The Attributable Mortality and Length of Stay of Trauma-Related Complications

A Matched Cohort Study

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Objective: To determine the attributable mortality (AM) and excess length of stay because of complications or complication groupings in the National Trauma Data Bank.

Summary Background Data: Resources devoted to performance improvement activities should focus on complications that significantly impact mortality and length of stay. To determine which post-traumatic complications impact these outcomes, we conducted a matched cohort study. AM is the proportion of all deaths that can be prevented if the complication did not occur.

Methods: We identified severely injured patients (Injury Severity Score, ≥9) at centers that contribute complications to the National Trauma Data Bank. To estimate the AM, a patient with a specific complication was matched to 5 patients without the complication. Matching was based on demographics and injury characteristics. Residual confounding was addressed through a logistic regression model. To estimate excess length of stay, matching covariates were identified through a Poisson regression model. Each case was required to match the control on all variables, and one control was selected per case.

Results: Of the 94,795 patients who met the inclusion criteria, 3153 died. The overall mortality rate was 3.33%, and 10,478 (11.1%) patients developed at least 1 complication. Four complication groupings (cardiovascular, acute respiratory distress syndrome, renal failure, and sepsis) were associated with significant AM. Infectious complications (surgical infections, sepsis, and pneumonia) were associated with the greatest excess length of stay.

Conclusions: This study used AM and excess length of stay to identify trauma-related complications for external benchmarking. Guideline development and performance improvement activities need to be focused on these complications to significantly reduce the probability of poor outcomes following injury.

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Reports documenting the variation in health care quality in the United States have stimulated the development of programs to measure and improve outcomes across multiple surgical specialties.[1–5] Performance improvement (PI) programs are required for trauma center verification and have long been a priority for providers of trauma care.[6] However, until recently, the primary methods for PI in trauma have been limited to internal benchmarking, which evaluates the quality of care provided within a single institution over time. Modeled after the American College of Surgeons National Surgical Quality Improvement Program, the Trauma Quality Improvement Program (TQIP) will provide risk-adjusted external benchmarking reports, affording interhospital comparisons of outcomes for severely injured trauma patients.[2,7–9]

Although mortality often serves as a standard outcome for quality improvement, such events are infrequent and, particularly in a trauma setting, not always preventable. Thus, nonmortal outcomes, such as complications, lengths of hospital and intensive care unit stay, and costs of hospitalization, are more appropriate end points for external benchmarking of trauma centers.

However, PI programs based on clinical data are expensive, both financially and from a workload perspective.[10] Thus, identifying the complications associated with the greatest mortality or excess resource utilization will allow resources devoted to external benchmarking to be allocated efficiently.[11]

The objective of this study was to evaluate the attributable mortality (AM) and length of stay (LOS) because of complications or complication groupings so as to identify potential complications to be benchmarked within TQIP.

METHODS

Study Design

We conducted a matched cohort study utilizing data derived from the National Trauma Data Bank (NTDB, 2007) v. 8.1. Outcomes of interest were mortality and LOS. The matched cohort design was used to estimate the AM and LOS in patients of similar baseline characteristics who differed only in the presence of a specific complication or complication grouping.

Data Source

The NTDB is the largest collection of trauma registry data available, containing records from over 2 million patients in the United States, Canada, and Puerto Rico. To better ensure that a center actually reported in-hospital complications to the NTDB, we only considered centers with at least one case of pneumonia, documented by complication field or International Classification of Disease Codes (ninth revision) (ICD-9). A similar strategy has been used in previously published work to address the potential for differential reporting of complications across centers.[12]

Patient Selection

Patients admitted during 2007 were identified based on the following inclusion criteria:

