Which hospital-acquired conditions matter the most in trauma? An evidence-based approach for prioritizing trauma program improvement

Patrick T. Lee, MD, PhD, Laura K. Krecko, MD, Stephanie Savage, MD, MS, Ann P. O'Rourke, MD, MPH, FACS, Hee Soo Jung, MD, FACS, FCCM, Angela Ingraham, MD, MS, FACS, Ben L. Zarzaur, MD, MPH, FACS, *and* **John E. Scarborough, MD, FACS**, *Madison, Wisconsin*

CONTINUING MEDICAL EDUCATION CREDIT INFORMATION

Accreditation

In support of improving patient care, this activity has been planned and implemented by CineMed and the American Association for the Surgery of Trauma. CineMed is jointly accredited by the Accreditation Council for Continuing Medical Education (ACCME), the Accreditation Council for Pharmacy Education (ACPE), and the American Nurses Credentialing Center (ANCC), to provide continuing education for the healthcare team.

AMA PRA Category 1 Credits™

CineMed designates this enduing material for a maximum of 1 *AMA PRA Category 1 Credit(s)™*. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

JOINTLY ACCREDITED PROVIDER™
INTERPROFESSIONAL CONTINUING EDUCATION

Objectives

After reading the featured articles published in the *Journal of Trauma and Acute Care Surgery*, participants should be able to demonstrate increased understanding of the material specific to the article. Objectives for each article are featured at the beginning of each article and online. Test questions are at the end of the article, with a critique and specific location in the article referencing the question topic.

Disclosure Information

In accordance with the ACCME Accreditation Criteria, CineMed must ensure that anyone in a position to control the content of the educational activity (planners and speakers/authors/discussants/moderators) has disclosed all financial relationships with any commercial interest (termed by the ACCME as "ineligible companies", defined below) held in the last 24 months (see below for definitions). Please note that first authors were required to collect and submit disclosure information on behalf all other authors/contributors, if applicable.

Ineligible Company: The ACCME defines an "ineligible company" as any entity producing, marketing, selling, re-selling, or distributing health care goods or services used on or consumed by patients. Providers of clinical services directly to patients are NOT included in this definition.

Financial Relationships: Relationships in which the individual benefits by receiving a salary, royalty, intellectual property rights, consulting fee, honoraria, ownership interest (e.g., stocks, stock options or other ownership interest, excluding diversified mutual funds), or other financial benefit. Financial benefits are usually associated with roles such as employment, management position, independent contractor (including contracted research), consulting, speaking and teaching, membership on advisory committees or review panels, board membership, and other activities from which remuneration is received, or expected.

Conflict of Interest: Circumstances create a conflict of interest when an individual has an opportunity to affect CME content about products or services of a commercial interest with which he/she has a financial relationship.

The ACCME also requires that CineMed manage any reported conflict and eliminate the potential for bias during the session. Any conflicts noted below have been managed to our satisfaction. The disclosure information is intended to identify any commercial relationships and allow learners to form their own judgments. However, if you perceive a bias during the educational activity, please report it on the evaluation. All relevant financial relationships have been mitigated.

AUTHORS/CONTRIBUTORS
Patrick T. Lee, Laura K. Krecko, Stephanie Savage, Ann P. O'Rourke, Hee Soo Jung, Angela Ingraham, Ben L. Zarzaur, and John E. Scarborough have nothing to disclose.

EDITORIAL BOARD MEMBERS					
First Name	Last Name	Disclosure?	Name of Commercial Interest	What was Received?	What was the Role?
Michael	Nance	Yes	Endo Pharmaceuticals	Consulting fee	Consultant
Heena	Santry	Yes	NBBJ	Salary	Employee
Jose	Diaz	Yes	Acumed/Acute Innovations	Consulting fee	Consultant
Lena	Napolitano	Yes	Merck Global Negative Advisory Board/Abbvie Critical Care Working Group	Consulting fee	Advisor/ Consultant

Roxie Albrecht, Walter Biffl, Karen Brasel, Clay Cothren Burlew, Raul Coimbra, Todd Costantini, Rochelle Dicker, Tabitha Garwe, Kenji Inaba, Rosemary Kozar, David Livingston, Ali Salim, Deborah Stein, Alex Valadka, Robert Winchell, Bishoy L. Zakhary, and Ben Zarzau have no disclosures or conflicts of interest to report. The Editorial Office staff has no disclosures to report.

Claiming Credit

To claim credit, please visit the AAST website at http://www.aast.org/ and click on the "e-Learning/MOC" tab. You must read the article, successfully complete the post-test and evaluation. Your CME certificate will be available immediately upon receiving a passing score of 75% or higher on the post-test. Post-tests receiving a score of below 75% will require a retake of the test to receive credit.

Credits can only be claimed online

Cost

For AAST members and Journal of Trauma and Acute Care Surgery subscribers there is no charge to participate in this activity. For those who are not a member or subscriber, the cost for each credit is $25.

Questions

If you have any questions, please contact AAST at 800-789-4006. Paper test and evaluations will not be accepted.

BACKGROUND: Prevention of hospital-acquired conditions (HACs) is a focus of trauma center quality improvement. The relative contributions of various HACs to postinjury hospital outcomes are unclear. We sought to quantify and compare the impacts of six HACs on early clinical outcomes and resource utilization in hospitalized trauma patients.

