Minor injury turns into major problem in severe acute kidney injury: a propensity matched analysis

Nasim Ahmed [1,2] Yen-Hong Kuo,[3] Roy O Mathew,[4] Arif Asif[5]

[1]Surgery, Division of Trauma, Jersey Shore University Medical Center, Neptune City, New Jersey, USA
[2]Hackensack Meridian School of Medicine, Nutley, NJ, USA
[3]Department of Research Administration, Jersey Shore University Medical Center, Neptune City, New Jersey, USA
[4]Medicine, Loma Linda VA Health Care System, Loma Linda, California, USA
[5]Medicine, Jersey Shore University Medical Center, Neptune City, New Jersey, USA

Correspondence to
Dr Nasim Ahmed; nasim.ahmed@hmhn.org

ABSTRACT

Objective Severe acute kidney injury (sAKI) has been associated with a higher mortality in trauma patients, and severity of trauma often correlates with risk of sAKI. Whether minor to moderate trauma is associated with sAKI is less clear. The purpose of the study was to examine the outcomes of minor to moderate trauma patients who developed sAKI.

Methods The National Trauma Database participant use files of 2017 and 2018 were accessed for the study. All patients aged 18 years old and above who sustained an Injury Severity Score (ISS) of <16 and who were brought to a level I or level II trauma center were included in the study. sAKI was defined as an abrupt decrease in kidney function either three times increase in serum creatinine (SCr) level from the baseline or increase in SCr to ≥4.0 mg/dL (≥353.6 µmol/L), initiation of renal replacement therapy, or anuria for ≥12 hours. Propensity matching analysis was performed between the groups who developed sAKI and without sAKI. Outcome of interest was in-hospital mortality.

Results A total of 655 872 patients fulfilled the inclusion criteria with complete information, of which 1896 patients were found to have sAKI. There were significant differences between the two groups on baseline characteristics. The propensity score matching eliminated all the differences and created 1896 pairs of patients. The median hospital length of stay was longer in patients with sAKI when compared with patients who did not develop sAKI (14 (13 to 15) vs. 5 (5 to 5), days p<0.001) . The overall in-hospital mortality was 20.6% in patients with sAKI compared with 2.1% without sAKI (p<0.001).

Conclusion The occurrence of sAKI in minor to moderate trauma patients was less than 0.5%. There was a three times longer hospital stay in patients with sAKI and 10-fold increase in mortality when compared with patients who did not develop sAKI.

Level of evidence IV.

Study type Observational cohort study.

INTRODUCTION

Trauma can be a leading cause of death and disability in patients aged 45 years or less.[1] The impact of trauma on society can be substantial.[2] Even for minor injury, the disability-adjusted life-year was found to be 5.2 per 1000 inhabitants.[2] The causes of immediate and early deaths of trauma have been associated with brain injury and cardiovascular collapse. However, late death (after 24 hours of injury) is often related to organ failure or infection.[3] Acute kidney injury (AKI) is one of the in-hospital organ failure complications that can result in higher mortality and morbidity.[4 5]

WHAT IS ALREADY KNOWN ON THIS TOPIC
⇒ Acute kidney injury was associated with higher severity of the injury.
⇒ Higher mortality was reported in severe acute kidney injury (sAKI).

WHAT THIS STUDY ADDS
⇒ Current study was designed to see the mortality outcome with minor to moderate injury.
⇒ Our study showed a significantly higher mortality associated with minor to moderate injury.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY
⇒ Prevention of AKI with aggressive resuscitation and monitoring may reduce the incidence of sAKI and overall mortality in trauma patients.

The true prevalence of AKI following a trauma is not known due to different definitions of AKI. Using the risk–injury–loss–failure–end stage (RIFLE) criteria, AKI occurrence was found to be approximately 3% to 9% following major injury.[6 7] Severe injury, higher Injury Severity Sore (ISS), hemorrhagic shock, and male gender were found to be some of the risk factors of AKI.[8–12] The mortality associated with AKI can range from 20% to 70%.[4 5] Likewise, the severity of AKI in the context of trauma often correlates with the outcomes, with more severe acute kidney injury (sAKI) (usually higher stages, eg, failure criteria in RIFLE) associated with worse outcomes.

