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Emergency department spirometric volume and base deficit delineate risk for torso injury in stable patients

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Abstract

Background: We sought to determine torso injury rates and sensitivities associated with fluid-positive abdominal ultrasound, metabolic acidosis (increased base deficit and lactate), and impaired pulmonary physiology (decreased spirometric volume and PaO_2/FiO_2).

Methods: Level I trauma center prospective pilot and post-pilot study (2000–2001) of stable patients. Increased base deficit was < 0.0 in ethanol-negative and ≤ -3.0 in ethanol-positive patients. Increased lactate was > 2.5 mmol/L in ethanol-negative and ≥ 3.0 mmol/L in ethanol-positive patients. Decreased PaO_2/FiO_2 was < 350 and decreased spirometric volume was < 1.8 L.

Results: Of 215 patients, 66 (30.7%) had a torso injury (abdominal/pelvic injury n = 35 and/or thoracic injury n = 43). Glasgow Coma Scale score was 14.8 ± 0.5 (13–15). Torso injury rates and sensitivities were: abdominal ultrasound negative and normal base deficit, lactate, PaO_2/FiO_2, and spirometric volume – 0.0% & 0.0%; normal base deficit and normal spirometric volume – 4.2% & 4.5%; chest/abdominal soft tissue injury – 37.8% & 47.0%; increased lactate – 39.7% & 47.0%; increased base deficit – 41.3% & 75.8%; increased base deficit and/or decreased spirometric volume – 43.8% & 95.5%; decreased PaO_2/FiO_2 – 48.9% & 33.3%; positive abdominal ultrasound – 62.5% & 7.6%; decreased spirometric volume – 73.4% & 71.2%; increased base deficit and decreased spirometric volume – 82.9% & 51.5%.

Conclusions: Trauma patients with normal base deficit and spirometric volume are unlikely to have a torso injury. Patients with increased base deficit or lactate, decreased spirometric volume, decreased PaO_2/FiO_2, or positive FAST have substantial risk for torso injury. Increased base deficit and/or decreased spirometric volume are highly sensitive for torso injury. Base deficit and spirometric volume values are readily available and increase or decrease the suspicion for torso injury.

Background

The American College of Surgeons Committee on Trauma developed the Advanced Trauma Life Support (ATLS) guidelines for evaluating and managing acutely injured patients.[1] The purpose of the ATLS primary survey is to detect vital function instability and enhance resuscitation. Patients with instability need an aggressive evaluation to detect torso injuries. Patients with vital function stability undergo the ATLS secondary survey, a comprehensive history and head-to-toe examination. An objective of the secondary survey is to detect clinically significant torso injuries not identified during the primary survey.

There are numerous publications describing missed injuries in patients incurring blunt and penetrating trauma [2-4]. Of particular concern, missed torso injuries have been documented (chest, [2-4] abdomen, [2-4] and pelvis[2,3]). There is no simple method to readily detect all clinically important torso injuries. The primary problem with identifying torso injuries is related to the diversity of organ and skeletal injuries and the variability of clinical manifestations[1,5]. Patients with a torso injury may have clinical findings that are suggestive, non-specific, or occult. A tertiary survey has been recommended to complement ATLS guidelines so that missed injuries will be decreased[4]

Depending on the clinical findings, there are numerous diagnostic recommendations for detecting chest, abdominal, and pelvic injuries [1,5]. The large number of diagnostic procedures for identification of torso injuries underscores the complexity associated with their detection. Chest computed tomography (CT) scan is recommended for select trauma patients following blunt[6,7] or penetrating [8,9] mechanisms. Several other diagnostic procedures, e.g., aortography, echocardiography, electrocardiography, and bronchoscopy, may be needed to identify a variety of chest injuries[1,5]. Following blunt trauma, there are variable recommendations for detecting abdominal injuries: diagnostic peritoneal lavage (DPL), [10] CT scan, [10] ultrasonography, [11] laparoscopy, [12] and celiotomy[13] There are divergent recommendations for detecting abdominal injuries following a stab wound to the abdomen: observation, [14] DPL, [15] CT scan, [16] laparoscopy, [17] and celiotomy[14]. Following a gunshot wound to the abdomen, there are variable recommendations for detecting abdominal injuries: observation, [18] DPL, [19] CT scan, [20] ultrasonography, [21] laparoscopy, [22] and celiotomy[23]. Additionally, there are variable recommendations for detecting pelvic ring disruption: antero-posterior, inlet, outlet, and Judet x-rays, and CT scan [24-27]. The multiplicity of diagnostic recommendations to evaluate the chest, abdomen, and pelvis underlie the notion that early torso injury identification is difficult.