METHODS: Adult patients from the 2013 to 2016 American College of Surgeons Trauma Quality Improvement Program Participant Use Data Files who required 5 days or longer of hospitalization and had an Injury Severity Score of 9 or greater were included. Multiple imputation with chained equations was used for observations with missing data. The frequencies of six HACs and five adverse outcomes were determined. Multivariable Poisson regression with log link and robust error variance was used to produce relative risk estimates, adjusting for patient-, hospital-, and injury-related factors. Risk-adjusted population attributable fractions estimates were derived for each HAC-outcome pair, with the adjusted population attributable fraction estimate for a given HAC-outcome pair representing the estimated percentage decrease in adverse outcome that would be expected if exposure to the HAC had been prevented.

RESULTS: A total of 529,856 patients requiring 5 days or longer of hospitalization were included. The incidences of HACs were as follows: pneumonia, 5.2%; urinary tract infection, 3.4%; venous thromboembolism, 3.3%; surgical site infection, 1.3%; pressure ulcer, 1.3%; and central line-associated blood stream infection, 0.2%. Pneumonia demonstrated the strongest association with in-hospital outcomes and resource utilization. Prevention of pneumonia in our cohort would have resulted in estimated reductions of the following: 22.1% for end organ dysfunction, 7.8% for mortality, 8.7% for prolonged hospitalization, 7.1% for prolonged intensive care unit stay, and 6.8% for need for mechanical ventilation. The impact of other HACs was comparatively small.

CONCLUSION: We describe a method for comparing the contributions of HACs to outcomes of hospitalized trauma patients. Our findings suggest that trauma program improvement efforts should prioritize pneumonia prevention. (*J Trauma Acute Care Surg.* 2022;93: 446–452. Copyright © 2022 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level IV.
KEY WORDS: Hospital-acquired condition; prevention; quality.

Injury and injury-related complications result in major morbidity and mortality. In a given year, nearly 200,000 people die from violence and unintentional injuries,[1] with millions requiring emergency department care and hospitalizations.[2] Despite improvements in modern trauma surgery management,[3,4] patients hospitalized after injury remain at high risk for in-hospital complications and subsequent mortality.[5,6] Hospital-acquired conditions (HACs), such as pneumonia, deep vein thrombosis, pulmonary embolism, and surgical site infection (SSI) lead to adverse outcomes far exceeding those associated with initial injury, including increased length of stay, resource utilization, morbidity, and mortality.[7,8]

To the extent that HACs reflect the quality of care delivered in trauma centers, their identification and prevention has become a primary focus of national trauma performance initiatives.[9,10] The American College of Surgeons Trauma Quality Improvement Program (ACS TQIP) prospectively collects data and provides participating centers with benchmarking metrics to compare their performance relative to similar institutions.[11] Although such efforts have clarified the incidences of various HACs, it remains unclear which HACs confer the greatest individual and institutional burden. Frequency of occurrence alone does not fully reflect a given complication's consequences; thus, a standardized method for assessing and prioritizing HACs according to overall importance is needed. The goal of the present study is to describe a method for comparing the relative impacts of various HACs to identify which complications merit the greatest attention for targeted improvement based on their effects on patient outcomes and resource utilization.

MATERIALS AND METHODS

The 2013 to 2016 ACS TQIP Participant Use Data Files (PUFs) were used for this analysis.[10] Patients were included in our study if they were 16 years or older, were admitted to the hospital from the emergency department (ED), had an Injury Severity Score (ISS) of 9 or greater, and had a length of index hospitalization of 5 days or longer. We excluded patients with nonsurvivable injury (defined as an ISS of 75) and patients who were hospitalized for fewer than 5 days. Patients with shorter hospitalizations were excluded under the assumption that a minimum duration of hospitalization would be necessary to develop and exhibit signs and/or symptoms of HACs.

The primary clinical outcome measures for our study were in-hospital end organ dysfunction (EOD) and mortality. A patient was considered to have sustained EOD if they developed one or more of the following complications during their postinjury index hospitalization: sepsis, septic shock, unplanned reintubation, stroke, cardiac arrest requiring cardiopulmonary resuscitation, acute respiratory distress syndrome, and/or acute kidney injury. The primary resource utilization outcomes for our study were prolonged index hospitalization,

Submitted: January 25, 2022, Revised: March 14, 2022, Accepted: March 30, 2022, Published online: April 8, 2022.
From the Department of Surgery (P.T.L., L.K.K.), University of Wisconsin School of Medicine and Public Health; and Department of Surgery (S.S., A.P.O., H.S.J., A.I., B.L.Z., J.E.S.), Division of Acute Care and Regional General Surgery, University of Wisconsin Hospital and Clinics, Madison, Wisconsin.
This study was presented at the AAST 2020 meeting. ORCID number: 0000-0002-5516-0664.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).
Address for reprints: Laura K. Krecko, MD, 600 Highland Ave, G5/340 CSC Madison, WI 53792-3236; email: lkrecko@uwhealth.org.

DOI: 10.1097/TA.0000000000003645

prolonged length of intensive care unit (ICU) stay, and need for mechanical ventilation. Prolonged postoperative hospitalization was defined as a length of hospitalization 75th percentile or greater of that observed for the entire study population (≥13 days).[12] Prolonged length of ICU stay (≥5 days) was defined in a similar manner.