Most prior studies found an association between sAKI and severe injury. Some of those factors that were associated with the complications of sAKI were also associated with mortality. Therefore, excluding severe injury may be a key component of determining the association of sAKI with mortality. There is a paucity of information regarding the incidence of sAKI in minor to moderate injury and associated outcomes. Therefore, we designed the study to include only mild to moderate trauma patients (excluding all major traumas) and used propensity matching methodology to find the association between sAKI and mortality.

METHODS
Data source and inclusion and exclusion criteria
The National Trauma Database (NTDB) participant use files of 2017 and 2018 were accessed for the study. NTDB is the largest trauma database for injured patients. Trauma centers across the USA deposit the data of injured patients voluntarily.

Currently, more than 800 centers participate in the data sharing program with NTDB. Included in the study are all patients aged 18 years old and above who sustained an ISS of <16 and who were brought to a level I or level II trauma center with signs of life and were admitted to the hospital for more than 1 day. The patients who sustained cardiac arrest at the scene and all emergency room deaths were excluded from the study. All patients with severe head injury including initial Glasgow Coma Scale (GCS) score of ≤8 or midline shift on brain imaging study or abnormal pupillary reactions were excluded. Patients who received intracranial monitoring for head injury were also excluded from the study. Patients who were discharged from the hospital within 24 hours of admission were excluded as well.

sAKI was defined as an abrupt decrease in kidney function, either a three times increase in serum creatinine (SCr) level from the baseline or an increase in SCr to ≥4.0 mg/dL (≥353.6 μmol/L), initiation of renal replacement therapy, or anuria for ≥12 hours.[13]

Outcomes
The primary outcome of the study was overall in-hospital mortality. The secondary outcomes were hospital length of stay (LOS) and discharge disposition.

Statistics
Patient demographic information and outcomes were summarized using summary statistics (median with IQR (first quartile to third quartile) for continuous variables, and frequency and percentage for categorical variables). To compare the two groups, with and without sAKI, the Wilcoxon rank-sum test was used for continuous variables, and the χ^2 test was used for categorical variables. Logistic regression analysis was performed to identify risk factors for sAKI among patients with mild to moderate traumatic injury.

Then the propensity score for 'sAKI' was calculated for each subject. One-to-one matching was performed using the 'nearest neighbor' approach with a caliper of 0.25 SD as the matching method to pair a subject who developed sAKI with a subject who did not develop sAKI. The propensity score matching was performed using the R package 'MatchIt'.[14] The variables used for calculating the propensity score were age, race (white), sex, hypotension at initial presentation, ISS, GCS score, and comorbidities (alcoholism, anticoagulant, bleeding disorder, chemotherapy, cirrhosis, chronic obstructive pulmonary disease, cerebrovascular accidents, dementia, diabetes, disseminated cancer, functional dependency, congestive heart failure, hypertension on medication, myocardial infarction, peripheral arterial disease, smoking, and steroid and substance abuse). All definitions of the comorbidities were strictly followed from the data dictionary. After matching, the numerical and graphical diagnostics were used to evaluate the improvement. The patient demographic information and outcomes from the matched subjects were summarized as mentioned previously. The Wilcoxon signed-rank test was used to compare the continuous variables between matched groups. McNemar's test was used to compare the categorical variables between matched groups. For the length of total hospital stay, the Kaplan-Meier procedure was used to estimate the median time, and the SE was estimated using Greenwood's formula. The Kaplan-Meier curves were generated. The log-rank test was used to compare the time (Kaplan-Meier curves) between the two groups. The two-sided p value was reported for each test. A p value of <0.01 was considered
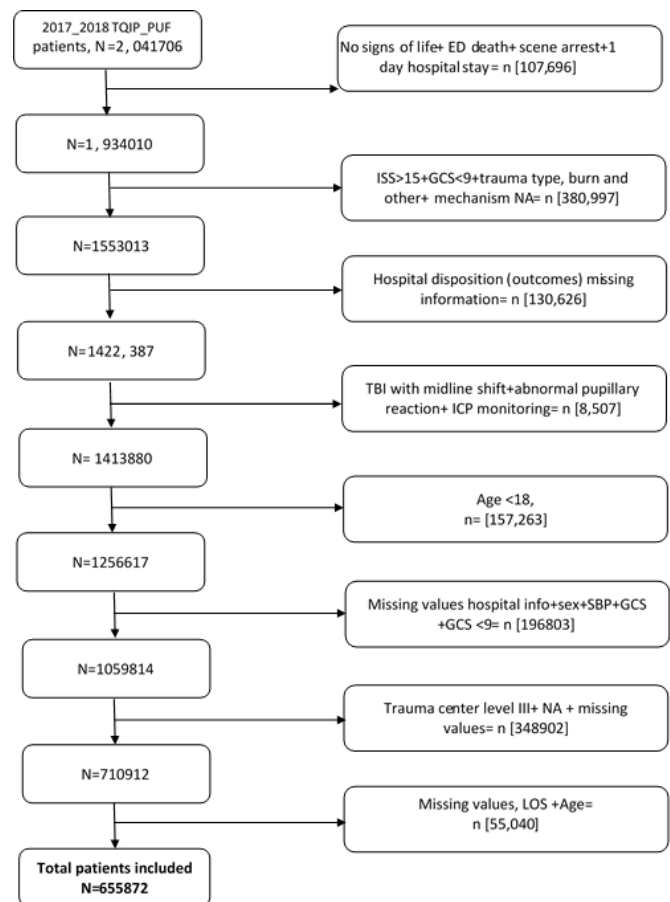