- Minimum age of 16 years;
- Valid trauma ICD-9 code in the range of 800 to 959.9, excluding late effects (905–909.9), superficial injuries (910–924.9), and foreign bodies (930–930.9);
- Primary mechanism of injury classified as either: (1) blunt (primary External Cause of Injury [E-code] grouped to: fall, machinery, motor vehicle, pedestrian, cyclist, and struck by or against) or (2) penetrating (primary E-code grouped to: cut/pierce and firearm);
- At least one Abbreviated Injury Scale (AIS) ≥3 (for blunt injuries, in any of the following AIS body regions: head, face, neck, thorax, abdomen, spine, and upper or lower extremity; for penetrating injuries, in any of the following AIS body regions: neck, thorax, or abdomen);
- Injury Severity Score (ISS) ≥9;
- Known Emergency Department (ED) discharge disposition and hospital discharge disposition.

Patients were excluded if they met any of the following criteria:

- Gunshot wound to the brain (any of the following E-codes: E922.0-.9, E955.0-.4, E965.0–4, E979.4, E985.0-.4, or E970 and at least one of the following ICD-9 codes: 800–801.99, 850–854.1);
- Documentation of a pre-existing advanced do not resuscitate directive to withhold life sustaining interventions;
- Dead on arrival;
- Death within 48 hours of admission.

Identification of Complications

Complications were identified by 1 of 2 approaches: either an individual had a listed complication in the "Hospital Complications" field of NTDB or an ICD-9 discharge diagnosis for the complication (Appendix 1, online only, Supplemental Digital Content 1, Available at: http://links.lww.com/SLA/A60). Complications were analyzed according to the following groupings: cardiovascular (cardiac arrest with cardiopulmonary resuscitation, myocardial infarction, and stroke/cerebrovascular accident), acute respiratory distress syndrome (ARDS), pulmonary embolism (PE), renal failure, pneumonia, urinary tract infection (UTI)/acute cystitis, systemic sepsis, surgical infections (organ space surgical site infection, empyema, peritonitis, wound disruption, superficial surgical site infection, deep surgical site infection, osteomyelitis/periostitis, necrotizing fasciitis, and infective myositis), and pseudomembranous colitis. Severe sepsis was defined as documented infection and acute organ dysfunction using criteria as detailed by Angus et al.[13]

Matching Attributed Mortality

To identify the patient attributes on which to match cases (patients with the complication of interest) and controls (patients without the complication of interest), we developed a forward stepwise logistic regression model with all available baseline characteristics as predictors and mortality as the outcome. The logistic model (C-statistic = 0.87, Hosmer-Lemeshow statistic $P = 0.02$) identified eleven predictors of mortality. Cases and controls were required to match perfectly on the first 5 selected variables: ED Glasgow Coma Score (GCS) motor component (1–2, 3–4, 5–6) age (16–25, 26–45, 46–65, 66–85, ≥86 years), ISS (9–15, 16–24, 25–47, 48–75), number of comorbidities (0, 1–2, 3–4, 5–6), and ED shock (systolic blood pressure ≤90 versus systolic blood pressure >90).

The remaining 6 variables (gender, chest AIS, lower extremity AIS, mechanism [cyclist, fall, firearm, motor vehicle, machinery, pedestrian, and struck], upper extremity AIS, and neck AIS) identified by the logistic regression were then weighted to represent the influence of each predictor on mortality. Based on the coefficients of the predictors, an overall weight was assigned to each patient. Patients were then divided into 6 roughly equal groups based on this overall weight. Matching was performed through a stratified simple random sampling without replacement so that each case was randomly matched to 5 controls with a patient able to serve as a control only once.

Matching—Attributable Length of Stay

We used a Poisson model to identify important predictors of LOS and isolate the patient characteristics on which to match. Based on the variables identified, each case could not be matched with 5 controls because of sample size limitations. Thus, each case was randomly matched to 1 control. Controls were required to match cases on all of the covariates identified: mortality status, GCS motor score, ISS, lower extremity AIS, age, spine AIS, shock, mechanism, number of comorbidities by organ system group, abdomen AIS, upper extremity AIS, chest AIS, neck AIS, and head AIS.