There is a need to develop an objective and simple complement to the ATLS secondary survey to indicate the probability for torso injury in stable patients. An assessment of metabolic acidosis status, pulmonary physiology, and abdominal ultrasound findings may be useful to determine the presence of a torso injury. Severity of injury has been shown to correlate with base deficit[28] and serum lactate[29]. Abdominal ultrasound has evolved as a method for initial screening for the detection of abdominal injuries; however, the sensitivity of this procedure is variable[11]. A reduction in PaO_2/FiO_2 has been described in patients with pulmonary contusion[30] and acute chest trauma, [31] while a decrease in spirometric volume has been found in patients with rib fractures[32] or operative torso trauma [33,34]. The purpose of this study was to determine the relationship of torso injury with base deficit, lactate, presence of fluid on abdominal ultrasound, PaO_2/FiO_2, and spirometric volume. This investigation was performed at the St. Elizabeth Health Center in Youngstown, OH, a Level I trauma center.

Methods

The Institutional Review Board for Human Investigations approved the study.

Inclusion and exclusion criteria

Inclusion criteria were blunt or penetrating trauma patients evaluated by the trauma service (emergency medical service trauma team alert or emergency department physician consultation). Exclusion criteria were patients who: failed to have spirometric volume, lactate, focused abdominal sonography for trauma (FAST), or arterial blood gas (ABG) within 4 hours of injury; were under 18 years or over 65 years; fell from a standing height; had persistent hemodynamic instability; smoked two or more packs of cigarettes per day; have COPD and require bronchodilator or home oxygen therapy; needed urgent tracheal intubation; or were unable to understand the proper technique of incentive spirometry. Routine evaluation for patients evaluated by the trauma service include spirometric volume, lactate, FAST exam, and ABG evaluation.

Clinically significant torso injuries

Clinically significant torso injuries included: chest wall or abdominal contusion (moderate to severe pain and tenderness with impaired chest wall excursion and decreased cough sound intensity); sternal fracture; three or more rib fractures; splenic injury; liver injury; gastrointestinal tract injury; pelvic ring disruption; thoracic esophageal injury; pneumothorax; hemothorax; lung contusion; diaphragmatic injury; great vessel injury; cardiac contusion or tamponade; pancreatic injury; renal injury; ureter or bladder injury; hip fracture or dislocation; thoracic spinal injury; lumbar spinal injury; and abdominal vascular injury.

Patient assessment and identification of torso injuries

An initial pilot study was performed. Prospective documentation was accomplished by completing data collection forms at the time of patient evaluation. The chief resident, under the supervision of the emergency department or trauma surgical attending, performed a standard FAST exam. The FAST exam was used to document the presence of fluid in the pericardial space, right upper quadrant, left upper quadrant, and pelvis. Base deficit and

PaO_2/FiO_2 were routinely obtained from the ABG. Lactate was obtained from a venous blood specimen. Incentive spirometry was taught to the patient by a respiratory therapist. The patient had three practice spirometry attempts. The patient was instructed to take in a deep breath, maximally expire, and then perform a maximal inspiratory effort. The goal was to generate the highest volume possible.

A torso physical examination was performed by the chief surgical resident who documented the presence of torso tenderness (none, mild, moderate, or severe), ecchymosis, lacerations, and abrasions. Ethanol status was positive when the toxicology screen revealed a positive ethanol level and was negative when the level was not detected. When there was no toxicology screen, the ethanol status was positive when there was a history of ethanol consumption or the physical examination indicated that the patient was intoxicated or smelled of alcohol. Otherwise, the ethanol status was negative.

