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National risk factors for blunt cardiac injury: Hemopneumothorax is the strongest predictor

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ABSTRACT

Background: Blunt cardiac injury (BCI) can occur after chest trauma and may be associated with sternal fracture (SF). We hypothesized that injuries demonstrating a higher transmission of force to the thorax, such as thoracic aortic injury (TAI), would have a higher association with BCI.

Methods: We queried the National Trauma Data Bank (NTDB) from 2007-2015 to identify adult blunt trauma patients.

Results: BCI occurred in 15,976 patients (0.3%). SF had a higher association with BCI ($OR = 5.52$, $CI = 5.32-5.73$, $p < 0.001$) compared to TAI ($OR = 4.82$, $CI = 4.50-5.17$, $p < 0.001$). However, the strongest independent predictor was hemopneumothorax ($OR = 9.53$, $CI = 7.80-11.65$, $p < 0.001$) followed by SF and esophageal injury ($OR = 5.47$, $CI = 4.05-7.40$, $p < 0.001$).

Conclusion: SF after blunt trauma is more strongly associated with BCI compared to TAI. However, hemopneumothorax is the strongest predictor of BCI. We propose all patients presenting after blunt chest trauma with high-risk features including hemopneumothorax, sternal fracture, esophagus injury, and TAI be screened for BCI.

Summary: Using the National Trauma Data Bank, sternal fracture is more strongly associated with blunt cardiac injury than blunt thoracic aortic injury. However, hemopneumothorax was the strongest predictor.

Introduction

Blunt cardiac injury (BCI) can present in a variety of ways ranging from asymptomatic myocardial contusions and transient arrhythmias to lethal cardiac rupture.[1] The absence of a clear definition for BCI makes the diagnosis difficult to make but the incidence after blunt trauma ranges from 16% in autopsy studies to 76% in clinic studies.[2] Although no gold standard exists, the diagnosis depends on a high index of suspicion combined with numerous modalities including plain radiographs of the chest, computed tomography (CT) imaging, electrocardiogram (ECG), serum troponin level and echocardiography.[3] BCI most commonly occurs following a motor vehicle collision but those involved in falls, blast injuries and sports injuries are also at risk.[4,5] Patients with BCI have higher mortality and a trend towards a longer hospital length of stay (LOS).[6]

In a large multicenter retrospective study, the strongest independent risk factor for BCI was sternal fracture (SF).[7] In other studies, SF was not shown to be associated with BCI and these patients could be safely discharged without further work-up if they remained hemodynamically stable.[8,9] While SF would imply direct force overlying the myocardium, we hypothesized that injuries demonstrating significant transmission of force to the thorax, such as a thoracic aortic injury (TAI),[10] would have a higher association with BCI.

Methods

We queried the National Trauma Data Bank (NTDB) from January 2007 through December 2015 to identify all patients admitted with a blunt mechanism of injury using the appropriate event-codes.[11] Patients with BCI were identified using the International Classification of Diseases (ICD version 9) diagnosis code

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861.01. Our exclusion criteria included patients <18 years of age. Our primary end-point of interest was the incidence of BCI. The relationship between BCI and baseline patient demographics, cardiovascular comorbidities, injury profile, and hospital outcomes including complications was analyzed.

Patient demographic information including age, gender and pre-hospital cardiovascular comorbidities including hypertension, peripheral vascular disease (PVD), myocardial infarction (MI) and history of angina in the previous 30 days were collected. The injury profile included the injury severity score (ISS). Associated thoracic injuries were identified by the appropriate ICD-9 diagnosis codes and included SF (open and closed), rib fracture, pulmonary contusion, pneumothorax, hemothorax, hemopneumothorax and TAI. An associated spine injury, upper extremity fracture and traumatic brain injury (TBI) were also included. The outcomes evaluated included total hospital LOS, intensive care unit (ICU) LOS, ventilator days and mortality. In-hospital complications included development of acute kidney injury (AKI), acute respiratory distress syndrome (ARDS), MI, pulmonary embolism (PE), pneumonia and unplanned intubation or ICU admission.

