RESEARCH ARTICLE

Injury Region and Risk of Hospital-Acquired Pneumonia Among Pediatric Trauma Patients

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ABSTRACT

OBJECTIVE: To describe the relationship between injury region and risk of hospital-acquired pneumonia (HAP) in pediatric trauma patients.

METHODS: Analyses included patients <19 years of age from the National Trauma Data Bank, during 2009–2011. Multivariable logistic regression was used to examine the association between injury region and odds of developing HAP stratified by age group.

RESULTS: A total of 71 377 patients were eligible for analysis, and 1818 patients developed pneumonia. In adjusted regression models both younger (11–15 years) and older (16–18 years) adolescents with multisite injuries including the head and neck had higher odds of developing HAP compared with adolescents with isolated head and neck injuries (odds ratio [OR] = 2.04, 95% confidence interval [CI] 1.34–3.10; OR = 1.47, 95% CI 1.14–1.89, respectively), and younger adolescents with multisite injuries not involving the head and neck also had higher odds of developing HAP (OR = 1.97, 95% CI 1.08–3.60). We found no significant association between injury region and risk of HAP in children <11 years of age. Younger and older adolescents with firearm (OR = 1.85, 95% CI 1.00–3.42; OR = 1.39, 95% CI 1.02–1.88, respectively) or pulmonary (OR = 3.78, 95% CI 1.26–11.3; OR = 2.56, 95% CI 1.01–6.51, respectively) injuries had higher odds of developing HAP compared with those with motor vehicle collision injuries.

CONCLUSIONS: Adolescent trauma patients with multisite injuries including the head and neck have a higher risk of developing HAP compared with those with isolated head and neck injuries. We identified several risk factors that can be used to inform future research focused on identifying subgroups at high risk for the development of HAP.

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Hospital-acquired infections (HAIs) are the most common complication in hospitalized patients, resulting in a large clinical and economic burden.[1,2] Trauma patients are at an increased risk of developing HAIs because their injuries lead to disruptions in tissue integrity and impaired host defense mechanisms.[3–5] Hospital-acquired pneumonia (HAP) is an important and potentially preventable HAI that is a significant cause of secondary morbidity in both adult and pediatric trauma patients.[2,6–8] Adult trauma patients with HAIs, including pneumonia, have been shown to have an increased length of stay (LOS), increased inpatient costs, and higher risk for mortality compared with patients without HAIs.[2] Although reducing HAIs is a top priority for both federal and nongovernmental agencies, there is a lack of research on HAP in pediatric trauma patients.[2,6]

We recently completed an analysis of the National Trauma Data Bank (NTDB), which was the first to identify risk factors for HAP in pediatric trauma patients using a large, multicenter database.[7] Several risk factors for the development of HAP in pediatric trauma patients were identified, including injury severity, presence of comorbid conditions, and days on mechanical ventilation.[7] Risk of HAP was also higher in older adolescents, and although it is not clear why, this is likely due to differences in injury patterns by age group. Another recent analysis of the NTDB found that age group modified the relationship between isolated head injury and hypotension.[9] Although head injuries have been shown to increase risk for HAP in adults, little is known regarding the relationship between injury region and risk of HAP in youth. To identify effective strategies for prevention, it is critical to identify subgroups of pediatric trauma patients at highest risk of developing HAP.

The primary objective of this study was to examine the association between injury region and risk of developing HAP in pediatric trauma patients. We also sought to determine whether the relationship between injury region and risk of developing HAP is modified by age group.

METHODS

Patient Population

This is a retrospective analysis of trauma patients younger than 19 years from the NTDB, years 2009 through 2011. The NTDB represents the largest centralized collection of trauma patients in the United States and is sponsored by the American College of Surgeons. More than 700 US trauma centers and hospitals voluntarily reported deidentified information to the NTDB, including >95% of all American College of Surgeons–verified level I and level II trauma centers.[10] 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 emergency department "dead on arrival," or if they "died after failed rescue." Patients were also excluded if they were not admitted or if their LOS was <2 days. The NTDB provides no follow-up patient data, and time-specific information about a diagnosis of pneumonia is not reported. For this analysis, we defined the term "hospital-acquired pneumonia" to include aspiration pneumonia, ventilator-associated pneumonia, and infectious pneumonia that developed 48 hours after hospital admission. Similar to other studies in trauma patients, we assumed that all patients with a diagnosis of pneumonia developed this infection while hospitalized because it is unlikely that patients admitted with traumatic injuries would have a preexisting case of pneumonia.[2] We chose to exclude all patients with a LOS <2 days because we assumed that patients who were discharged or who died within this time period would not have time to develop HAP. We included patients with the following *International Classification of Diseases, Ninth Revision* (*ICD-9*) codes for ventilator-associated, aspiration, or infectious pneumonia: 997.31, 507.0, 481 through 486. An injured child was also considered to have HAP if pneumonia was listed as a hospital complication in the NTDB database.