Figure 1 Flow diagram of selection of patients in severe acute kidney injury study. ED, emergency department; GCS, Glasgow Coma Scale; ISS, Injury Severity Score; LOS, length of stay; PUF, participant use file; SBP, systolic blood pressure; TBI, traumatic brain injury; ICP, intracranial pressure; NA, not available

an indication of statistical significance. Statistical analysis was performed using the R language.[15]

RESULTS
Patients' characteristics and univariate analysis
A total of 655872 patients fulfilled the inclusion criteria with complete information (figure 1).

Out of the total, 1896 patients were found to have sAKI. There were significant differences found between the groups who developed sAKI versus who did not. Those differences were more pronounced on age, race and certain comorbidities. The median age of the patients in the sAKI group was 71 years versus 57 years and the patients were predominantly Caucasians (77.9% vs. 74.3%) when compared with patients who did not develop sAKI. Patients with sAKI suffered from higher severity of injury (ISS 9 (5 to 10) vs. 8 (4 to 9)), and a higher proportion of patients presented with hypotension (4.3% vs. 1.3%) (table 1).

Risk factors for sAKI in this cohort included male gender, older age, and higher severity of injury within the mild to moderate category. Hypotension (systolic blood pressure <90 mm Hg) was the strongest predictor with an estimated OR of 3.35 (95% CI 2.68 to 4.19, p<0.001). White race was associated with an elevated risk of sAKI (OR 1.22, 95% CI 1.09 to 1.36; p<0.001),