Descriptive statistics were performed for all variables. A Student's *t*-test was used to compare continuous variables and chi-square was used to compare categorical variables for bivariate analysis. Categorical data were reported as percentages, and continuous data were reported as medians with interquartile range or means with standard deviation.

The magnitude of the association between predictor variables and the incidence of BCI was first measured using a univariable logistic regression model. Covariates were then entered into a hierarchical multivariable logistic regression model and the adjusted risk for BCI was reported with an odds ratio (OR) and 95% confidence intervals (CI). The reference group included all adult patients with a blunt mechanism of injury. All p values were two-sided, with a statistical significance level of <0.05. The majority of the variables chosen for our regression analyses were based on ICD-9 diagnosis codes and were coded as present or absent. The remainder were mandated reportable comorbid conditions. All statistical analyses were performed with IBM SPSS Statistics for Windows (Version 24, IBM Corp., Armonk, NY).

Results

From 4,571,161 adult patients involved in blunt trauma between years 2007–2015, 15,976 were identified to have BCI (0.3%). The mean age was 48.8 years, most were male (67.9%) and the median ISS was 19. Most patients were involved in a motor vehicle accident (66.3%). The most common associated thoracic injuries were rib fracture (57.1%), pulmonary contusion (41.2%), closed SF (22.3%) and pneumothorax (21.4%). TAI and hemopneumothorax occurred less frequently at 3.7% and 0.4%, respectively. Nearly half the patients had TBI (41.1%) (Table 1).

The median LOS for all patients with BCI was 10.6 days and the overall mortality rate was 19.1%. The most common in-hospital complication was the development of pneumonia (9.8%) followed by ARDS (6.0%) (Table 2).

On univariable analysis for risk of BCI in adult blunt trauma patients, the strongest risk factor was hemopneumothorax (OR 48.40, 95% CI 46.58–50.30, $p < 0.001$) (Table 3). After adjusting for covariates in a multivariable logistic regression analysis, hemopneumothorax continued to be the strongest independent risk factor for BCI (OR 9.43, 95% CI 7.80, $p < 0.001$) followed by SF (OR 5.52, 95% CI 5.32–5.73, $p < 0.001$), esophagus injury (OR 5.47, 95% CI 4.05–7.40, $p < 0.001$) and TAI (OR 4.82, 95% CI 4.50–5.17, $p < 0.001$) (Table 4).

In a post-hoc analysis using a similar multivariable logistic regression model, we found an open SF to have higher risk for BCI compared to a closed SF (OR 1.98, 95% CI 1.35–2.92, $p < 0.05$). We then compared BCI with SF to BCI without SF and found the former to have increased ICU LOS ≥ 1 day (OR 1.21, 95% CI 1.11–1.31, $p < 0.001$) and total LOS ≥ 6 days (OR 1.21, 95% CI 1.12–1.31, $p < 0.001$). Additionally, BCI patients with SF had increased risk for ventilator days ≥ 2 days (OR 1.16, 95% CI 1.06–1.26, $p < 0.001$). There were no differences in hospital complications (ARDS, pneumonia or PE) ($p > 0.05$) (Table 5).

Table 1
Patient characteristics of blunt cardiac injury in adult blunt trauma patients (INCIDENCE:<0.1%).

Characteristic	(n = 15976)
Age, years, mean (SD)	48.8 (22)
Sex, male, n (%)	10854 (67.9%)
ISS, median (IQR)	19 (5%)
Blunt mechanism, n (%)	
Motor vehicle	10592 (66.3%)
Motorcycle	1325 (8.3%)
Bicycle	216 (1.4%)
Fall	521 (3.3%)
Other	3326 (20.7%)
Thoracic Injuries, n (%)	
Isolated sternal fracture*	989 (6.2%)
Sternal fracture, closed	3561 (22.3%)
Sternal fracture, open	16 (0.1%)
Clavicle fracture	1596 (10.0%)
Rib fracture	9129 (57.1%)
Pulmonary contusion	6590 (41.2%)
Pneumothorax	3413 (21.4%)
Hemothorax	1636 (10.2%)
Hemopneumothorax	62 (0.4%)
Thoracic aorta injury	593 (3.7%)

SD = standard deviation, IQR = interquartile range.
* = no other thoracic fracture.