Injury Region

Injury region was based on *ICD-9* body region codes as defined by the Barell Injury Diagnosis Matrix. We classified patients as having isolated head and neck injuries or multisite injuries. Patients with multiple injury regions were classified into 2 groups: multisite injuries including the head and neck region and multisite injuries not including the head and neck region. Patients were excluded if they did not have multisite or head and neck injuries or if information on region of injury was missing.

Covariates

Additional data obtained from the NTDB included age, sex, race/ethnicity, Injury Severity Score (ISS), Glasgow Coma Scale (GCS), LOS (days), number of days in the ICU, days on mechanical ventilation, mechanism of injury, and comorbid conditions. Race/ethnicity was categorized as follows: white, African American, Hispanic, Asian, and other (Native Hawaiian or other Pacific Islander, other race) or unknown. Mechanism of injury was categorized as motor vehicle collision (MVC), pulmonary, fall, firearm, blunt trauma, and other/unspecified. We categorized the following injury mechanisms as pulmonary as they would be the most likely to result in damage to the lungs: drowning/submersion, suffocation, and fire. The NTDB categorizes 24 comorbid conditions. A patient was considered to have ≥1 comorbid conditions if he or she had any condition listed in the NTDB database.

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. Logistic regression was used to examine the association between injury region and odds of developing HAP. We first examined the relationship between injury region and age group by adding an interaction term to the model. We found a significant interaction

between injury pattern and age group ($P \leq .0001$), and thus, we stratified all further analyses by age group (0–5 years, 6–10 years, 11–15 years, 16–18 years). Logistic regression models were first run without adjustment for confounders. A final multivariable model was run based on levels of statistical significance ($P < .05$) seen in the unadjusted models. The final multivariable model included injury region, mechanism of injury, sex, ISS, GCS, number of days on a ventilator, ICU days, LOS (days), and comorbid conditions (yes/no). GCS was missing for a large proportion of our study sample (18.9%). We ran our main models both including and excluding GCS. Because results changed significantly when excluding GCS, we chose to include this variable in our final regression models, and all patients with missing GCS were excluded. All analyses were run using the Statistical Analysis System (SAS, version 9.3, Cary, NC). All *P* values were from 2-tailed tests and were considered to be statistically significant if <.05.

RESULTS

In 2009–2011, there were 391 086 pediatric trauma patients in the NTDB database. Our final analysis cohort included 71 377 patients (Fig 1), of which 1818 (2.6%) developed HAP. The majority of HAP cases were found in adolescents between 11 and 18 years of age ($n = 1458$), and only 48 infants <1 year of age developed HAP. Demographics and characteristics of our overall study population along with HAP cases are provided in Table 1. The majority of patients were between the ages of 11 and 18 years (63.4%), and slightly more than half were white (52.2%). Most patients were male (65.7%), had no comorbidities (85.6%), and were not considered severely injured (64.3% with an ISS <16). Reasons for visit were as follows: 40.7% of patients visited for isolated head and neck injuries, 40.8% visited for multisite injuries including the head and neck, and 18.5% visited for multisite injuries not including the head and neck.

Injury Region by Age Group

Region of injury differed significantly by age group ($P < .0001$, Table 2). The percent of visits for isolated head and neck injuries was highest in patients aged 5 years or younger and decreased with increasing age group (60.9% of visits in patients aged 0–5 years compared with 28.1% in patients aged 16–18 years). The opposite was found for multisite injuries including head and neck regions, which represented only 23.9% of visits in patients <5 years of age, but 49.7% of visits in 16- to 18-year-olds. Multisite injuries not including the head and neck represented the least common injury for all age groups, ranging from 14.8% (6- to 10-year-olds) to 22.2% (16- to 18-year-olds).