There was a routine assessment of patients discharged within 72 hours of injury. Patients were discharged only when their vital signs, chest wall excursion, and cognition were stable. Patients were considered stable when there was normotension, heart rate $\leq$ 100 beats per minute, respiratory rate $\leq$ 24 breaths per minute, incentive spirometric volume $\geq$ 30 mL/kg weight, and normal cognition. The patient's weight was recorded during hospitalization. Routine clinic visit and/or home telephone call was performed within 3 to 7 days for patients discharged within 72 hours of injury.

Diagnostic imaging included routine chest x-ray and pelvic x-rays. Chest CT and abdominal/pelvic CT scans were performed at the discretion of the attending trauma surgeon.

There were 88 patients in the prospective observational pilot study. There was one missed torso injury found during the routine follow-up. Total patients with torso injuries in the pilot study were 26 (29.5%).

A post-pilot study was conducted that had the same study design as the pilot study. However, there was no obligatory clinic visit or telephone follow-up for patients discharged within 72 hours of injury. The patients seen in the trauma clinic were assessed for missed torso injury. The complete study included data from the pilot and post-pilot studies. This data were combined for statistical assessment.

Demographics
Mechanism of injury was studied for both blunt (motor vehicular crash, motorcycle crash, fall, assault, other) and penetrating (gunshot wound, stab wound) injuries. Age and weight were documented as well as Glasgow Coma Score and Injury Severity Score (ISS). The non-torso injury with the highest Abbreviated Injury Scale (AIS) score and its body region were documented.

Torso injury relationships with metabolic acidosis status and pulmonary physiology
The base deficit for patients with and without torso injury was determined. A previous study by the first author showed a univariate relationship between base deficit and ethanol status and between base deficit and ISS[28]. Multivariate regression analysis also showed that base deficit was independently associated with ethanol status and ISS. The relationship between base deficit and ethanol status and ISS was determined in the current study. The levels selected for increased base deficit were the base deficit values where the odds ratio and sensitivity for torso injury were the greatest for ethanol-negative and ethanol-positive patients.

The lactate for patients with and without torso injury was determined. The relationship between lactate and ethanol status and ISS was determined. The levels selected for increased lactate were the lactate values where the odds ratio and sensitivity for torso injury were the greatest for ethanol-negative and ethanol-positive patients.

The PaO_2/FiO_2 for patients with and without torso injury was determined. The level selected for decreased PaO_2/FiO_2 was the PaO_2/FiO_2 value where the odds ratio and sensitivity for torso injury were the greatest. The spirometric volume for patients with and without torso injury was determined. The level selected for decreased spirometric volume was the volume where the odds ratio and sensitivity for torso injury were the greatest.

FAST and torso injury relationship
The right upper quadrant (RUQ), left upper quadrant (LUQ), and pelvis were categorized relative to the presence of fluid: present, absent, or poor visualization. A positive abdominal FAST was the presence of fluid in the RUQ, LUQ, or pelvis. The pericardial space was categorized relative to the presence of fluid: present, absent, or poor visualization. A positive pericardial FAST was the presence of fluid in the pericardial space. The relationship between a positive pericardial FAST and chest injury was determined. The relationship between a positive abdominal FAST and abdominal injury was determined. The relationship between fluid-positive thoracic or abdominal/pelvic ultrasound and torso injury was determined.

Truncal soft tissue injury and torso injury relationship

Table 1: Torso injuries in study patients

Abdominal injuries:	#	**Thoracic injuries**:	#
gastrointestinal	1	cardiac	2
kidney	2	hemothorax	7
liver	8	lung contusion	17
spleen	6	pneumothorax	22
urinary bladder	1	rib fractures	23
lumbar spine	3	sternal fracture	2
pelvic ring	10	thoracic spine	1
hip fracture/dislocation	8	severe chest contusion	3

Patients with abdominal injury: 35; Patients with thoracic injury: 43; Patients with torso injury: 66.

