark P, Gårdlund B, Persson JO, Ekdahl K. Nosocomial pneumonia in the ICU: a prospective cohort study. *Scand J Infect Dis*. 2007;39:676–682.
5. Magnotti LJ, Croce MA, Fabian TC. Is ventilator-associated pneumonia in trauma patients an epiphenomenon or a cause of death? *Surg Infect (Larchmt)*. 2004;5:237–242.
6. National Nosocomial Infections Surveillance System. National Nosocomial Infections Surveillance (NNIS) System Report, data summary from 1992 through 2004, issued October 2004. *Am J Infect Control*. 2004;32:470–485.
7. Elward AM, Warren DK, Frasier VJ. Ventilator-associated pneumonia in pediatric intensive care unit patients: risk factors and outcomes. *Pediatrics*. 2002;109:758–764.
8. Taira BR, Fenton KE, Lee TK, Meng H, McCormack JE, Huang E, Singer AJ, Scriven RJ, Shapiro MJ. Ventilator-associated pneumonia in pediatric trauma patients. *Pediatr Crit Care Med*. 2009;10:491–494.
9. Haider AH. Improving the quality of science arising from the NTDB: we can do this! *J Trauma Acute Care Surg*. 2013;74(2):352–353.
10. Hui X, Haider AH, Hashmi ZG, Rushing AP, Dhiman N, Scott VK, Selvarajah S, Haut ER, Efron DT, Schneider EB. Increased risk of pneumonia among ventilated patients with traumatic brain injury: every day counts! *J Surg Res*. 2013;184:438–443.
11. Gautam A, Ganu SS, Tegg OJ, Andresen DN, Wilkins BH, Schell DN. Ventilator-associated pneumonia in a tertiary paediatric intensive care unit: a 1 year prospective observational study. *Crit Care Resusc*. 2012;14(4):283–289.
12. Gamberoni C, Colombo G, Aspesi M, Mascheroni C, Severgnini P, Minora G, Pelosi P, Chiaranda M. Respiratory mechanics in brain injured patients. *Minerva Anestesiol*. 2002;68:291–296.
13. Serrano PE, Khuder SA, Fath JJ. Obesity as a risk factor for nosocomial infections in trauma patients. *J Am Coll Surg*. 2010;211(1):61–67.
14. Waibel BH, Durham CA, Newell MA, Schlitzkus LL, Sagraves SG, Rotondo MF. Impact of hypothermia in the rural pediatric trauma patient. *Pediatr Crit Care Med*. 2010;11(2):199–204.
15. George DL. Epidemiology of nosocomial pneumonia in intensive care unit patients. *Clin Chest Med*. 1995;16:29–30.
16. Finegold SM. Aspiration pneumonia. *Rev Infect Dis*. 1991;13(9):737–738.
17. Verghese A, Berk SL. Bacterial pneumonia in the elderly. *Medicine*. 1983;62:271–273.
18. Ciocon JO, Silverstone FA, Graver LM, Foley CJ. Tube feedings in elderly patients. Indications, benefits, complications. *Arch Intern Med*. 1988;148:429–432.
19. Kikawada M, Iwamoto T, Taksaki M. Aspiration and infection in the elderly: epidemiology, diagnosis, and management. *Drugs Aging*. 2005;22:115–118.
20. Dubose J, Teixeira PG, Inaba K, Lam L, Talving P, Plurad D, Green DJ, Demetriades D, Belzberg H. Measurable outcomes of quality improvement using a daily quality rounds checklist: one-year analysis in a trauma intensive care unit with sustained ventilator-associated pneumonia reduction. *J Trauma*. 2010;69(4):855–860.
21. Palmer JL, Metheny NA. Preventing aspiration in older adults with dysphagia. *Am J Nurs*. 2008;108:40–41.
22. Straube B, Blum JD. The policy on paying for treating hospital-acquired infections. *Health Aff (Milwood)*. 2009;28:1494–1495.
23. Shorr AF, Owens RC. Guidelines and quality for community-acquired pneumonia: measures from the Joint Commission and Centers for Medicare and Medicaid Services. *Am J Health Syst Pharm*. 2009;66(4):2–7.
24. Semenov YR, Starmer HM, Gourin CG. The effect of pneumonia on short term outcomes and cost of care after head and neck cancer surgery. *Laryngoscope*. 2012;122:1994–1996.