The primary predictor variables for our study were the presence or absence of six HACs: SSI, central line-associated blood stream infection (CLABSI), urinary tract infection (UTI), venous thromboembolism (VTE), decubitus ulcer, and pneumonia. Surgical site infection was defined as the development of an incisional and/or organ/space SSI during index hospitalization while VTE was defined as the development of a deep VTE and/or pulmonary embolism during index hospitalization. Additional predictor variables included the patient, hospital, and injury-related characteristics listed in Table 1.

Multiple imputation using chained equations was used for observations with missing data for one or more variables, with 10 data sets being imputed, averaging predictions, and adjusting standard errors for uncertainty owing to imputation.[13] The degree of missingness ranged from 0.04% to 8.5%. Those variables with missing data for one or more observations included gender (n = 186 missing observations), age (n = 32,537), race/ethnicity (n = 16,468), geographic region (n = 7,611), insurance status (n = 26,877), initial ED blood pressure (n = 7,837), initial ED Glasgow Coma Scale (n = 20,974), injury mechanism (n = 291), presence of drug intoxication on arrival to ED (n = 45,142), presence of alcohol intoxication on arrival to ED (n = 36,275), length of ICU stay (n = 6,470), and need for mechanical ventilation (n = 11,327).

Multivariable Poisson regression with log link and robust error variance was used to produce relative risk (RR) estimates for each HAC-outcome pair (i.e., the ratio of the probability of the outcome occurring for patients without that HAC to the probability of the same outcome occurring for patients with the HAC). A separate regression model was used for HAC-outcome pair, with the covariates listed in Table 1 being included as predictor variables in all of these models. Other HACs were not included in these regression models in recognition of the potential causal relationships among the different HACs. Adjusting for other HACs in the setting of such causal relationships would interfere with estimating the overall effect of the specific HAC being considered.

The RR estimates derived from the aforementioned regressions were then used to calculate estimated population attributable fractions (PAFs) for each HAC-outcome pair in a manner allowing adjustment for known patient, hospital, and injury characteristics.[14] The unadjusted PAF can be calculated as $PAF = [Pc \times (RR - 1)]/[Pc \times (RR - 1) + 1]$, with Pc denoting the frequency of the HAC and RR denoting the risk ratio of the outcome given the HAC.[15] Our adjusted PAF estimate is thus reported as the percentage reduction in a given adverse outcome (with 95% confidence intervals) that would be anticipated if the specific HAC were completely prevented within the study population.[16] Stata Version 14.0 (StataCorp) was used for all statistical analyses. Strengthening the Reporting of Observational Studies in Epidemiology guidelines for cross-sectional studies were used for reporting of methods (Supplemental Digital Content, http://links.lww.com/TA/C492).[17]

RESULTS

Using the ACS TQIP PUFs, a total of 529,856 patients requiring more than 5 days of hospitalization were analyzed for this study. A majority of the patients were between 55 years and 74 years old (29.2%), White (71.4%), and from the South

TABLE 1. Patient, Hospital, and Injury Characteristics of 529,856 Hospitalized Trauma Patients

Characteristics			% of Patients*
Demographics	Female		38.4
	Age, y	<35	23.9
		35–54	22.3
		55–74	29.2
		≥75	24.7
	Race/ethnicity	White	71.3
		Black	13.6
		Hispanic	9.7
		Other	5.4
	Geographic region	South	41.4
		Northeast	18.3
		Midwest	21.2
		West	19.1
	Insurance status	Private	30.3
		Medicare	35.2
		Medicaid	12.8
		Other insurance	11.4
		Self-pay	10.3
Hospital	Teaching status	University	54.0
		Community	36.0
		Nonteaching	10.0
	Level I trauma center		66.4
Comorbid conditions	Diabetes mellitus		15.0
	Chronic obstructive pulmonary disease		8.6
	Hypertension		37.9
	Congestive heart failure		4.7
	Prior myocardial infarction		1.5
	Chronic kidney disease		1.8
	Prior stroke		3.1
	Bleeding disorder		9.0
	Nonindependent functional status		5.2
	Dementia		5.6
Injury characteristics	Initial SBP < 90 mm Hg		4.0
	Initial GCS ≤ 8		11.3
	Injury mechanism	Blunt	91.5
		Penetrating	8.5
	Acute drug intoxication		18.5
	Acute alcohol intoxication		16.8
	Immediate surgery		18.4
	ISS	≤9	25.9
		10–14	24.7
		15–24	28.8
		≥24	20.5

*Results are based on multiple imputation and therefore reported as percentages and not exact numbers of patients.

SBP, systolic blood pressure; GCS, Glasgow Coma Scale.

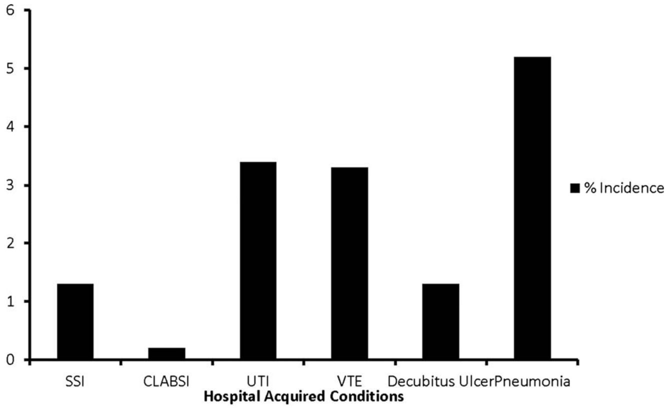

Figure 1. Incidence of HACs. Six HACs were evaluated for the study including SSI, CLABSI, UTI, VTE, decubitus ulcer, pneumonia. Incidence of HACs: SSI, 1.3%; CLABSI, 0.2%; UTI, 3.4%; VTE, 3.3%; decubitus ulcer, 1.3%; pneumonia, 5.2%. Total number of patients = 529,856.