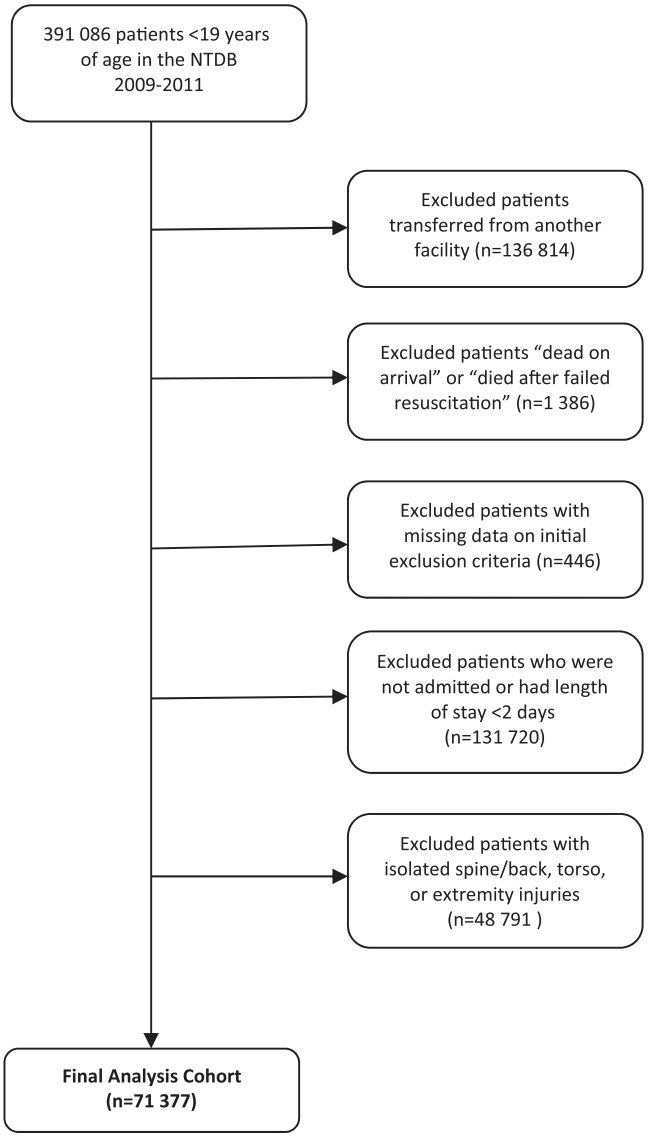

FIGURE 1 Patient selection

Injury Region and Risk of Developing HAP

In multivariable regression models, both younger (aged 11–15 years) and older (aged 16–18 years) adolescents with multisite injuries including the head and neck had higher odds of developing HAP compared with patients with isolated head and neck injuries (Table 3). Younger adolescents with multisite injuries not including the head and neck also had higher odds of developing HAP compared with those with isolated head and neck injuries. We found no significant associations between injury region and odds of