Table 1 Comparison of patients with and without AKI before matching

Variables	All (N=655 872)	No sAKI (n=653 974)	sAKI (n=1898)	P value
Age (years), median (Q1–Q3)	57 (36–73)	57 (36–73)	71 (58–81)	<0.001
Race (white), n (%)	487 581 (74.3)	486 103 (74.3)	1478 (77.9)	<0.001
Sex, n (%)				0.248
Female	271 345 (41.4)	270 585 (41.4)	760 (40)	
Male	384 527 (58.6)	383 389 (58.6)	1138 (60)	
Hypotension, n (%)	8662 (1.3)	8581 (1.3)	81 (4.3)	<0.001
ISS, median (Q1–Q3)	8 (4–9)	8 (4–9)	9 (5–10)	<0.001
GCS score, median (Q1–Q3)	15 (15–15)	15 (15–15)	15 (15–15)	<0.001
Trauma type, n (%)				<0.001
Blunt	594 366 (90.6)	592 582 (90.6)	1784 (94)	
Penetrating	61 506 (9.4)	61 392 (9.4)	114 (6)	
Trauma center, n (%)				0.007
Level I	403 938 (61.6)	402 827 (61.6)	1111 (58.5)	
Level II	251 934 (38.4)	251 147 (38.4)	787 (41.5)	
Comorbidities, n (%)				
Chronic alcoholism	39 766 (6.1)	39 593 (6.1)	173 (9.1)	<0.001
Anticoagulant	62 872 (9.6)	62 417 (9.5)	455 (24)	<0.001
Bleeding disorder	9335 (1.4)	9269 (1.4)	66 (3.5)	<0.001
Chemotherapy	3475 (0.5)	3452 (0.5)	23 (1.2)	<0.001
Cirrhosis	7327 (1.1)	7210 (1.1)	117 (6.2)	<0.001
COPD	49 141 (7.5)	48 798 (7.5)	343 (18.1)	<0.001
CVA	19 340 (2.9)	19 222 (2.9)	118 (6.2)	<0.001
Dementia	33 879 (5.2)	33 725 (5.2)	154 (8.1)	<0.001
Diabetes	102 621 (15.6)	101 915 (15.6)	706 (37.2)	<0.001
Stage IV cancer	4468 (0.7)	4435 (0.7)	33 (1.7)	<0.001
Functionally dependent	57 575 (8.8)	57 219 (8.7)	356 (18.8)	<0.001
CHF	28 576 (4.4)	28 247 (4.3)	329 (17.3)	<0.001
HTN	248 781 (37.9)	247 492 (37.8)	1289 (67.9)	<0.001
MI	5548 (0.8)	5489 (0.8)	59 (3.1)	<0.001
Smoking	144 706 (22.1)	144 407 (22.1)	299 (15.8)	<0.001
Steroid	7571 (1.2)	7521 (1.2)	50 (2.6)	<0.001
Substance abuse	47 519 (7.2)	47 401 (7.2)	118 (6.2)	0.092

GCS: hypotension, initial systolic blood pressure <90 mm Hg; MI: history of MI during the last 6 months; HTN on medication.

N= total sample size, n= sub sample size

AKI, acute kidney injury; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; GCS, Glasgow Coma Scale; HTN, hypertension; ISS, Injury Severity Score; MI, myocardial infarction; n, sub sample size; N, total sample size; sAKI, severe acute kidney injury.

whereas Asian race was associated with lower risk of sAKI (OR 0.49, 95% CI 0.31 to 0.77; p=0.002).

Propensity matching analysis

The propensity matching created 1896 pairs of patients. There was more than 90% improvement on standardized mean difference of many variables after the matching (figure 2 and table 2).

Outcomes

The overall in-hospital mortality was 20.6% in patients with sAKI compared with 2.1% without sAKI. Similarly, the median hospital LOS in patients with sAKI was 14 days (13 to 15) versus 5 days (5 to 5). The median intensive care unit (ICU) stay and ventilator days were prolonged in sAKI when compared with patients who did not develop sAKI (9 days (9 to 10) vs. 3 (3 to 3), p<0.0001, and 14 (12 to 15) vs. 3 (2 to 5), p<0.001) (figure 3 and table 3).

Higher proportion (34.2% vs. 25.2%) of patients with sAKI was placed in the skilled nursing facility compared with patients without sAKI (table 4).

When the in-hospital complications were compared with the two groups, patients with sAKI had a significantly higher complication rate that included pneumonia, sepsis, DVT, PE, etc (table 5).

DISCUSSION

Our study showed very high mortality (20.6% vs. 2.1%) in patients with a minor and moderate injury who suffered from sAKI when compared with patients who did not develop sAKI. Patients with sAKI stayed approximately three times longer in the hospital, and a significantly higher number of patients were discharged to a skilled nursing facility.