Statistical Analysis

Patient and injury characteristics were compared using χ^2 test for categorical variables and Student t test and Wilcoxon rank-sum tests for continuous variables, as appropriate, with significance set at $P \leq 0.05$. Crude mortality and median LOS were determined for each complication or complication grouping. AM, reported as the relative risk increase (RRI), was calculated as defined by Levin,[14] and 95% confidence intervals (CI) were determined as derived by Fleiss.[15] RRI is the percent increase in mortality after having had a complication. Excess LOS was determined by subtracting the LOS of the case from the LOS of the control with significant differences identified through paired t tests. All data manipulation and analyses were conducted with SAS version 9.1 (SAS Institute Inc., Cary, NC).

RESULTS

Of 507,262 patients in the NTDB, admission year 2007, 94,795 patients from 264 centers met inclusion criteria. The overall mortality rate was 3.3%. Over 11% (n = 10,478) of patients developed at least one complication. The mortality rate among patients who developed at least one complication was 13.6%, compared with only 2.1% among those without a documented complication (relative risk, 6.62; 95% CI, 6.19–7.08).

Patients who developed a complication had marked differences in baseline characteristics compared with those without a complication (Table 1). It should be noted, however, that because of the large sample size of the population studied small differences in patient characteristics between those with and without complications can reach statistical significance. Patients who developed a complication were older, more frequently male with a greater comorbidity burden, and were more likely to be injured as a result of penetrating trauma. These patients were also more severely injured, with a 4-fold greater probability of shock in the ED, a lower presenting motor GCS, and more severe injuries to the head, neck, chest, abdomen, and spine (Table 2). Consistent with these more severe injuries, global injury severity as measured by the ISS was significantly greater.

The cumulative incidence of complications ranged from 0.04% (pseudomembranous colitis) to 5.6% (pneumonia) (Table 3). The 2 most common complications were pulmonary in nature, pneumonia (5.6%) and ARDS (2.8%). Of the 94,795 patients, 9.2% (n = 8764) had an infectious complication (pneumonia, UTI/acute cystitis, severe sepsis, surgical infections, and pseudomembranous colitis).

Matching of Cases and Controls

Using our matching algorithms, the number of suitable matches identified varied depending on the complication being studied. Suitable matches were identified for 10% to 88% of the patients with complications in the AM analysis and for 28% to 74%

TABLE 1. Characteristics of Patients With and Without Complication(s) Present

	Any Complication Present (n = 10,478)	No Complication Present (n = 84,317)	*P*
Age (median ± IQR)	48 (29–67)	46 (27–67)	<0.0001
Male gender (n, %)	7441 (71)	54,371 (64)	<0.0001
Race (n, %)			0.0008
White	6983 (67)	56,181 (67)	
African-American	1557 (15)	11,592 (14)	
Other	1938 (19)	16,544 (20)	
No. comorbidities (n, %)			<0.0001
0	6184 (59)	57,947 (68)	
1	2364 (23)	17,151 (20)	
2	1337 (13)	7198 (8.5)	
≥3	593 (5)	2021 (2.4)	
Comorbidities (n, %)			
Neurologic	695 (6.6)	4081 (4.8)	<0.0001
Cardiovascular	2687 (26)	15,536 (18)	<0.0001
Pulmonary	387 (3.7)	1941 (2.3)	<0.0001
Hematologic	529 (5.1)	2121 (2.5)	<0.0001
Renal	90 (0.86)	260 (0.31)	<0.0001
Hepatologic	88 (0.84)	248 (0.29)	<0.0001
Oncologic	53 (0.51)	458 (0.54)	0.62
Diabetes	1189 (11)	5775 (6.9)	<0.0001
Peripheral vascular disease	4 (0.04)	38 (0.05)	0.75
Current smoking	212 (2.0)	1520 (1.8)	0.11
Alcoholism/chronic alcohol abuse	1000 (9.5)	5947 (7.1)	<0.0001
Mechanism (n, %)			<0.0001
Blunt (n, %)	9609 (91.7)	78,517 (93.1)	
Penetrating (n, %)	869 (8.3)	5800 (6.9)	

IQR indicates interquartile range.