TABLE 1 Demographics and Characteristics of the Study Population

Variable	Overall Population (n = 71 377)	Pneumonia (n = 1818)	No Pneumonia (n = 69 559)	P[a]
Sex, *n* (%)				
Female	24 448 (34.3)	518 (28.5)	23 930 (34.4)	<.0001
Male	46 885 (65.7)	1300 (71.5)	45 585 (65.6)	
Age, *n* (%)				
0–5	17 643 (24.7)	220 (12.1)	17 423 (25.1)	<.0001
6–10	8524 (11.9)	140 (7.7)	8384 (12.1)	
11–15	15 959 (22.4)	316 (17.4)	15 643 (22.5)	
16–18	29 251 (41.0)	1142 (62.8)	28 109 (40.4)	
Race/ethnicity, *n* (%)				
White	37 280 (52.2)	1039 (57.2)	36 241 (52.1)	.0007
African American	14 508 (20.3)	332 (18.3)	14 176 (20.4)	
Hispanic	12 380 (17.3)	293 (16.1)	12 087 (17.4)	
Asian	1264 (1.8)	28 (1.5)	1236 (1.8)	
Other/unknown	5945 (8.3)	126 (6.9)	5819 (8.4)	
Injury region, *n* (%)				
Multisite with head and neck	29 056 (40.7)	1255 (69.0)	27 801 (40.0)	<.0001
Multisite without head and neck	13 170 (18.5)	200 (11.0)	12 970 (18.7)	
Isolated head and neck	29 151 (40.8)	363 (20.0)	28 788 (41.4)	
Injury mechanism *n* (%)				
MVC	31 232 (43.8)	1128 (62.1)	30 104 (43.3)	<.0001
Pulmonary	951 (1.3)	40 (2.2)	911 (1.3)	
Fall	12 639 (17.7)	144 (7.9)	12 495 (18.0)	
Firearm	3509 (4.9)	164 (9.0)	3345 (4.8)	
Blunt trauma	6014 (8.4)	63 (3.5)	5951 (8.6)	
Other/unspecified	17 032 (23.9)	279 (15.4)	16 753 (24.1)	
ISS				
Mean (SD)	12.1 (9.9)	26.6 (12.6)	11.8 (9.6)	<.0001
Median (IQR)	10 (5–17)	26 (17–34)	10 (5–17)	
<16, *n* (%)	41 469 (64.3)	162 (11.0)	41 307 (65.5)	<.0001
≥16, *n* (%)	23 074 (35.8)	1317 (89.1)	21 757 (34.5)	
GCS score				
Mean (SD)	13.3 (3.6)	7.4 (4.8)	13.4 (3.4)	<.0001
Median (IQR)	15 (14–15)	6 (3–12)	15 (14–15)	
<8, *n* (%)	6446 (11.1)	989 (61.3)	5457 (9.7)	<.0001
≥8, *n* (%)	51 422 (88.9)	624 (38.7)	50 798 (90.3)	
LOS (d)				
Mean (SD)	6.0 (8.4)	24.2 (18.6)	5.5 (7.4)	<.0001
Median (IQR)	3 (2–6)	20 (13–31)	3 (2–6)	
Intensive care days				
Mean (SD)	2.5 (5.8)	16.7 (13.9)	2.1 (4.9)	<.0001
% with days	49.7	88.7	18.0	
Ventilation days				
Mean (SD)	1.2 (4.4)	12.4 (12.1)	0.9 (3.5)	<.0001
% with days	19.9	97.0	48.4	
Comorbidities, n (%)				
0	61 074 (85.6)	1451 (79.8)	59 623 (85.7)	<.0001
≥1	10 303 (14.4)	367 (20.2)	9936 (14.3)	

IQR, interquartile range.

[a] P value from t test (continuous variables) or χ^2 (categorical variables).

developing HAP in children (aged 0–5 and 6–10 years).

Other Risk Factors for HAP Development

Injury severity and GCS score were associated with higher odds of developing HAP in all age groups, whereas intensive care days and having ≥1 comorbid conditions was associated with increased odds in all age groups except 6- to 10-year-olds (Table 3). Older and younger adolescents with firearm or pulmonary injuries had higher odds of developing HAP compared with adolescents with MVC injuries, and younger adolescents with injuries resulting from a fall also had higher odds of developing HAP. Females in the older adolescent age group had lower odds of developing HAP compared with males. Finally, number of days on mechanical ventilation was associated with higher odds of developing HAP in adolescents, but not in children. The number and percentage of patients who developed HAP by age group and risk factor is presented in Supplemental Table 4.

DISCUSSION

We found a significant relationship between injury region and risk of developing HAP in adolescent trauma patients. Both younger and older adolescent patients with multisite injuries that included the head and neck had significantly higher odds of developing HAP compared with patients with isolated head and neck injuries, and younger adolescents with multisite injuries not including the head and neck also had significantly higher odds of developing HAP. In addition, both younger and older adolescents with firearm or pulmonary injuries had significantly higher odds of developing HAP compared with adolescents with MVC injuries. We found no significant relationship between injury region or mechanism in children under 11 years of age. To our knowledge, this is the first study to examine the relationship between injury region and development of HAP in pediatric patients.

Reducing HAIs, including pneumonia, is a top priority for federal government and nongovernmental entities.[2] HAP continues to be a major challenge for critical care physicians and is associated with increased

TABLE 2 Injury Region by Age Group

	Age Group				
	0–5 y	6–10 y	11–15 y	16–18 y	*P*[a]
Isolated head and neck	10 739 (60.9)	3957 (46.4)	6237 (39.1)	8218 (28.1)	<.0001
Multisite without head and neck	2686 (15.2)	1257 (14.8)	2724 (17.1)	6503 (22.2)	
Multisite with head and neck	4218 (23.9)	3310 (38.8)	6998 (43.9)	14 530 (49.7)	
Total	17 643	8524	15 959	29 251	

[a] *P* value from χ^2.