(41.4%). Most had Medicare (35.2%) and were treated at university (54%) and Level I trauma centers (66.4%). The most common patient comorbidity was hypertension (37.9%). Other comorbid conditions evaluated included the following: chronic obstructive pulmonary disease, congestive heart failure, diabetes, kidney disease, and prior stroke. All conditions are listed in Table 1. Injury severity can be associated with length of hospital stay, with higher ISS correlated to increased length of hospital stay.[18] In this study, the patient populations were nearly evenly spread across ISS groups, but a slight majority at 28.8% of the population had an ISS of 15 to 24 (Table 1).

Of the six HACs evaluated, pneumonia had the highest incidence among patients at 5.2% (Fig. 1). This was followed in order by: UTI, VTE, SSI, decubitus/pressure ulcer, and CLABSI. We then evaluated the association of these six HACs with EOD and mortality of the patient population. All HACs demonstrated significant adjusted RRs with EOD. Central line–associated blood stream infection (47.8%), decubitus ulcer (32.4%), and pneumonia (31.5%) were associated with highest rates of EOD (Table 2A). Similarly, when analyzing mortality, death associated with CLABSI demonstrated the highest percentage of affected patients at 13.4%, with pneumonia following closely at 12.1%. Adjusted RR (ARR) was significant for both data points (Table 2A). Urinary tract infections were not significantly associated with death in the hospitalized patient population.

We then studied the effect of resource utilization on outcomes including prolonged hospitalization, length of ICU stay, and the need for mechanical ventilation. All HACs demonstrated significant adjusted RR associated with prolonged hospitalization, ICU stay, and mechanical ventilation (Table 2B). Surgical site infection was associated with the highest risk for prolonged hospitalization (86.9%), followed closely by CLABSI (86.2%). Pneumonia was associated with the highest increased risk for prolonged ICU stay (89.5%), with CLABSI following closely at 86.1%. Pneumonia was also associated with the highest need for mechanical ventilation (86.9%).

Given the significant resource utilization, we determined the PAF estimated as a percentage reduction in the adverse outcomes. With all adverse outcomes, prevention of pneumonia would have resulted in the greatest reduction of all outcomes when compared with the other HACs. By taking measures to prevent pneumonia, theoretical reduction in EOD (incidence 5.9%) was 22.1% and reduction in 30-day mortality (incidence 3.5%) was 7.8% (Table 3). Furthermore, prevention of pneumonia would also reduce prolonged hospitalization (incidence 26.6%) by 8.7%, prolonged ICU stay (incidence 26.6%) by 7.1%. and the need for mechanical ventilation (incidence 26.9%) by 6.8%. The effect of the remaining five HACs was comparatively small.

DISCUSSION

This study used ACS TQIP data to analyze the impact that six HACs have on morbidity, mortality, and resource utilization in trauma patients. We used PAFs to reflect both the prevalence of each HAC, as well as its impact on clinical condition and resource utilization.[19] The PAFs have been previously used to evaluate complications in patients admitted for emergency surgery to assess their impact on morbidity and to identify quality improvement initiatives that would most robustly improve patient health and minimize excessive resource use.[19] Using this method, the present study found that of the six examined HACs (pneumonia, UTI, VTE, SSI, decubitus/pressure ulcer, and CLABSI), pneumonia had the most significant impact on morbidity, mortality, and resource utilization in trauma patients.

Infectious complications, and in particular pneumonia, are common in trauma patients[20–24] and are associated with increased hospital resource use[23] and worse long-term prognosis.[25] The impact of pneumonia on outcomes such as length of stay and mortality in trauma patients has been variably reported.[5,8,21,26]

TABLE 2A. Risk-Adjusted Association Between HACs and In-Hospital Clinical Outcomes

	Outcome: End-Organ Dysfunction		Outcome: Mortality	
Index Complication	% With EOD	ARR* (95% CI); EOD	% Died	ARR* (95% CI)
SSI	23.5%	3.08 (2.95–3.23); $p < 0.001$	3.4%	0.79 (0.70–0.90); $p < 0.001$
CLABSI	47.8%	4.66 (4.34–5.01); $p < 0.001$	13.4%	1.75 (1.50–2.05); $p < 0.001$
UTI	19.9%	2.84 (2.75–2.94); $p < 0.001$	5.7%	1.01 (0.95–1.08); $p = 0.75$
VTE	21.7%	2.80 (2.71–2.90); $p < 0.001$	6.9%	1.19 (1.12–1.26); $p < 0.001$
Decubitus ulcer	32.4%	3.54 (3.41–3.68); $p < 0.001$	9.4%	1.32 (1.23–1.43); $p < 0.001$
Pneumonia	31.5%	4.72 (4.60–4.85); $p < 0.001$	12.1%	1.76 (1.69–1.83); $p < 0.001$

CI, confidence interval.
*Adjusted for patient, hospital, and injury characteristics and for the presence or absence of the specific index complication.
Six HACs were evaluated and demonstrated significant effects on EOD and mortality.