Discussion

Our study focused on identifying risk factors for BCI using a large national trauma database. Almost two-thirds of the patients with BCI presented after a motor vehicle accident. More than half the patients had concomitant rib fracture. The strongest independent risk factors for BCI, in order, were hemopneumothorax, SF, esophagus injury and TAI. Patients with open SF had higher risk for BCI compared to closed SF.

Established firm guidelines on which patients to offer BCI screening are lacking. Eastern Association for the Surgery of Trauma (EAST) guidelines suggest that the decision to screen a patient for

Table 2
Patient outcomes of blunt cardiac injury in adult blunt trauma patients.

Characteristic	(n = 15976)
Outcomes	
LOS, days, mean (SD)	10.6[15]
ICU, days, mean (SD)	9.5[11]
Ventilator, days, mean (SD)	9.5[12]
Mortality, n (%)	3059 (19.1%)
Complications, n (%)	
Acute kidney injury	565 (3.5%)
ARDS	955 (6.0%)
Myocardial infarction	306 (1.9%)
Pulmonary embolism	205 (1.3%)
Unplanned ICU	132 (0.8%)
Unplanned intubation	304 (1.9%)
Pneumonia	1568 (9.8%)

LOS = length of stay, SD = standard deviation, ICU = intensive care unit, ARDS = acute respiratory distress syndrome.

Table 3
Univariable analysis of risk factors for blunt cardiac injury in adult blunt trauma patients.

Risk factor	OR	CI	p value
History of myocardial infarction	1.21	1.08–1.35	<0.05
History of angina last 30 days	1.88	1.44–2.45	<0.001
Scapula fracture	2.87	2.71–3.04	<0.001
Clavicle fracture	2.88	2.74–3.02	<0.001
Pneumothorax	3.16	3.06–3.26	<0.001
Rib fracture	8.03	7.80–8.26	<0.001
Pulmonary contusion	8.84	8.58–9.11	<0.001
Hemothorax	12.52	12.08–12.97	<0.001
Sternal fracture	14.54	14.04–15.05	<0.001
Esophagus injury	22.56	17.31–29.39	<0.001
Thoracic aorta injury	24.92	23.43–26.51	<0.001
Hemopneumothorax	48.40	46.58–50.30	<0.001

BCI is to be determined by the treating clinician but with strong consideration in patients with a significant mechanism of injury that is not responding appropriately to resuscitation.[12] The first diagnostic test in evaluating patients for BCI includes a 12-lead ECG.[13] The negative predictive value of a normal ECG is 95%. The addition of a normal serum troponin level upon arrival with a normal ECG affectively rules out BCI with a 100% negative predictive value.[14] Therefore, we propose that all trauma patients presenting with blunt chest trauma with any high-risk features including hemopneumothorax, sternal fracture, esophagus injury, or TAI be screened for BCI using a 12-lead ECG with consideration of a troponin level. Applying all these high-risk features provides a negative predictive value of 99.9%. Future prospective studies can validate the risk factors identified in our study to introduce screening criteria for BCI and determine which patients can be safely discharged.