morbidity while also imposing a significant financial burden on the health care system.[11] The Centers for Disease Control and Prevention has created evidence-based guidelines focused on reducing or eliminating HAIs via device-associated infection prevention "bundles."[12] After the introduction of an implementation science initiative based on these Centers for Disease Control and Prevention guidelines, a recent study found that rates of ventilator-associated pneumonia in adult trauma patients declined by 24.9% over a 28-month period.[13] Another recent study found a significant reduction in ventilator-associated pneumonia in adult burn patients with the use of prevention bundles.[14] Although a reduction in HAIs could have a significant impact on health care costs and outcomes in both children and adults, there is a lack of pediatric-specific research.[2,6] Information on subgroups of pediatric patients at highest risk of HAP is crucial because it can be used to risk stratify who gets HAP prophylaxis. Although we have identified several risk factors for the development of HAP, we cannot currently determine which patients are truly high risk or whether there are subgroups of patients that should be treated early and aggressively. A crucial next step will be to combine the risk

TABLE 3 OR of Developing HAP by Injury Region and Age Group

	0–5 y OR (95% CI)[a]	6–10 y OR (95% CI)[a]	11–15 y OR (95% CI)[a]	16–18 y OR (95% CI)[a]
Region of injury				
Isolated head and neck	Reference	Reference	Reference	Reference
Multisite without head and neck	1.88 (0.92–3.86)	0.71 (0.23–2.20)	1.97 (1.08–3.60)[b]	1.12 (0.79–1.57)
Multisite with head and neck	1.23 (0.82–1.86)	1.11 (0.63–1.97)	2.04 (1.34–3.10)[b]	1.47 (1.14–1.89)[b]
Mechanism of injury				
MVC	Reference	Reference	Reference	Reference
Pulmonary	0.44 (0.10–1.90)	4.37 (0.81–23.69)	3.78 (1.26–11.3)[b]	2.56 (1.01–6.51)[b]
Fall	0.96 (0.58–1.60)	0.72 (0.31–1.72)	1.87 (1.10–3.18)[b]	0.71 (0.46–1.08)
Firearm	0.19 (0.02–1.99)	—	1.85 (1.00–3.42)[b]	1.39 (1.02–1.88)[b]
Blunt trauma	1.09 (0.53–2.25)	0.65 (0.19–2.16)	1.73 (0.87–3.42)	0.79 (0.46–1.36)
Other/unspecified	0.80 (0.48–1.18)	0.89 (0.47–1.69)	0.93 (0.62–1.40)	0.95 (0.72–1.25)
Sex				
Male	Reference	Reference	Reference	Reference
Female	0.97 (0.68–1.39)	1.05 (0.66–1.67)	1.08 (0.78–1.50)	0.75 (0.62–0.92)[b]
ISS				
<16	Reference	Reference	Reference	Reference
≥16	3.60 (2.19–5.92)[b]	7.01 (3.29–14.9)[b]	9.44 (5.44–16.4)[b]	4.24 (3.23–5.58)[b]
GCS score				
<8	4.93 (3.26–7.45)[b]	4.70 (2.81–7.86)[b]	3.36 (2.36–4.78)[b]	2.91 (2.39–3.54)[b]
≥8	Reference	Reference	Reference	Reference
Ventilation days	1.01 (0.98–1.04)	1.01 (0.96–1.06)	1.07 (1.04–1.10)[b]	1.07 (1.05–1.09)[b]
Length of stay (d)	1.00 (0.98–1.02)	1.02 (0.99–1.04)	1.01 (0.99–1.03)	1.02 (1.02–1.03)[b]
Intensive care days	1.06 (1.02–1.10)[b]	1.05 (1.00–1.09)[b]	1.03 (0.99–1.06)	1.06 (1.04–1.08)[b]
Comorbid conditions				
0	Reference	Reference	Reference	Reference
1+	2.28 (1.42–3.66)[b]	2.04 (1.17–3.56)[b]	1.27 (0.85–1.89)	1.37 (1.11–1.68)[b]

—, no data.
[a] Models mutually adjusted for all variables shown.
[b] $P \leq .05$.

factors identified in this article into a prediction model.