The mortality associated with minor to moderate injury is lower than severe injury. McHale and colleagues evaluated the Trauma Audit and Research Network dataset for England and found 30 days' mortality at 4.2% in patients whose ISS was between 9 and 15 and at 3.6% for ISS of <9.[16] The mortality was also related to age distribution. The mortality of 85+ years of age was 10.1% versus 1.3% when compared with patients 40 years to 64 years of age with minor to moderate injury. The
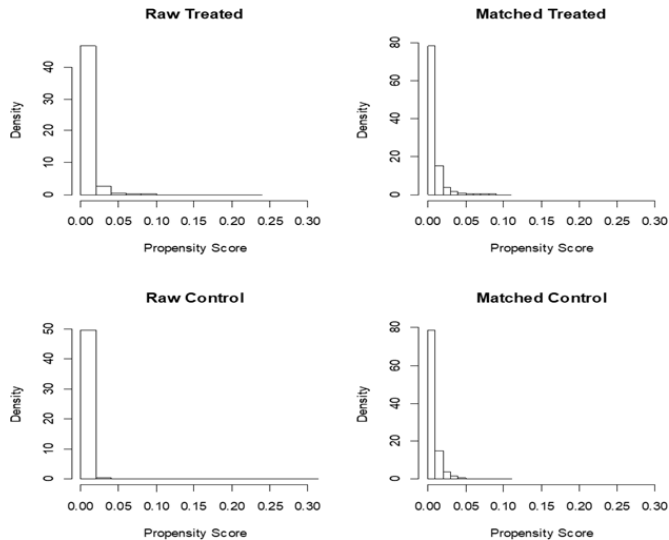
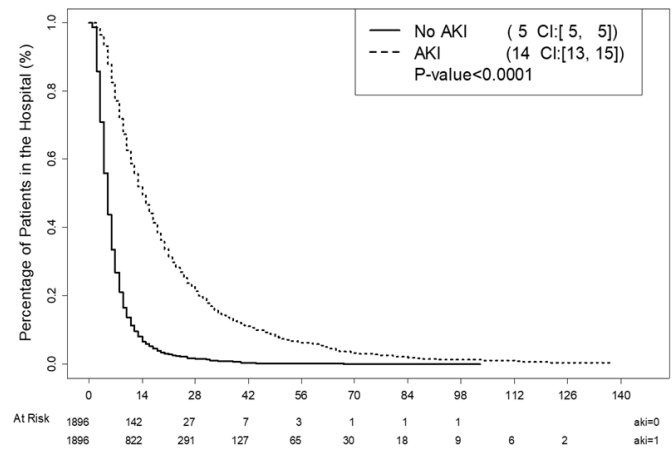**Figure 2** Histogram showing improvement in variables after propensity matching.

Figure 3 Hospital length of stay between the AKI and no-AKI groups. AKI, acute kidney injury.

Table 2 Comparison of patients with and without AKI after matching

Variable	All (N=3792)	No sAKI (n=1898)	sAKI (n=1898)	P value
Age (years), median (Q1–Q3)	71 (58–81)	71 (57.75–81)	71 (58–81)	0.534
Race (white), n (%)	2964 (78.2)	1488 (78.5)	1476 (77.8)	0.66
Sex, n (%)				0.479
Female	1498 (39.5)	738 (38.9)	760 (40.1)	
Male	2294 (60.5)	1158 (61.1)	1136 (59.9)	
Hypotension, n (%)	157 (4.1)	76 (4)	81 (4.3)	0.748
ISS, median (Q1–Q3)	9 (5–10)	9 (5–10)	9 (5–10)	0.631
GCS score, median (Q1–Q3)	15 (15–15)	15 (15–15)	15 (15–15)	0.086
Trauma type, n (%)				0.023
Blunt	3596 (94.8)	1814 (95.7)	1782 (94)	
Penetrating	196 (5.2)	82 (4.3)	114 (6)	
Trauma center, n (%)				0.145
Level I	2265 (59.7)	1155 (60.9)	1110 (58.5)	
Level II	1527 (40.3)	741 (39.1)	786 (41.5)	
Comorbidities, n (%)				
Chronic alcoholism	345 (9.1)	173 (9.1)	172 (9.1)	>0.99
Anticoagulant	879 (23.2)	426 (22.5)	453 (23.9)	0.318
Bleeding disorder	128 (3.4)	64 (3.4)	64 (3.4)	>0.99
Chemotherapy	45 (1.2)	22 (1.2)	23 (1.2)	>0.99
Cirrhosis	225 (5.9)	110 (5.8)	115 (6.1)	0.784
COPD	666 (17.6)	325 (17.1)	341 (18)	0.524
CVA	231 (6.1)	114 (6)	117 (6.2)	0.892
Dementia	290 (7.6)	136 (7.2)	154 (8.1)	0.299
Diabetes	1376 (36.3)	672 (35.4)	704 (37.1)	0.292
Stage IV cancer	67 (1.8)	34 (1.8)	33 (1.7)	>0.99
Functionally dependent	690 (18.2)	336 (17.7)	354 (18.7)	0.464
CHF	626 (16.5)	298 (15.7)	328 (17.3)	0.208
HTN	2557 (67.4)	1270 (67)	1287 (67.9)	0.568
MI	97 (2.6)	39 (2.1)	58 (3.1)	0.065
Smoking	621 (16.4)	322 (17)	299 (15.8)	0.336
Steroid	105 (2.8)	55 (2.9)	50 (2.6)	0.688
Substance abuse	248 (6.5)	132 (7)	116 (6.1)	0.312