Hemopneumothorax is a known sequelae of blunt trauma to the chest.[15] In contrast to a previous report identifying SF as the strongest predictor of BCI, our study demonstrates hemopneumothorax to be the strongest independent risk factor for BCI.[7] The incidence of hemopneumothorax in patients with BCI was quite low at 0.4%. Although no previous studies have looked at the incidence of hemopneumothorax in BCI patients, the incidence of hemopneumothorax in blunt trauma ranges between 2 and 33%.[16–18] This wide range may be a reflection of small hemopneumothoraces being undiagnosed initially during physical exam or with chest radiograph alone.[19,20] Although hemopneumothorax occurred at a low rate in our study, when found it was strongly associated with BCI. Therefore, we encourage clinicians to obtain a 12-lead EKG and troponin to diagnose BCI. However, other thoracic injuries such as pulmonary contusion, hemothorax, and rib fracture occurred at a significantly higher rate and were also independently associated with risk for BCI. Consideration for screening of BCI should also be made when one or more of these injuries are identified.

Table 4
Adjusted* odds ratio for risk of blunt cardiac injury in all adult blunt trauma patients.

Risk factor	OR	CI	p value
History of myocardial infarction	1.39	1.24–1.56	<0.001
History of angina last 30 days	2.17	1.65–2.85	<0.001
Pulmonary contusion	3.01	2.91–3.12	<0.001
Hemothorax	3.17	3.03–3.32	<0.001
Rib fracture	3.48	3.35–3.60	<0.001
Thoracic aorta injury	4.82	4.50–5.17	<0.001
Esophagus injury	5.47	4.05–7.40	<0.001
Sternal fracture	5.52	5.32–5.73	<0.001
Hemopneumothorax	9.53	7.80–11.65	<0.001

* = controlled for significant variables from univariable analysis.

Table 5
Subgroup analysis of outcomes in adult blunt trauma patients with blunt cardiac injury and sternal fracture compared to blunt cardiac injury without sternal fracture.

Outcome	OR	CI	p value
ICU LOS ≥1	1.21	1.11–1.31	<0.001
LOS ≥6	1.21	1.12–1.31	<0.001
Vent days ≥2	1.16	1.06–1.26	<0.001
ARDS	1.10	0.94–1.29	0.23
Pneumonia	1.13	0.99–1.28	0.06
PE	1.14	0.83–1.58	0.41

ICU = intensive care unit, LOS = length of stay, ARDS = acute respiratory distress syndrome, PE = pulmonary embolism.

SF is another recognized concomitant thoracic injury in patients with BCI with an incidence as high as 32%.[7,21,22] BCI patients in the NTDB had a concomitant SF in 22.4% of cases. SF can simply be a marker of significant force dispersed to the chest from blunt trauma resulting in injuries to surrounding structures including the heart.[23] This is supported by one study in which no patients with isolated SF (less destructive force) were found to have clinically significant cardiac injury.[24] A higher amount of energy is generally required to cause a displaced fracture versus non-displaced fracture. De Waele et al. found a higher percentage of patients with displaced SF to have signs of BCI compared to patients with non-displaced SF (54% vs 21%, $p < 0.05$) and significantly more arrhythmias during hospitalization (23.5% vs 5.6%, $p < 0.05$).[21] In support of these reports, we also demonstrate a nearly two-fold increased relative risk of BCI in patients with open SF compared to closed SF.

BCI is associated with high mortality which may be attributed partly to concomitant thoracic injuries. Due to the discrepancy in the definition of BCI, the mortality rate varies widely from 0.04-86%.[2,25–30] We identified a mortality rate of 19.1% in patients with BCI. These patients often have concomitant thoracic injuries, such as TAI, which may contribute to a higher mortality rate. TAI requires a significant amount of force and is considered a lethal condition if not recognized early and treated appropriately.[31–34] The incidence of BCI in patients with TAI ranges from 18-77%.[34,35] Although we did not find TAI to be the strongest predictor of BCI, it still was associated with a five-fold relative increased risk of BCI. Thus, we believe TAI should warrant screening for BCI and certainly hypotension in the setting of TAI should warrant evaluation for BCI with echocardiogram.

