The Chaos of Triage: A Model for Early Exclusion of Cardiac Injury in Chest Gunshot Wound Patients

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Abstract

Introduction

Heart injury caused by thoracic gunshot wounds (GSW) is especially life-threatening and require prompt diagnosis and treatment. Heart injury is especially life-threatening and requires prompt diagnosis and treatment. During the pre-hospital phase and initial triage in the emergency department (ED), early recognition of a patient with heart GSW is difficult but important. The purpose of this study was to evaluate the predictability of heart injury in patients with chest GSWs.

Methods

The National Trauma Data Bank was queried for patients with chest GSW treated at all US trauma centres from July 1, 2009, to June 30, 2016. Patients with and without heart injuries (ICD-9: 861.00-03, 861.10-13) were compared and analyzed. Multivariate logistic regression was performed to evaluate independent factors of heart injury which could be obtained during the pre-hospital or triage phase only. Step-backward selection was used to establish a model for such patients. We used the receiver operating characteristic (ROC) curve to test the accuracy of this model and Youden's J statistic to find the cutoff value of sensitivity/specificity. Level 1 trauma registry data from Stroger Hospital of Cook County (July 1, 2016, to June 30, 2017) was used for external validation of this prediction model.

Results

47,044 patients with chest GSW were evaluated in the ED and 8.6% of them had heart injuries. The mortality rates of patients without cardiac injury versus those with cardiac injury were 9.0% (3864/42997) and 21.7% (879/4047) respectively. Patients with heart injuries were significantly younger (28.4 vs. 29.3, p<0.001), had lower SBP (34.7 vs. 103.8 mmHg, p<0.001), had lower GCS (5.1 vs. 11.2, p<0.001) and a higher probability of apnea (58.3% vs. 14.7%, p<0.001), higher rate of pulselessness (59.9% vs. 12.0%, p<0.001), and more self-inflicted injuries (9.7% vs. 8.5%, p<0.001) than patients without heart injuries. The cutoff values of SBP and GCS for prediction of heart injury were 61mmHg (AUC: 0.783) and 5.5 (AUC: 0.768) respectively. Integration of six independent factors (age, SBP, GCS, apnea, lack of pulse and suicide intent) with multivariate logistic regression showed an AUC: 0.823 and specificity of 88.8% in the heart injury prediction model. External validation with the local database showed 95.6% specificity.

Conclusion

Early diagnosis of heart injury is important in the management of patients with chest GSWs. Our model has high specificity and can be beneficial for early triage of cardiac injury in patients with GSW to the chest.

Introduction

Cardiac injury can be lethal. Historically, clinical experience with cardiac injury due to gunshot wounds (GSWs) was uncommon. Recently with an increased access (1)(2) and use of firearms throughout the U.S., the incidence of penetrating injuries to the chest and heart has risen (3). Some studies suggest that the mortality rate in cardiac injury patients is as high as 60–74% (4). Early recognition of patients with cardiac injuries is necessary for prompt diagnosis and treatment to reduce the high mortality associated with cardiac injuries.

Several studies suggest that mortality can be reduced when major trauma patients are transported directly to a trauma center (5)(6)(7)(8). However, the triage and decision to transfer can be prolonged or delayed due to an unpredictable pattern of injury seen in GSW patients. Early identification of cardiac injury in these patients could be lifesaving. Currently, prehospital personnel are unable to predict cardiac injury in patients with GSW to the chest.

The current study examines the incidence of cardiac injuries and identifies independent factors that predict such injuries. We used the National Trauma Data Bank (NTDB) to predict heart injuries in patients with GSW to the chest. We developed and validated a model that can be used both in the pre-hospital environment and Emergency Department (ED) to identify patients with cardiac injury.

Method

The National Trauma Data Bank (NTDB) was analyzed between July 1, 2009 to June 30, 2016. The NTDB is the largest multi-institutional information repository prospectively gathered from Trauma Centers and maintained by the American College of Surgeons (ACS). In the current study, patients with intra-thoracic injuries (ICD-9:860.0-862.9) due to GSW were included. Non-GSW penetrating injuries, non-chest injuries and records with missing key values were excluded. Patients with and without heart injuries (ICD-9: 861.00–03, 861.10–13) were compared and analyzed. Data extracted included demographics, vital signs, Injury Severity Score (ISS) and Glasgow Comma Scale (GCS). Pre-hospital data such as intention of suicide with the use of a firearm and patients' condition on arrival in the ED such as pulselessness and apnea were also included.