GCS: hypotension; initial systolic blood pressure <90 mm Hg; HTN on medication, MI: history of MI during the last 6 months.
AKI, acute kidney injury; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; GCS, Glasgow Coma Scale; HTN, hypertension; ISS, Injury Severity Score; MI, myocardial infarction; sAKI, severe acute kidney injury.

Table 3 Mortality and hospital LOS in matched sample

Variable	All (N=3792)	No sAKI (n=1896)	sAKI (n=1896)	Absolute risk difference (95% CI)	P value
Died	430 (11.3)	39 (2.1)	391 (20.6)	0.186 (0.168 to 0.204)	<0.0001
Hospital LOS	8 (8–8)	5 (5–5)	14 (13–15)		<0.0001
ICU days	6 (6–7)	3 (3–3)	9 (9–10)		<0.0001
Ventilator days	11 (9–13)	3 (2–5)	14 (12–15)		<0.0001

AKI, acute kidney injury; ICU, intensive care unit; LOS, length of stay; sAKI, severe acute kidney injury.

study did not evaluate patients with in-hospital infection or sAKI. The current analysis suggests that the occurrence of sAKI is associated with a 10-fold increase in mortality in minor to moderate trauma.

Our study also found three times longer hospital LOS and ICU stay and approximately five times longer on ventilator days in patients who developed sAKI versus no sAKI. The patients with sAKI were found to have increased occurrence of in-hospital complication that may have resulted in longer stays in the hospital. As important, we found a 44% of patients in the need for skilled facility placement post hospitalization in those with sAKI. A recent review identified the importance of examining non-mortality outcomes in trauma, given the significant long-term effects on both the individual and society.[17] Thus, preventing the long-term consequences of disability remains an important goal of the care of the trauma patient. In this regard, sAKI is an important entity even in minor to moderate trauma, given the effects on mortality and non-mortality outcomes. Identifying means to prevent sAKI or treat to resolve it should be a goal of future studies in this population.

Prior studies evaluated the risk of sAKI in trauma patients found to have a median ISS of >17.[5 18] The patients with sAKI who died in these studies had an ISS of >25. Higher ISS is also a known factor for mortality. Therefore, we excluded all patients who had an ISS of ≥16. Despite that, the mortality of the trauma patients with sAKI was approximately 10-fold higher than those who did not develop sAKI. Further analysis of the data showed that advanced age, black race, male gender, higher ISS, and presence of hypotension were associated with sAKI, which is consistent with prior studies.[5 18] The majority of risk factors identified in the current analysis are not modifiable (age, gender, and race). However, hypotension conferred a threefold increase in sAKI risk. Thus, despite seeming lower severity of trauma, using all preventive measure that includes aggressive resuscitation remains relevant to preventing sAKI.[12] Recently, STOP THE BLEED program, which was started a few years ago,

is being implemented across the country by emergency medical service providers, law enforcement agents on the ground and by standard.[19] More patients with extremity injury with hemorrhage are being brought to the hospital with tourniquet. Recent whole blood transfusion at the scene and during transportation on hypotensive patients has shown survival benefit.[20] Ultimately knowing the cause of AKI is important in providing preventive measures or therapeutics; however, in the current analysis, the exact cause of sAKI is not known. Direct trauma to the kidney is a less frequent event, but indirect impact of immunomodulation after a trauma may be a factor that causes the susceptibility of patients for developing sAKI even in a seemingly minor traumatic injury.[21]