TABLE 2B. Risk-Adjusted Association Between HACs and In-Hospital Resource Utilization

Index Complication	Prolonged Hospitalization: % With Prolonged LOS	Prolonged Hospitalization: ARR* (95% CI) EOD	Prolonged ICU Stay: % Prolonged ICU	Prolonged ICU Stay: ARR* (95% CI) Mortality	Need for Mechanical Ventilation: % Needing Vent	Need for Mechanical Ventilation: ARR* (95% CI) Need for Vent
SSI	86.9%	2.18 (2.14, 2.21); $p < 0.001$	66.2%	1.54 (1.51, 1.57); $p < 0.001$	67.2%	1.38 (1.35, 1.40); $p < 0.001$
CLABSI	86.3%	1.93 (1.87, 2.00); $p < 0.001$	86.1%	1.66 (1.60, 1.72); $p < 0.001$	79.6%	1.48 (1.42, 1.55); $p < 0.001$
UTI	64.1%	2.09 (2.06–2.11); $p < 0.001$	59.2%	1.59 (1.57–1.61); $p < 0.001$	49.5%	1.44 (1.42–1.49); $p < 0.001$
VTE	71.4%	1.94 (1.92–1.96); $p < 0.001$	68.7%	1.56 (1.54–1.58); $p < 0.001$	62.5%	1.40 (1.38–1.42); $p < 0.001$
Decubitus Ulcer	82.1%	2.02 (1.99–2.05); $p < 0.001$	77.9%	1.59 (1.57–1.62); $p < 0.001$	73.2%	1.50 (1.47–1.54); $p < 0.001$
Pneumonia	83.1%	2.14 (2.12–2.16); $p < 0.001$	89.5%	1.82 (1.80–1.83); $p < 0.001$	86.9%	1.68 (1.66–1.69); $p < 0.001$

LOS, length of stay

*Adjusted for patient, hospital, and injury characteristics and for the presence or absence of the specific index complication.

The six HACs evaluated all demonstrated a significant association with increased resource utilization, including hospitalization, ICU stay, and mechanical ventilation.

The high incidence of hospital-acquired pneumonia (HAP) in trauma patients may be attributed to this populations' tendency toward impaired mobility and need for sedation and mechanical ventilation.[24] Moore et al.[27] cited pneumonia as one of three complications recommended for use in trauma hospital evaluation; however, this was stated as a weak recommendation given the lack of clinical justification for complications included in reviewed studies. The present study addresses this limitation by quantifying the extent to which the elimination of pneumonia would result in reductions in EOD, prolonged hospitalization, ICU stay, the need for mechanical ventilation, and mortality compared with five other HACs. Based on our findings, we posit that prevention and early recognition/management of pneumonia should be brought to the forefront of TQIPs to improve patient outcomes and minimize excess resource utilization.[3,7,19]

While protocols have been implemented nationwide to reduce hospital-acquired infections, such as SSI, central line-associated bloodstream infections, and catheter-associated UTI, comparatively fewer efforts have centered around HAP prevention.[28,29] HAP is the most prevalent hospital-acquired infection[28,30] and nonventilator associated HAP (NV-HAP) may be underreported, emphasizing the need for further study and improved prevention strategies.[28,31] Standardized HAP prevention is challenging due variable diagnostic criteria, nonsystematic surveillance methods, and a paucity of evidence-based prevention protocols.[29] Current NV-HAP and ventilator-associated pneumonia (VAP) prevention strategies center on the principles of increasing mobility,[28,32] screening for and managing dysphagia,[28,33] and providing oral care to minimize oropharyngeal colonization and risk for subsequent aspiration and pneumonia.[28,34] Oral chlorhexidine rinses, gels and swabs may lower risk for both NV-HAP and VAP;[35] however, evidence for other oral care measures (e.g., toothbrushing, iodine swabs) is limited,[35] and oral antibiotic use may facilitate growth of resistant organisms.[29,34,36] In trauma patients, bundled prevention protocols implementing multifocal strategies may decrease the incidence of VAP.[34,37] Additional practices with theoretical benefit include probiotic administration to reduce pathogenic intestinal bacterial overgrowth[34,38] and routine hand hygiene and equipment cleaning to reduce nosocomial spread of respiratory pathogens.[34] Importantly, many of these recommendations are based on observational studies, nonrandomized trials, and/or theoretical benefit, with minimal randomized data to support most current HAP prevention strategies.[29,34]

Given the present study's determination of the comparatively greater impact of pneumonia on resource utilization, morbidity, and mortality in trauma patients relative to five other HACs, we posit that evidence-based HAP prevention protocols should be increasingly studied and implemented as trauma center quality improvement initiatives. Our use of TQIP data does not allow us to distinguish between NV-HAP and VAP and we therefore cannot make recommendations based on our findings alone about which, if one, should be prioritized. It has been suggested by other groups, however, that NV-HAP is less reported and less studied compared with VAP despite conferring similar lethality and incurring higher costs.[28,39] Contextualizing our work within these findings, it is reasonable to suggest that quality improvement programs pursue both VAP and NV-HAP prevention, with NV-HAP perhaps meriting particular attention. To accomplish this, there is a critical need for both NV-HAP and VAP for (1) increased systematic surveillance and reporting; (2) standardization of diagnostic criteria; and (3) prospective randomized trials to establish rigorous and cost-effective prevention strategies for trauma patients.