Our study is a retrospective analysis using a large database and so a reporting bias is undoubtedly present. All data fields in the NTDB are subject to input error. The lack of a uniformed definition and method of diagnosing BCI in the NTDB may result in inaccurate reporting for this patient population. Relevant data fields missing in the NTDB include type of arrhythmia in BCI patients, displaced versus non-displaced SF, clinically significant cases of BCI (shock, significant arrhythmia, etc.) and the method of diagnosis for BCI (ECG, laboratory studies, echocardiogram, etc.). And lastly, the NTDB only follows patients during their index hospitalization and so we were unable to determine post-discharge outcomes.

Conclusion

In a large national database study of blunt trauma patients, SF is more strongly associated with BCI compared to TAI; however, hemopneumothorax is the strongest predictor of BCI. We propose that all trauma patients presenting with blunt chest trauma with any high-risk features including hemopneumothorax, sternal fracture, esophagus injury, and TAI be screened for BCI using a 12-lead ECG with consideration of a serum troponin level.

Conflicts of interest

The authors do not have any conflicts of interest to report, financial or otherwise.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.amjsurg.2018.07.043.

References

1. Mattox KL, Flint LM, Carrico CJ, et al. Blunt cardiac injury. *J Trauma Inj Infect Crit Care*. 1992;33(5), 649-50.
2. Shorr RM, Crittenden M, Indeck M, et al. Blunt thoracic trauma. Analysis of 515 patients. *Ann Surg*. 1987;206(2):200.
3. Pasquale MD, Nagy K, Clarke J. Practice management guidelines for screening of blunt cardiac injury. *J Trauma*. 1998;44(6), 941-57.
4. Bu'Lock F, Prothero A, Shaw C, et al. Cardiac involvement in seatbelt-related and direct sternal trauma: a prospective study and management implications. *Eur Heart J*. 1994;15(12), 1621-7.
5. Crown LA, Hawkins W. Commotio cordis: clinical implications of blunt cardiac trauma. *Am Fam Physician*. 1997;55, 2467-72.
6. Skinner D, Laing G, Rodseth R, et al. Blunt cardiac injury in critically ill trauma patients: a single centre experience. *Injury*. 2015;46(1):66–70.
7. Hanschen M, Kanz K-G, Kirchhoff C, et al. Blunt cardiac injury in the severely injured—a retrospective multicentre study. *PLoS One*. 2015;10(7), e0131362.
8. Chiu WC, D'Amelio LF, Hammond JS. Sternal fractures in blunt chest trauma: a practical algorithm for management. *Am J Emerg Med*. 1997;15(3):252–255.
9. Gouldman JW, Miller RS. Sternal fracture: a benign entity? *Am Surg*. 1997 Jan;63(1):17–19. PubMed PMID: 8985065. Epub 1997/01/01. eng.
10. Nzewi O, Slight RD, Zamvar V. Management of blunt thoracic aortic injury. European journal of vascular and endovascular surgery. *Off. J. Eur. Soc. Vasc. Surg*. 2006 Jan;31(1):18–27. PubMed PMID: 16226902. Epub 2005/10/18. eng.
11. Surgeons ACo. *National Trauma Data Bank*. American College of Surgeons; 2016.
12. Clancy K, Velopulos C, Bilaniuk JW, et al. Screening for blunt cardiac injury: an Eastern Association for the Surgery of Trauma practice management guideline. *J. Trauma Acute Care Surg*. 2012;73(5):S301–S306.
13. Walsh P, Marks G, Aranguri C, et al. Use of V4R in patients who sustain blunt chest trauma. *J Trauma*. 2001 Jul;51(1):60–63. PubMed PMID: 11468467. Epub 2001/07/27. eng.