A univariate analysis was created to study the characteristics of the patient population. A bivariate analysis comparing mortality in patients with and without heart injury was created. Variables were compared between patients with and without heart injuries using chi square testing and independent t-test. Multivariate logistic regression (MLR) analysis was performed to evaluate independent variables predictive of cardiac injury. Variables gathered during the pre-hospital phase included age, race, Systolic Blood Pressure (SBP), GCS, pulselessness, apnea and intention of suicide. A step-backward selection method was used to create an accurate model that predicted heart injury in chest GSW. Odds ratio with 95% confidence intervals were calculated and statistical significance was set at a p-value < 0.05.

Receiver operating characteristic (ROC) curves were created for SBP and GCS values, along with the MLR model to predict a cut off score for cardiac injury in this patient population via the Youden's J statistic (sensitivity/1-specificity). Level 1 trauma registry data from Stroger Hospital of Cook County (July 1, 2016 to June 30, 2017) was used for external validation of this prediction model. All original files from the NTBD with required data were merged and analyzed using R (V3.3.1) (9). Microsoft Excel (V15.32) was used for data entry and generating the associated figures.

Results

47,044 patients with GSW to the chest were evaluated. Patients with heart injuries comprised 8.6% (4,047) of this population. The mean age was 29 years and 89.7% (42,192) were male. The mean ISS was 20.9 and mortality rate was 10.1% (4,743) in all patients (Table 1). Table 2 compares survivors and non-survivors among all GSW patients.

The mortality rate of chest trauma patients with and without heart injury was 21.7% (879/4,047) and 9.0% (3,864/42,997) respectively. Patients with heart injuries were significantly younger (28.4 vs. 29.3 years, $p < 0.001$), had a lower SBP (34.7 vs. 103.8 mmHg, $p < 0.001$), and GCS (5.1 vs. 11.2, $p < 0.001$). Cardiac injury patients also had a higher probability of apnea (58.3% vs. 14.7%, $p < 0.001$), pulselessness (59.9% vs. 12.0%, $p < 0.001$) and self-inflicted injury (9.7% vs. 8.5%, $p < 0.001$) than patients without heart injuries (Table 3).

Multivariate regression analysis (Table 4) showed that age, SBP, GCS, apnea and pulselessness were independent risk factors for heart injury in patients with GSW to the chest. For every unit increase in SBP, the odds of a heart injury decreased by 0.9% and for every unit increase in GCS, the odds of heart injury decreased by 7.3%. Apnea and pulselessness increased the odds of a heart injury by 13.8% and 2.22-fold respectively. GCS and SBP were selected to create the ROCs. The cutoff values of SBP and GCS for prediction of heart injury were 61mmHg (Area Under Curve, AUC: 0.783) and 5.5 (AUC: 0.768) respectively. Both values of AUC for the stated variables were considered fair values.

We performed a step-backward selection for the multivariate logistic regression model to include only independent factors for heart injury in the study population (Table 4). The following formula was derived as a heart injury prediction model:

$b=-1.347 + 0.418\ (\text{Suicide } 1/0) + 0.797\ (\text{Pulseless } 1/0) - 0.004\ (\text{Age}) - 0.009\ (\text{SBP}) + 0.127\ (\text{Apnea } 1/0) - 0.075\ (\text{GCS})$

From this formula, another ROC was created with the following independent risk factors for heart injury: age, SBP, GCS, apnea, pulselessness, and suicide intent. The heart injury prediction model specificity was 88.8% with AUC = 0.823. The cut off score was determined to be 29 per Youden's J index. Patients with GSWs to the chest with a score below 29 were determined to have an 88.8% chance of not having a heart injury (Fig. 1).

The level 1 trauma registry data from Stroger Hospital of Cook County in Chicago, Illinois from July 1, 2016 to June 30, 2017 was used for external validation of the suggested heart injury prediction model. Patients with the same inclusion and exclusion criteria showed a 95.6% specificity in our model.