A final consideration based on our results is how these findings may guide prioritization and allocation of finite healthcare resources. Because of the recently increased attention on the importance of quality improvement initiatives, institutional resources are at risk for being unintentionally shifted away from areas most likely to improve patient care and toward relatively less impactful efforts.[40] Our findings may help facilitate the prudent use of finite resources by discouraging overallocation of additional resources toward prevention of relatively lower-impact HACs, such as SSI. This premise can be extended to conditions, such as CLABSI, which, while individually severe, occur less commonly than pneumonia and thus based on our analysis have a lower relative overall impact on trauma population outcomes and resource utilization. Of note, we do not suggest the need to terminate existing HAC prevention protocols, but rather to use our findings as a guide to focus additional efforts, particularly in settings where resources are limited.

This study has several limitations. First, while ACS TQIP is the largest data repository for trauma patients in the United

TABLE 3. Risk-Adjusted PAFs (and 95% CIs) for Each Index HAC-Outcome Pair

End-Organ Dysfunction (Incidence = 5.9%)	30-Day Mortality (Incidence = 3.5%)	Prolonged Hospitalization (Incidence = 26.6%)	Prolonged ICU Stay (Incidence 26.6%)	Need for Mechanical Ventilation (Incidence = 26.9%)
1. Pneumonia, 22.1 (21.6–22.7)*	1. Pneumonia, 7.8 (7.1–8.4)*	1. Pneumonia, 8.7 (8.6–8.8)*	1. Pneumonia, 7.1 (7.0–7.2)*	1. Pneumonia, 6.8 (6.6–6.9)*
2. VTE, 7.8 (7.4–8.1)*	2. VTE, 1.0 (0.6–1.4)*	2. UTI, 4.3 (4.2–4.4)*	2. VTE, 2.7 (2.6–2.8)*	2. VTE, 2.2 (2.1–2.3)*
3. UTI, 7.4 (7.1–7.8)*	3. Decubitus ulcer, 0.9 (0.6–1.1)*	3. VTE, 4.2 (4.2–4.3)*	3. UTI, 2.5 (2.5–2.6)*	3. UTI, 1.9 (1.8–2.0)*
4. Decubitus ulcer, 5.2 (5.0–5.5)*	4. CLABSI, 0.4 (0.3–0.5)*	4. SSI, 2.3 (2.2–2.3)*	4. Decubitus ulcer, 1.3 (1.3–1.4)*	4. Decubitus ulcer, 1.2 (1.1–1.3)*
5. SSI, 3.5 (3.3–3.7)*	5. UTI, 0.1 (−0.3–0.4)**	5. Decubitus ulcer, 2.1 (2.0–2.1)*	5. SSI, 1.0 (1.0–1.1)*	5. SSI, 0.9 (0.8–0.9)*
6. CLABSI, 1.6 (1.4–1.7)*	6. SSI −0.3 (−0.5 to −0.2)*	6. CLABSI, 0.4 (0.4–0.4)*	6. CLABSI, 0.3 (0.3–0.3)*	6. CLABSI, 0.2 (0.2–0.3)*

*Not significant.
**$p < 0.001$.
Prevention of pneumonia would result in a 22.1% reduction in EOD, a 7.8% reduction in mortality, an 8.7% reduction in prolonged hospitalization, a 7.1% reduction in prolonged ICU stay and a 6.8% reduction in the need for mechanical ventilation.

States and our study population is similar to many major trauma centers, our sample is not necessarily representative of the demographic makeup of the United States as a whole and we therefore cannot assume that our findings are broadly applicable to all trauma populations. Second, the interpretation of PAFs rests on the assumption that a given complication can be completely prevented following admission for traumatic injury, and on the additional assumption that all evaluated complications are equally preventable, neither of which is necessarily true in practice.[19,41] Other described pitfalls associated with analysis of PAFs include the risk of confounding bias, incorrect interpretation, and analysis of unmodifiable risk factors.[42] We mitigate these risks by controlling for several confounding variables; by refraining from the common misinterpretation that our PAFs represent the proportion of outcomes that are "explained" by a given condition,[42] and by evaluating HACs that we reasonably believe are at least partially modifiable. Third, our analysis evaluates different HACs in isolation and thus does not distinguish the effects of one HAC from another co-occurring HAC. Fourth, we included EOD as an outcome measure given that this is a more prevalent outcome in trauma patients than mortality; however, this is not intended to be offered as a validated outcome measure.[19] Fifth, while our analysis adjusts for various patient, hospital, and injury characteristics, additional patient characteristics could contribute to our outcomes, such as tobacco use, obesity, asthma, history of VTE, and history of chronic urinary tract infections. In addition, our data do not capture the spectrum of severity of blunt mechanisms. This may be particularly salient to our study given that elderly patients who sustain low-energy injuries, such as falls, may be disproportionately susceptible to HACs due to other comorbidities. Finally, we have evaluated only six HACs, which is not an exhaustive list of all complications and conditions that impact trauma patient outcomes and resource utilization.