14. Salim A, Velmahos GC, Jindal A, et al. Clinically significant blunt cardiac trauma: role of serum troponin levels combined with electrocardiographic findings. *J. Trauma Acute Care Surg*. 2001;50(2):237–243.
15. Sturm JT, Points BJ, Perry Jr JF. Hemopneumothorax following blunt trauma of the thorax. *Surg Gynecol Obstet*. 1975 Oct;141(4):539–540. PubMed PMID: 1166378. Epub 1975/10/11. eng.
16. Misthos P, Kakaris S, Sepsas E, et al. A prospective analysis of occult pneumothorax, delayed pneumothorax and delayed hemothorax after minor blunt thoracic trauma. *Eur J Cardio Thorac Surg*. 2004;25(5):859–864.
17. Simon BJ, Chu Q, Emhoff TA, et al. Delayed hemothorax after blunt thoracic trauma: an uncommon entity with significant morbidity. *J. Trauma Acute Care Surg*. 1998;45(4):673–676.
18. Sharma OP, Sara H, Oswanski MF. Prevalence of delayed hemothorax in blunt thoracic trauma. *Am Surg*. 2005;71(6):481–486.
19. Karmy-Jones R, Jurkovich GJ. Blunt chest trauma. *Curr Probl Surg*. 2004;41(3): 223–380.
20. Richardson JD, Miller FB, Carrillo EH, Spain DA. Complex thoracic injuries. *Surg Clin*. 1996;76(4):725–748.
21. De Waele JJ, Calle PA, Blondeel L, Vermassen FE. Blunt cardiac injury in patients with isolated sternal fractures: the importance of fracture grading. *Eur J Trauma*. 2002;28(3):178–182.
22. A-a Khoriati, Rajakulasingam R, Shah R. Sternal fractures and their management. *J Emergencies, Trauma, Shock*. 2013;6(2):113.
23. Johnson I, Branfoot T. Sternal fracture—a modern review. *Arch Emerg Med*. 1993;10(1):24.
24. Dua A, McMaster J, Desai PJ, et al. The association between blunt cardiac injury and isolated sternal fracture. *Cardiol Res Pract*. 2014;2014, 629687. PubMed PMID: 24653859. Pubmed Central PMCID: PMC3933392. Epub 2014/03/22. eng.
25. Prêtre R, Chilcott M. Blunt trauma to the heart and great vessels. *N Engl J Med*. 1997;336(9):626–632.
26. Parmley LF, Manion WC, Mattingly TW. Nonpenetrating traumatic injury of the heart. *Circulation*. 1958;18(3):371–396.
27. Fulda G, Brathwaite C, Rodriguez A, et al. Blunt traumatic rupture of the heart and pericardium: a ten-year experience (1979-1989). *J Trauma*. 1991;31(2), 167-72; discussion 72–73.
28. Teixeira PG, Inaba K, Oncel D, et al. Blunt cardiac rupture: a 5-year NTDB analysis. *J. Trauma Acute Care Surg*. 2009;67(4):788–791.
29. Santavirta S, ArajÄrvi E. Ruptures of the heart in seatbelt wearers. *J. Trauma Acute Care Surg*. 1992;32(3):275–279.
30. El-Chami MF, Nicholson W, Helmy T. Blunt cardiac trauma. *J Emerg Med*. 2008;35(2):127–133.
31. Fabian TC, Richardson JD, Croce MA, et al. Prospective study of blunt aortic injury: multicenter trial of the American Association for the Surgery of Trauma. *J. Trauma Acute Care Surg*. 1997;42(3):374–383.
32. McGillicuddy D, Rosen P. Diagnostic dilemmas and current controversies in blunt chest trauma. *Emerg Med Clin*. 2007;25(3):695–711.
33. Mirvis SE, Shanmuganathan K. Diagnosis of blunt traumatic aortic injury 2007: still a nemesis. *Eur J Radiol*. 2007;64(1):27–40.
34. Cook J, Salerno C, Krishnadasan B, et al. The effect of changing presentation and management on the outcome of blunt rupture of the thoracic aorta. *J Thorac Cardiovasc Surg*. 2006;131(3):594–600.
35. Kaewlai R, de Moya MA, Santos A, et al. Blunt cardiac injury in trauma patients with thoracic aortic injury. *Emerg. Med. Int*. 2011;2011, 848013. PubMed PMID: 22046549. Pubmed Central PMCID: PMC3200124. Epub 2011/11/03. eng.