Discussion

Cardiac injuries due to GSWs are uncommon but highly lethal. Early detection and triage are vital for survival. There are several scoring systems to help predict patient mortality such as Trauma Injury Severity Score (TRISS) and Thorax Trauma Severity Score (TTSS). However, there is no reliable score for predicting cardiac injury in patients with GSWs to the chest. We found that cardiac injuries can be identified through a combination of easily measurable variables in patients with GSW to the chest.

The cardiac box is an anatomical region defined as the area on the anterior thorax limited by the clavicles superiorly, midclavicular lines laterally and the line connecting midclavicular lines at the costal margin inferiorly. Degiannis et al. (10) found that mortality from injuries outside the cardiac box were higher compared to those in the box. Literature suggesting the use of cardiac box as a predictor of cardiac injury was limited by small size (11, 12). Simply relying on the anatomic borders of the cardiac box to predict cardiac injury is inadequate (13).

In 1996, Focused Assessment with Sonography in Trauma (FAST) was introduced as a diagnostic tool to detect pericardial effusions in trauma patients (14). While, FAST has high sensitivity and specificity in traumatic pericardial effusion, a negative FAST examination does not exclude penetrating cardiac injury (15). Ultrasound use is not feasible for early identification of cardiac injury during prehospital triage due to lack of availability and lack of trained staff (16). MGAP (Mechanism, GCS, Age and arterial Pressure) utilizes parameters that are simple to measure. However, the prediction for mortality is inferior to that of TRISS (17).

The trauma and injury severity score (TRISS) (18), developed by Champion et al. in 1983, has been used globally because of its high accuracy for predicting the probability of survival in trauma patients (19)(20)(21). However, TRISS has several limitations, especially for patients with GSW to the chest. Chamption et al evaluated the performance of TRISS for triage primarily on blunt injured patients (18). TRISS underestimates survival probability in patients with GSW to the chest.

Calculation of TRISS includes ISS which cannot be calculated in the prehospital setting. Pape et al developed the thoracic trauma severity score (TTSS) in 2000 (22). Similar to TRISS, Pape et al evaluated their scoring system on blunt trauma patients; however, it was designed for thoracic non cardiac trauma. TTSS is not the best model to easily and quickly detect cardiac injuries in patients with GSW to the chest.

Asensio et al (23) created a predictive model for penetrating cardiac injury outcomes using the NTDB database and included 2016 patients with penetrating cardiac injuries and 1264 patients with GSW as the mechanism of injury. The study suggested that in patients with cardiac GSW's field CPR, the absence of spontaneous ventilation, the presence of an associated abdominal GSW, need for ED intubation and aortic cross-clamping were independent predictors of mortality. This study provides insightful information on penetrating cardiac injury; however, it's more useful when evaluating in-hospital patients. In our study, we have evaluated a larger (47,044) but specific population (GSW patients to the chest) with 4,047 patients with cardiac injury. We primarily focused on triage and early identification of patients with cardiac injury. This model stratifies a patient's risk of having cardiac injury due to GSW by incorporating easily measured variables including age, presence of self-inflicted injury, pulselessness, apnea, SBP and GCS. As expected, the predicted model demonstrated an excellent result with 95.6% specificity during external validation with the local database from Stroger Hospital of Cook County.

We found a close relationship between suicide intent and cardiac injury in GSW to the chest. GSWs are most commonly the result of assaults (24), however, self-inflicted injury with firearms has higher mortality rate (25). Our study shows that cardiac injury after GSW to the chest is more common in younger patients. According to Center for Disease Control (CDC), suicide by firearms was the second leading cause of death among 15 to 35 years old in 2017 (26). Prevalence of GSW in the younger age group has been studied extensively and is explained by a greater access to firearms (1, 2).