Our analysis of ACS TQIP data using PAFs quantifies the extent to which the elimination of pneumonia and five other HACs would result in reductions in EOD, mortality, prolonged hospitalization, ICU stay, and need for mechanical ventilation in trauma patients. Of the six HACs examined, we found that the elimination of pneumonia would have the most significant impact on morbidity, mortality, and resource utilization. Our use of PAFs facilitates prioritization of conditions for which prevention may most powerfully impact outcomes and resource utilization. Trauma quality improvement programs should prioritize assessment and implementation of pneumonia prevention strategies to improve outcomes and decrease resource utilization for hospitalized trauma patients.

AUTHORSHIP

P.T.L. and J.E.S. contributed to study design. P.T.L. and J.E.S. contributed to study analysis. P.T.L. and J.E.S. contributed to interpretation of results. P.T.L. and L.K.K. contributed to literature review. P.T.L., J.E.S., and L.K.K. contributed to the drafting of the article. P.T.L., L.K.K., H.S.J., B.L.Z., and J.E.S. provided critical appraisal to the article. P.T.L. L.K.K., S.S., A.P.O., H.S.J., A.I., B.L.Z., and J.E.S. all approve of the final article submission.

ACKNOWLEDGMENTS

L.K.K is supported by the National Cancer Institute of the NIH, grant T32CA090217. A.I. is supported by an Agency for Healthcare Research and Quality Career Development Award (1K08HS025224-01A1). For the remaining authors, no sources of funding were declared. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

DISCLOSURE

A.I. served as a Clinical Consultant for the American College of Surgeons. S.S. performs site surveys for the states of Tennessee/Mississippi and Arkansas Trauma systems. The remaining authors declare no conflicts of interest.