Limitations

Our study is the first to evaluate the outcomes of sAKI in trauma patients with minor and moderate injury and showed an associated extremely high mortality. However, our study is limited by its retrospective nature. We opted to perform the propensity matching analysis to limit the selection bias. Nevertheless, some potentially important covariates were unavailable for direct evaluation. For instance, due to the unavailability of data relating to the response of resuscitation to the shock state, we could

Table 4 Discharge disposition of patients who survived hospital admission in matched sample

	No sAKI (n=1857)	sAKI (n=1505)	P value
Discharge destinations, n (%)			<0.001
Home with care	187 (10.1)	103 (6.8)	
Home without care	805 (43.3)	346 (23)	
Hospice care	28 (1.5)	75 (5)	
Others	37 (2)	31 (2.1)	
Rehab	288 (15.5)	300 (19.9)	
Short-term, Intermediate, long-term care facility	44 (2.4)	136 (9)	
Skilled nursing facility	468 (25.2)	514 (34.2)	

sAKI, severe acute kidney injury.

Table 5 In-hospital complications in the matched data

Variable, n (%)	All (n=3792)	No AKI (n=1896)	AKI (n=1896)	P value
Superficial SSI	14 (0.4)	1 (0.1)	13 (0.7)	>0.99
Deep SSI	29 (0.8)	4 (0.2)	25 (1.3)	<0.001
Organ space SSI	13 (0.3)	1 (0.1)	12 (0.6)	0.006
Catheter-associated urinary tract infection	41 (1.1)	5 (0.3)	36 (1.9)	<0.001
Pneumonia	55 (1.5)	3 (0.2)	52 (2.7)	<0.001
Sepsis	207 (5.5)	8 (0.4)	199 (10.5)	<0.001
Pressure ulcer	88 (2.3)	8 (0.4)	80 (4.2)	<0.001
Deep vein thrombosis (DVT)	85 (2.2)	11 (0.6)	74 (3.9)	<0.001
Pulmonary embolism (PE)	58 (1.5)	7 (0.4)	51 (2.7)	<0.001
Respiratory complications including, Acute respiratory distress syndrome(ARDS)	104 (2.7)	4 (0.2)	100 (5.3)	<0.001
Myocardial infarction	78 (2.1)	9 (0.5)	69 (3.6)	<0.001
Cardiac arrest	168 (4.4)	10 (0.5)	158 (8.3)	<0.001
Unplanned intubation	359 (9.5)	23 (1.2)	336 (17.7)	<0.001
Stroke (CVA)	43 (1.1)	5 (0.3)	38 (2)	<0.001
Unplanned ICU	497 (13.1)	56 (3)	441 (23.3)	<0.001

AKI, acute kidney injury; ARDS, acute respiratory distress syndrome; CVA, cerebrovascular accident; ICU, intensive care unit; SSI, surgical site infection.

not adjust for the duration of shock and outcomes. Despite the minimization of confounding with propensity score matching, residual confounding cannot be completely eliminated. The NTDB does not provide the exact SCr level or creatinine clearance of the patients. Furthermore, the timing of sAKI is also not available from the database. It is important for all providers to be aware of the consequences of sAKI that minor injuries can turn into devastating events.

CONCLUSION

The occurrence of sAKI injury in minor to moderate trauma is less than 1%. However, patients with sAKI had an associated three times longer hospital stay and a 10-fold increase in mortality when compared with patients who did not develop sAKI. Future studies should identify means to prevent the development of or progression to sAKI in minor to moderate traumatic injury.

ORCID iD
Nasim Ahmed http://orcid.org/0000-0001-8347-0726

REFERENCES

1 Traumatic brain injury. 2022. Available: https://www.aast.org/resources/trauma-facts [Accessed 12 Oct 2022].

2 Polinder S, Haagsma JA, Toet H, van Beeck EF. Epidemiological burden of minor, major and fatal trauma in a national injury pyramid. *Br J Surg* 2012;99 Suppl 1:114–21.

3 Sobrino J, Shafi S. Timing and causes of death after injuries. *Proc (Bayl Univ Med Cent)* 2013;26:120–3.

4 Haines RW, Fowler AJ, Kirwan CJ, Prowle JR. The incidence and associations of acute kidney injury in trauma patients admitted to critical care: a systematic review and meta-analysis. *J Trauma Acute Care Surg* 2019;86:141–7.