TABLE 2. Injury Severity of Patients With and Without Complication(s)

	Any Complication Present (n = 10,478)	No Complication Present (n = 84,317)	*P*
Shock (SBP ≤90) (n, %)	987 (9.4)	2233 (2.7)	<0.0001
GCS motor (n, %)			<0.0001
1–2	2967 (28)	4823 (5.7)	
3–4	568 (5.4)	1574 (1.9)	
5–6	6943 (66)	77,920 (92)	
AIS ≥3 by body region (n, %)			
Head	4979 (48)	32,803 (39)	<0.0001
Neck	91 (0.87)	209 (0.25)	<0.0001
Chest	5169 (49)	27,996 (33)	<0.0001
Abdomen	1579 (15)	6039 (7.2)	<0.0001
Spine	891 (8.5)	3067 (3.6)	<0.0001
Upper extremity	420 (4.0)	3789 (4.5)	0.02
Lower extremity	3360 (32)	26,740 (32)	0.46
ISS (mean ± SD)	23.5 ± 12.8	15.2 ± 8.4	<0.0001

ISS indicates Injury Severity Score; AIS, Abbreviated Injury Scale; SBP, Systolic Blood Pressure; and GCS, Glasgow Coma Scale; SD, Standard deviations.

TABLE 3. Cumulative Incidence, Crude Mortality, and Length of Stay Associated With Complications in Severely Injured Patients (N = 94,795)

Complication	Cumulative Incidence (n, %)	Crude Mortality (n, %)	Length of Stay (Median, IQR)
Cardiovascular	1254 (1.3)	518 (41.3)	13 (7–27)
ARDS	2679 (2.8)	476 (17.8)	20 (11–33)
PE	681 (0.72)	55 (8.1)	17 (10–28)
Renal failure	1222 (1.3)	358 (29.3)	19 (9–35)
Pneumonia	5334 (5.6)	602 (11.3)	23 (14–35)
UTI/Acute cystitis	465 (0.49)	38 (8.2)	13 (7–24)
Sepsis	1882 (2.0)	315 (16.7)	27 (17–41)
Surgical infections	1041 (1.1)	57 (5.5)	27 (17–41)
Pseudomembranous colitis	42 (0.04)	1 (2.4)	26 (20–41)

IQR indicates interquartile range; ARDS, Acute Respiratory Distress Syndrome; PE, pulmonary embolism; UTI, urinary tract infection.

of the patients with complications in the attributable LOS analysis. For example, in the AM analysis, suitable matches were identified for 29% (n = 367) of the patients for the cardiovascular complication, and 35% (n = 235) of the patients for PE.

Excess Mortality Attributable to Complications

The crude mortality for cases ranged from 2.4% (pseudomembranous colitis) to 41% (cardiovascular events). The RRI because of complications ranged from −2.0% (surgical infections) to 33% (cardiovascular event) (Fig. 1). Complications with significant RRI included cardiovascular events (33%), renal failure (24%), ARDS (16%), and sepsis (13%). PE (4.8%) and pneumonia (2.4%) were associated with nonsignificant RRIs for mortality.

Excess LOS Attributable to Complications

Our study estimated that the excess LOS attributable to complications ranged from 7.8 days (95% CI, 5.0–11 days) for UTI/acute cystitis to 22 days (95% CI, 19–24 days) for surgical infections (Fig. 2). The complications accounting for the greatest excess LOS were primarily related to infectious processes (surgical infections, sepsis, and pneumonia).

DISCUSSION

In this matched cohort study, we determined the AM and LOS associated with complications or complication groupings in severely injured trauma patients. We have demonstrated that the greatest AM is associated with cardiovascular events, renal failure, ARDS, and sepsis. By contrast, infectious-related complications and renal failure are associated with the greatest excess LOS in this patient population. The events leading to an excess of mortality or LOS are not identical, consistent with the probability that severe complications lead to early death (and hence a shorter LOS).