REFERENCES

1. Estimated Lifetime Medical and Work-Loss Costs of Fatal Injuries—United States. 2013. Available at: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6438a4.htm?s_cid=mm6438a4_w. Accessed September 10, 2021.
2. Estimated Lifetime Medical and Work-Loss Costs of Emergency Department–Treated Nonfatal Injuries—United States. 2013. Available at: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6438a5.htm?s_cid=mm6438a5_w. Accessed September 10, 2021.
3. Glance LG, Osler TM, Mukamel DB, Dick AW. Outcomes of adult trauma patients admitted to trauma centers in Pennsylvania, 2000–2009. *Arch Surg*. 2012;147(8):732–737.
4. Pfeifer R, Tarkin IS, Rocos B, Pape H-C. Patterns of mortality and causes of death in polytrauma patients—has anything changed? *Injury*. 2009;40(9):907–911.
5. Osler T, Glance LG, Hosmer DW. Complication-associated mortality following trauma: a population-based observational study. *Arch Surg*. 2012;147(2):152–158.
6. Hemmila MR, Jakubus JL, Maggio PM, Wahl WL, Dimick JB, Campbell DA Jr., et al. Real money: complications and hospital costs in trauma patients. *Surgery*. 2008;144(2):307–316.
7. Mondello S, Cantrell A, Italiano D, Fodale V, Mondello P, Ang D. Complications of trauma patients admitted to the ICU in level I academic trauma centers in the United States. *Biomed Res Int*. 2014;2014:e473419.
8. Ingraham AM, Xiong W, Hemmila MR, Shafi S, Goble S, Neal ML, et al. The attributable mortality and length of stay of trauma-related complications: a matched cohort study. *Ann Surg*. 2010;252(2):358–362.
9. Moore L, Lauzier F, Stelfox HT, Le Sage N, Bourgeois G, Clément J, et al. Complications to evaluate adult trauma care: an expert consensus study. *J Trauma Acute Care Surg*. 2014;77(2):322–329.
10. *Trauma Quality Programs (TQP) Participant Use File (PUF) User Manual: Admission years 2007-2016*. Chicago, IL: American College of Surgeons; 2019: Available at: https://web4.facs.org/TQIPFiles/TQP%20PUF%20User%20Manual%202007%20-%202016.pdf. Accessed April 27, 2020.
11. Blackmore AR, Leonard J, Madayag R, Bourg PW. Using the Trauma Quality Improvement Program metrics data to enhance clinical practice. *J Trauma Nurs*. 2019;26(3):121–127.
12. Collins TC, Daley J, Henderson WH, Khuri SF. Risk factors for prolonged length of stay after major elective surgery. *Ann Surg*. 1999;230(2):251–259.
13. White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. *Stat Med*. 2011;30(4):377–399.
14. Newson RB. Attributable and Unattributable risks and fractions and other scenario comparisons. *Stata J*. 2013;13(4):672–698.
15. Poole C. A history of the population attributable fraction and related measures. *Ann Epidemiol*. 2015;25(3):147–154.
16. Scarborough JE, Schumacher J, Kent KC, Heise CP, Greenberg CC. Associations of specific postoperative complications with outcomes after elective colon resection: a procedure-targeted approach toward surgical quality improvement. *JAMA Surg*. 2017;152(2):e164681.
17. Elm Evon, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet*2007;370(9596):1453–1457.
18. Linn S, Linn R, Sheps S, Sarid M, Michaelson M, Geva H, et al. Injury severity scoring and length of stay in hospital of war casualties—demonstration of an association and possible selection Bias. *Int J Epidemiol*. 1993;22(5):905–910.
19. Scarborough JE, Schumacher J, Pappas TN, McCoy CC, Englum BR, Agarwal SK Jr., et al. Which complications matter most? Prioritizing quality improvement in emergency general surgery. *J Am Coll Surg*. 2016;222(4):515–524.
20. van Wessem KJP, Hietbrink F, Leenen LPH. Attenuation of MODS-related and ARDS-related mortality makes infectious complications a remaining challenge in the severely injured. *Trauma Surg Acute Care Open*. 2020;5(1):e000398.
21. Hofman M, Andruszkow H, Kobbe P, Poeze M, Hildebrand F. Incidence of post-traumatic pneumonia in poly-traumatized patients: identifying the role of traumatic brain injury and chest trauma. *Eur J Trauma Emerg Surg*. 2020;46(1):11–19.
22. Prin M, Li G. Complications and in-hospital mortality in trauma patients treated in intensive care units in the United States, 2013. *Inj Epidemiol*. 2016;3(1):18.
23. Kaufman EJ, Earl-Royal E, Barie PS, Holena DN. Failure to rescue after infectious complications in a statewide trauma system. *Surg Infect*. 2017;18(2):89–98.
24. Teixeira Lopes MCB, Júnior de Aguiar W, Yamaguchi Whitaker I. In-hospital complications in trauma patients according to injury severity. *J Trauma Nurs*. 2019;26(1):10–16.
25. Kumar RG, Kesinger MR, Juengst SB, Brooks MM, Fabio A, Dams-O'Connor K, et al. Effects of hospital-acquired pneumonia on long-term recovery and hospital resource utilization following moderate to severe traumatic brain injury. *J Trauma Acute Care Surg*. 2020;88(4):491–500.
26. Chou SE, Rau CS, Tsai YC, Hsu SY, Hsieh HY, Hsieh CH. Risk factors and complications contributing to mortality in elderly patients with fall-induced femoral fracture: a cross-sectional analysis based on trauma registry data of 2,407 patients. *Int J Surg*. 2019;66:48–52.
27. Moore L, Stelfox HT, Turgeon AF. Complication rates as a trauma care performance indicator: a systematic review. *Crit Care*. 2012;16(5):R195.
28. Mitchell BG, Russo PL, Cheng AC, Stewardson AJ, Rosebrock H, Curtis SJ, et al. Strategies to reduce non-ventilator-associated hospital-acquired pneumonia: a systematic review. *Infect Dis Health*. 2019;24(4):229–239.
29. Lyons PG, Kollef MH. Prevention of hospital-acquired pneumonia. *Curr Opin Crit Care*. 2018;24(5):370–378.
30. Magill SS, O'Leary E, Janelle SJ, Thompson DL, Dumyati G, Nadle J, et al. Changes in prevalence of health care-associated infections in U.S. Hospitals. *N Engl J Med*. 2018;379(18):1732–1744.
31. Quinn B, Baker DL, Cohen S, Stewart JL, Lima CA, Parise C. Basic nursing care to prevent nonventilator hospital-acquired pneumonia. *J Nurs Scholarsh*. 2014;46(1):11–19.
32. Titsworth WL, Hester J, Correia T, Reed R, Guin P, Archibald L, et al. The effect of increased mobility on morbidity in the neurointensive care unit. *J Neurosurg*. 2012;116(6):1379–1388.
33. Hinchey JA, Shephard T, Furie K, Smith D, Wang D, Tonn S, Stroke Practice Improvement Network Investigators. Formal dysphagia screening protocols prevent pneumonia. *Stroke*. 2005;36(9):1972–1976.
34. Modi AR, Kovacs CS. Hospital-acquired and ventilator-associated pneumonia: diagnosis, management, and prevention. *Cleve Clin J Med*. 2020;87(10):633–639.
35. El-Rabbany M, Zaghlol N, Bhandari M, Azarpazhooh A. Prophylactic oral health procedures to prevent hospital-acquired and ventilator-associated pneumonia: a systematic review. *Int J Nurs Stud*. 2015;52(1):452–464.
36. Leone M, Bouadma L, Bouhemad B, Brissaud O, Dauger S, Gibot S, et al. Hospital-acquired pneumonia in ICU. *Anaesth Crit Care Pain Med*. 2018;37(1):83–98.
37. Lansford T, Moncure M, Carlton E, Endress R, Shik N, Udobi K, et al. Efficacy of a pneumonia prevention protocol in the reduction of ventilator-associated pneumonia in trauma patients. *Surg Infect*. 2007;8(5):505–510.
38. Xie X, Lyu J, Hussain T, Li M. Drug prevention and control of ventilator-associated pneumonia. *Front Pharmacol*. 2019;10:298.
39. Authority PPS. *A second breadth: hospital-acquired pneumonia in Pennsylvania, nonventilated versus ventilated patients | advisory*. Pennsylvania Patient Safety Authority: Available at: http://patientsafety.pa.gov:80/ADVISORIES/Pages/201809_NVHAP.aspx. Accessed March 9, 2022.
40. Meyer GS, Nelson EC, Pryor DB, James B, Swensen SJ, Kaplan GS, et al. More quality measures versus measuring what matters: a call for balance and parsimony. *BMJ Qual Saf*. 2012;21(11):964–968.
41. Greenland S. Attributable fractions: bias from broad definition of exposure. *Epidemiology*. 2001;12(5):518–520.
42. Rockhill B, Newman B, Weinberg C. Use and misuse of population attributable fractions. *Am J Public Health*. 1998;88(1):15–19.