Our study shows that patients with a cardiac injury had significantly lower SBP (34.7 mmHg) compared to patients without cardiac injury (103.8 mmHg), and that most patients were found to be pulseless [59.9% (2423) vs. 12% (5166), $p < 0.001$]. Our results showed that one more unit of SBP (mmHg) in the ED decreased the probability of heart injury by 0.9%, and patients arriving with immeasurable pulse had a 2.2 times higher mortality rate. Despite proper triage, patients with cardiac injury require immediate resuscitation to prevent irreversible cardiac damage resulting from increased stress and anaerobic loading onto myocardial tissues and cells. Teixeira et al. found similar findings in that mortality was higher among patients with cardiac injury that presented with SBP < 90 mmHg compared to patients with SBP > 90 mmHg (85% vs 65%, $p = 0.01$) (27). This is consistent with other research findings, which stated that systolic BP is the best univariate predictor in pre-hospital trauma patients.

A GCS < 8 is a common finding in cardiac injury associated with increased mortality (28). As in previous studies, GCS was found to be an independent variable in our predictive model. GCS and SBP both had a 71.5% specificity and AUC of 0.768 and 0.783 respectively. Combination of variables in our suggested model including age, SBP, GCS, apnea, pulselessness and suicide intent show a specificity of 88.8% with AUC of 0.823.

The primary limitation of this study was its retrospective nature both during development and validation of the suggested model. The study is also limited by the nature of NTDB. External validation of the suggested model at a single institution might also be considered a limitation, therefore, a multi-institutional validation is required. However, our model is efficient, robust and relies on easily obtainable factors such as pulselessness and suicidal intent. We developed a model specific for patients with GSW to chest that is quick and easy to use during triage both by paramedics and ED personnel.

Conclusion

Early diagnosis of heart injury is important in the management of patients with chest GSWs. Our established model has acceptable sensitivity and specificity which is proven to be beneficial for primary screening of GSWs to the heart. Our model has high specificity suggesting that the paramedics and ED personnel can confidently assess and identify whether patients with GSW have cardiac injury, compared to those who do not.

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Tables

Table 1. Demographics of chest GSW patients (N=47044)

Age	29.3±15.2
Gender (Male) (N, %)	42192 (89.7%)
SBP in the ED (mmHg)	97.8±57.4
GCS in the ED	10.7±5.7
Pulseless in the ED (N, %)	7589 (16.1%)
Apnea in the ED (N, %)	8685 (18.5%)
Intention (N, %)	
Assault	38073 (80.9%)
Self-inflicted	4030 (8.6%)
Unintentional	2365 (5.0%)
Undetermined	1304 (2.8%)
Other	1272 (2.7%)
Race	
African American	25357 (53.9%)
White	12045 (25.6%)
Asian	400 (0.9%)
American Indian	227 (0.5%)
Native Hawaiian or other Pacific islander	81 (0.2%)
Other race	6449 (13.7%)
Unknown	2485 (5.3%)
ISS	20.9±17.0
Heart injury (N, %)	4047 (8.6%)
Mortality (N, %)	4743 (10.1%)

Table 2. Comparisons of the characteristics between the death and survivor in chest GSW patients (N=47044)

	Chest GSW patients (N=47044)		
	Non-survivors (N=4743)	Survivors (N=42301)	p-value
Age	31.0	29.1	<0.001[$]
Male (N, %)	4315 (91.0%)	37877 (89.5%)	0.002[#]
SBP in ED (mmHg)	62.4	101.8	<0.001[$]
GCS in ED	6.2	11.2	<0.001[$]
Suicide (N, %)	528 (11.1%)	3502 (8.3%)	<0.001[#]
Assault (N, %)	3751 (79.1%)	34322 (81.1%)	0.001[#]
African American (N, %)	2436 (51.4%)	22921 (54.2%)	<0.001[#]
Heart injury (N, %)	879 (18.5%)	3168 (7.5%)	<0.001[#]
ISS	30.7	19.8	<0.001[$]

\$ Student T test   # Chi-square test

Table 3. Comparisons of the characteristics between patients with and without heart injury in chest GSW patients (N=47044)