AM and excess LOS have not been well established for many complications following severe injury. Although associations between higher mortality and complications have been reported, this identification of AM is distinctly different. Beyond identifying the association between complications and mortality, the AM quantifies the increased risk of mortality that can be assigned to a particular complication. For example, others have reported a higher risk of death among patients developing renal failure following severe injury;[16–19] however, unlike these previous estimates, we measured

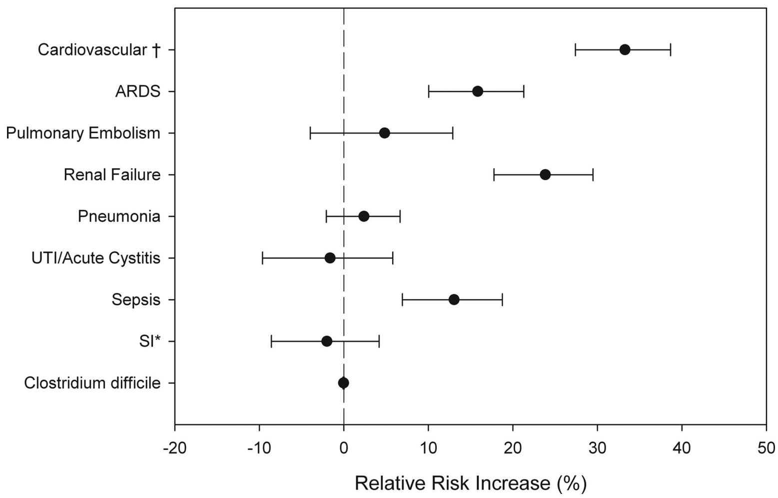

FIGURE 1. Attributable mortality because of complications in severely injured trauma patients. †Cardiovascular complications include cardiac arrest, myocardial infarction, and stroke. *Surgical Infectious complications include organ space infection, surgical site infection, empyema, peritonitis, intra-abdominal abscess, wound disruption, evisceration, osteomyelitis, periostitis, necrotizing fasciitis, and infective myositis. ARDS indicates acute respiratory distress syndrome; UTI, urinary tract infections.

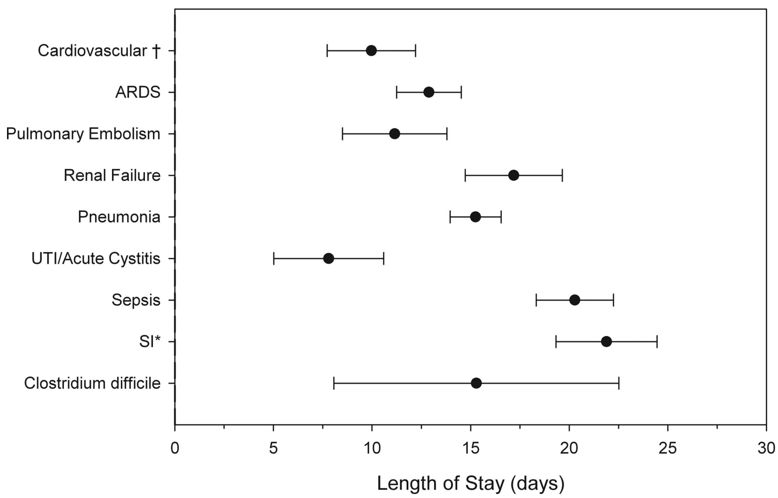

FIGURE 2. Attributable length of stay (days) because of complications in severely injured trauma patients. †Cardiovascular complications include cardiac arrest, myocardial infarction, and stroke. *Surgical infectious complications include organ space infection, surgical site infection, empyema, peritonitis, intra-abdominal abscess, wound disruption, evisceration, osteomyelitis, periostitis, necrotizing fasciitis, and infective myositis. ARDS indicates acute respiratory distress syndrome; UTI, urinary tract infections.