Few studies have examined the development of pneumonia in pediatric trauma patients. In 2009, Tiara et al examined ventilator-associated pneumonia in pediatric patients treated at a regional level 1 trauma center. Although they concluded that head injury may increase risk for pneumonia in pediatric patients, their study was limited by a small sample size including only 7 true cases.[6] The current study, along with our previous analysis of HAP in pediatric patients, used the largest centralized collection of data on trauma patients in the United States.[7] We did not find that pediatric trauma patients with isolated head and neck injuries were at highest risk of developing HAP but instead found that adolescent patients with multiple injury regions including the head and neck were at the highest risk, even when adjusting for injury severity. Although we are not sure why adolescent patients with multiple injuries are at increased risk for HAP, it is possible that a more global, multiorgan injury could lead to a higher level of trauma-induced alteration of the immune system called immunoparalysis. Studies have shown that a significant proportion of patients with multiple traumatic injuries develop immunoparalysis,[15] which has been shown to increase risk for the development of HAIs in children.[16] Multisite injuries can also be associated with chest wall trauma, which may increase risk for HAP development.

Multiple studies have found that head injury is associated with HAP in adult trauma patients.[17,18] Specifically, patients with severe traumatic brain injury may represent a subgroup of patients at very high risk of HAP.[17] A variety of factors may explain this increased risk, including altered respiratory mechanics in patients with brain injuries,[19] and the necessity for prolonged mechanical ventilation.[18] Zygun et al examined adult patients with traumatic brain injury, and, similar to our results, found that patients with injuries to multiple body regions had a higher risk of pneumonia compared with patients with isolated head injuries.[17] To our knowledge, this is the first study to examine whether the association between multisite injuries and HAP development differs depending on whether injuries to the head and neck are involved. Further research is needed to better elucidate the relationship between injury region and HAP risk in pediatric trauma patients using large data sets, including an examination of HAP in youth with traumatic brain injury.

We found that both younger and older adolescents with pulmonary or firearm injuries had higher odds of developing HAP compared with patients with MVC injuries. A recent study in adult trauma patients found that patients with a gunshot wound were at higher risk of developing an HAI, but this study did not examine pulmonary injuries.[2] We categorized injuries caused by suffocation, drowning or submersion, or fire as pulmonary as these mechanisms can all cause damage to a patient's lungs. Pulmonary damage may result in decreased clearance of infectious organisms, increasing risk for developing HAP.[14] While our results suggest that adolescent trauma patients with firearm or pulmonary injuries are a high-risk group, more research is needed on how different mechanisms of injury impact the risk of developing HAP in pediatric trauma patients using larger datasets and more detailed categorization.

In a previous analysis, we found that older pediatric trauma patients had higher odds of developing HAP compared with younger patients, and we hypothesized that older adolescents might be at greater risk as a result of differences in injury region by age group.[7] In the current study, we found that region of injury differed significantly by age group, with infants and preschoolers visiting trauma centers more often for isolated head and neck injuries and older adolescents visiting more often for multisite injuries. We also found that age group significantly modified the relationship between injury region and risk of developing HAP. Age-related alterations in immunity and immune system response to traumatic injury may vary, and our data do suggest a different relationship between injury region and risk for HAP in children versus adolescents. Our current study was limited by a small number of HAP cases in the youngest age groups, especially infants, and more research is needed with larger samples to fully determine how the relationship between injury patterns and risk of HAP development differs by age.

Our study is subject to several limitations. Although the NTDB provides a unique opportunity to examine a large number of patient visits to trauma centers, the database has many limitations. As stated by Hui et al, 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.[18] Therefore, long-term outcomes and temporal effects cannot be fully determined when using the NTDB.[18] Missing data are a concern with the NTDB data and may affect our results. However, NTDB inclusion criteria and data collection procedures have been standardized with the implementation of the National Trauma Standard,[10] improving the quality and consistency of the data. We used *ICD-9* codes to determine HAP cases. *ICD-9* codes have been shown to have a high specificity for identifying pneumonia cases but have lower sensitivity.[2] HAP cases may be underreported in the NTDB, and if this is the case, would underestimate the true incidence of HAP in our population. This underreporting may lead to an underestimation of the impact of our predictor variables on our outcome due to inclusion of HAP cases in the population of patients classified as not having HAP.[2] The small number of pneumonia cases in the youngest patients meant that we could not fully explore all injury regions and also limited our ability to examine risk factors for HAP in toddlers and infants. Finally, there is the potential that confounders not reported by the NTDB contribute to the conclusions in this study.

CONCLUSIONS

Older and younger adolescent trauma patients with multisite injuries that include the head and neck are at higher risk of developing HAP compared with those with isolated head and neck injuries. We identified several risk factors in this study that can be used to inform future research focused on identify subgroups of patients at high risk for the development of HAP. Finally, we found that the relationship between injury region and HAP was significantly

modified by age group; therefore, future research in this area should examine children and adolescents separately.

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