5 Ahmed N, Mathew RO, Kuo Y, Asif A. Risk of in-hospital mortality in severe acute kidney injury after traumatic injuries: a national trauma quality program study. *Trauma Surg Acute Care Open* 2021;6:e000635.

6 Hoste EAJ, Clermont G, Kersten A, Venkataraman R, Angus DC, De Bacquer D, Kellum JA. Rifle criteria for acute kidney injury are associated with hospital mortality in critically ill patients: a cohort analysis. *Crit Care* 2006;10:R73.

7 Bihorac A, Delano MJ, Schold JD, Lopez MC, Nathens AB, Maier RV, Layon AJ, Baker HV, Moldawer LL. Incidence, clinical predictors, genomics, and outcome of acute kidney injury among trauma patients. *Ann Surg* 2010;252:158–65.

8 Shashaty MGS, Meyer NJ, Localio AR, Gallop R, Bellamy SL, Holena DN, Lanken PN, Kaplan S, Yarar D, Kawut SM, et al. African american race, obesity, and blood product transfusion are risk factors for acute kidney injury in critically ill trauma patients. *J Crit Care* 2012;27:496–504.

9 Skinner DL, Hardcastle TC, Rodseth RN, Muckart DJJ. The incidence and outcomes of acute kidney injury amongst patients admitted to a level I trauma unit. *Injury* 2014;45:259–64.

10 Eriksson M, Brattström O, Mårtensson J, Larsson E, Oldner A. Acute kidney injury following severe trauma: risk factors and long-term outcome. *J Trauma Acute Care Surg* 2015;79:407–12.

11 Heegard KD, Stewart IJ, Cap AP, Sosnov JA, Kwan HK, Glass KR, Morrow BD, Latack W, Henderson AT, Saenz KK, et al. Early acute kidney injury in military casualties. *J Trauma Acute Care Surg* 2015;78:988–93.

12 Ahmed N, Mathew RO, Kuo Y-H, Md AA. Risk of severe acute kidney injury in multiple trauma patients: risk estimation based on a national trauma dataset. *Injury* 2020;51:45–50.

13 National trauma daata standard data dictionary 2019 admissions. Available: https://www.facs.org/~/media/files/quality%20programs/trauma/ntdb/ntds/data%20dictionaries/ntdb_data_dictionary_2019_revision.ashx [Accessed 11 Mar 2019].

14 Ho DE, Imai K, King G, Stuart EA. **matchit**: nonparametric preprocessing for parametric causal inference. *J Stat Soft* 2011;42:1–28. Available: http://www.jstatsoft.org/v42/i08/.

15 R Core Team. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing, 2021. Available: https://www.R-project.org

16 McHale P, Hungerford D, Taylor-Robinson D, Lawrence T, Astles T, Morton B. Socioeconomic status and 30-day mortality after minor and major trauma: a retrospective analysis of the trauma audit and research network (TARN) dataset for England. *PLoS ONE* 2018;13:e0210226.

17 Gruen RL, Gabbe BJ, Stelfox HT, Cameron PA. Indicators of the quality of trauma care and the performance of trauma systems. *Br J Surg* 2012;99 Suppl 1:97–104.

18 Perkins ZB, Captur G, Bird R, Gleeson L, Singer B, O'Brien B. Trauma induced acute kidney injury. *PLoS One* 2019;14:e0211001.

19 Stop the bleed. Available: https://www.dhs.gov/stopthebleed [Accessed 14 Oct 2022].

20 Braverman MA, Smith A, Pokorny D, Axtman B, Shahan CP, Barry L, Corral H, Jonas RB, Shiels M, Schaefer R, et al. Prehospital whole blood reduces early mortality in patients with hemorrhagic shock. *Transfusion* 2021;61 Suppl 1:S15–21.

21 Messerer DAC, Halbgebauer R, Nilsson B, Pavenstädt H, Radermacher P, Huber-Lang M. Immunopathophysiology of trauma-related acute kidney injury. *Nat Rev Nephrol* 2021;17:91–111.