the mortality directly attributable to renal failure to be 24%. Consistent with previous studies, we have also demonstrated a significant relationship between ARDS and subsequent mortality after traumatic injuries.[20–22] Utilizing causal pathway models, Shah et al demonstrated that acute lung injury accounted for 40 percent of the association between baseline Acute Physiologic and Chronic Health Evaluation III score and mortality.[23] Consistent with our findings of an AM of 15.8% because of ARDS, these findings speak in favor of ARDS being a true complication of trauma rather than simply a marker of injury severity with no association with increased mortality.[24–26] Finally, through a multivariable matched cohort study based on the 2000 Healthcare Cost and Utilization Project Nationwide Inpatient Sample database, Zhan et al estimated the AM because of postoperative sepsis to be 21.92%,[27] which is slightly higher than our finding of 13.0% as the AM because of severe sepsis, yet the context differs with trauma patients being sicker at baseline. This difference in baseline likely accounts for the lesser mortality attributable to severe sepsis in trauma.

Similar to other studies in nontraumatically injured populations,[27–30] we demonstrated that infectious complications (sepsis [20 days], surgical infections [22 days], and pneumonia [15 days]) tend to be associated with the greatest excess LOS in the trauma population. In critically ill surgical patients, Dimick et al demonstrated that catheter-related bloodstream infections were associated with a 22-day increase in hospital LOS.[30] In their analysis of the Nationwide Inpatient Sample database, Zhan et al estimated the excess LOS because of postoperative sepsis to be 10.9 days.[27] Utilizing multivariable linear regression to evaluate patients who underwent noncardiac surgery at a tertiary care center, Khan et al demonstrated the increased LOS associated with several complications: pneumonia (75%), stroke (98%), infectious complications (122%), cardiac (46%), and deep venous thrombosis/PE (103%).[29] Cocanour et al conducted a case control study to estimate the attributable cost of ventilator-associated pneumonia at Memorial Hermann Hospital in trauma and surgical patients intubated for greater than 24 hours, matched on age and ISS. Patients who were diagnosed with ventilator-associated pneumonia had significantly longer total LOS (34.5 ± 2.4 vs. 20.4 ± 0.8, $P \leq 0.05$),[31] which is similar to the 15 days we have attributed to pneumonia in this study. In a single center study of 525 trauma patients, Hemmila et al determined the median increase in LOS associated with infectious or incisional (13 days), cardiovascular (14 days), renal (11 days), and respiratory (15 days) complications;[32] direct comparisons with our estimates are limited because of differences in complication groupings.

The results of our study must be considered in light of several limitations. First, the NTDB does not collect when in the course of the hospitalization a patient develops a complication. Thus, patients could not be matched on exposure time (the time between admission, development of a complication, and death), which would control for the effect of severe complications being associated with death and hence a shorter LOS. Second, we excluded patients from the cohort study with early death (within 48 hours); however, this is unlikely to have introduced significant bias as these patients would likely have died prior to developing any of the complications studied, limiting the potential for misclassification bias. Third, underreporting of complications is common in the NTDB.[33,34] We reduced the potential impact of this limitation through identifying institutions submitting high quality data by requiring that patients came from institutions that submitted at least one pneumonia.

The identification of complications with the greatest AM and excess LOS will allow future quality improvement efforts in trauma care to be focused on adverse events associated with the most significant burden to patients and the healthcare system. As more attention is directed by patients, providers, and payers toward the quality of health care provided in the United States, programs that assess and improve the outcomes following surgical procedures and traumatic injuries will take on greater significance. Because of the limited resources available for PI, efforts should first be directed toward adverse events associated with the most morbidity and mortality. Through this study, we have identified in the NTDB the post-traumatic complications associated with the greatest AM and excess LOS, which will serve to direct external benchmarking within the TQIP.

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