	Chest GSW patients (N=47044)		
	Heart injury (+) (N=4047)	Heart injury (-) (N=42997)	p-value
Age	28.4	29.3	<0.001$
Male (N, %)	3650 (90.2%)	38542 (89.6%)	0.270#
SBP in ED (mmHg)	34.7	103.8	<0.001$
GCS in ED	5.1	11.2	<0.001$
Pulseless in ED (N, %)	2423 (59.9%)	5166 (12.0%)	<0.001#
Apnea in ED (N, %)	2358 (58.3%)	6327 (14.7%)	<0.001#
Suicide (N, %)	393 (9.7%)	3637 (8.5%)	<0.001#
White (N, %)	938 (23.2%)	11107 (25.8%)	<0.001#
African American (N, %)	2274 (56.2%)	23083 (53.7%)	0.002#
ISS	41.8	18.9	<0.001$
Mortality (N, %)	879 (21.7%)	3864 (9.0%)	<0.001#
Complication (N, %)	1794 (44.3%)	19082 (44.4%)	0.951#
Open cardiac massage (N, %)	820 (20.3%)	2029 (4.7%)	<0.001#
Resuscitative thoracotomy (N, %)	1268 (31.3%)	4512 (10.5%)	<0.001#

$ Student T test   # Chi-square test

Table 4: Multivariate logistic regression analysis of independent factors of heart injury in chest GSW patient.

Variables	B	Exp(B)	p-value
Suicide	0.482	1.62	0
Age	-0.004	0.996	0.001
SBP in ED (mmHG)	-0.009	0.991	0
GCS in ED	-0.075	0.927	0
African American	-0.064	0.938	0.16
Assault	0.055	1.056	0.375
White	-0.9	0.914	0.116
Apnea	0.129	1.138	0.03
Pulselessness	0.795	2.215	0
Constant	-1.346	0.26	0

Declarations

This study only included deidentified, Health Insurance Portability and Accountability Act-compliant data from a national database; hence, it was exempt from institutional review board approval. All authors have no conflicts of interest to disclose. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Figures

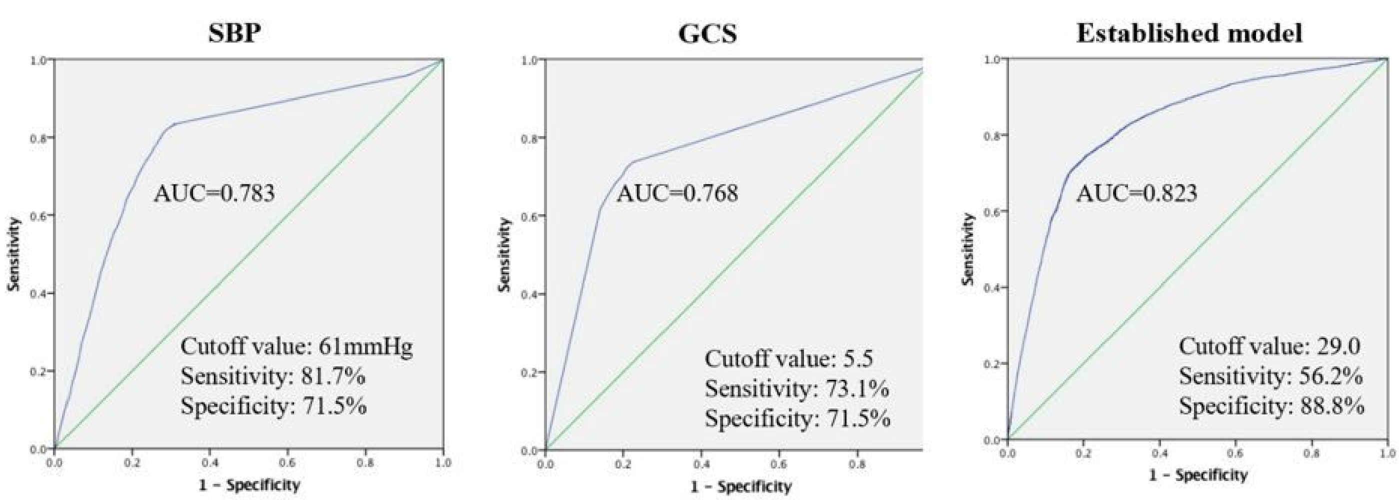

Figure 1

Receiver operating characteristic (ROC) curve with Youden's J statistic for heart injury prediction in chest GSW patients.