Truncal soft tissue injury was the presence of chest or abdominal wall abrasion, ecchymosis, or laceration. The relationship between truncal soft tissue injury and torso injury was determined.

Statistical analysis

Statistical analysis was performed on the SAS System for Windows, release 6.11, SAS Institute Inc. (Cary, NC). A Fisher's exact test was used to compare the torso injury rate with other dichotomous variables. Correlation coefficient analysis was utilized to assess the relationship between two continuous variables. A T-test was used to compare the mean value of two groups. Multiple regression analysis was utilized to assess the influence of ethanol status and base deficit on base deficit and lactate. Multivariate logistic regression analysis was used to determine the effect of two more independent variables on the presence or absence of torso injury. A P value < 0.05 was considered statistically significant.

Results

Study patients

There were 88 trauma patients who met the criteria for inclusion in the pilot study and 26 (29.5%) had a torso injury. Sixty-three patients (71.6%) were discharged within 72 hours of emergency department presentation. One of these patients had a torso injury undiagnosed during hospitalization (rib fractures), but was found during the routine follow-up. The post-pilot study group included another 127 trauma patients who met the criteria for study inclusion.

Of the 215 patients in the total study group, 66 patients (30.7%) had a torso injury (abdominal/pelvic and/or thoracic injury). Of the 66 patients with torso injury, 35 had abdominal or pelvic injury and 43 had thoracic injury. Specific abdominal/pelvic and thoracic injuries are depicted in Table 1. Of the total study group, 135 patients (62.8%) were discharged within 72 hours. All 215 patients had a chest x-ray taken. A pelvic x-ray was taken in 177 patients (82.3%). An abdominal CT scan was performed in 59 patients (27.4%) and a chest CT scan was done in 38 patients (17.7%).

Demographics

Blunt trauma was present in 194 patients (90.2%) (motor vehicle crash, motorcycle crash, fall, assault, or crush injury). Penetrating injury was found in 21 patients (9.8%) (gunshot or stab wound). The torso injury rate was similar for the blunt trauma (30.4%) and the penetrating trauma patients (33.3%; P = 0.78). There were no significant differences (P ≥ 0.05) between the patients with torso injury and without torso injury relative to age (36.7 and 32.9 years), weight (172 and 176 pounds), and Glasgow Coma Scale score (14.8 and 14.8). The ISS was higher in the patients with torso injury (16.2 ± 9.2) when compared to the patients without torso injury (5.6 ± 4.3, P = 0.0001). The hospital length of stay for patients with a torso injury was 5.3 days (62.8% had length of stay > 72 hours). Body regions with the highest non-torso injury AIS score were head – 80 (37.2%), neck – 18 (8.4%), upper extremity – 38 (17.7%), lower extremity – 60 (27.9%), and none – 19 (8.8%). The distribution of the highest non-torso injury AIS score was 1 – 59 (27.4%), 2 – 80 (37.2%), 3 – 53 (24.7%), 4 – 4 (1.9%), and 0 – 19 (8.8%). Ethanol status was positive in 26.5% (57/215) and negative in 73.5% (158/215). An ethanol level was measured in 80.5% (173/215) of the patients. Of the 42 without an ethanol level, four (9.5%) had clinical evidence of ethanol consumption and were considered to be ethanol-positive.

Torso injury relationships with metabolic acidosis status and pulmonary physiology

The base deficit was greater in the patients with torso injury (-2.6 ± 3.0) when compared to the patients without torso injury (-1.0 ± 2.0, P = 0.0001). The base deficit was inversely related to the ISS (r = -0.44, P = 0.0001). The

Table 2: Risk assessment for torso injuries in 215 stable trauma patients

Risk Factor	#	TI Rate	Sensitivity	Specificity	NPV	OR	P-value
increased BD	121	41.3%	75.8%	52.3%	83.0%	3.4	.0001
increased lactate	78	39.7%	47.0%	68.5%	74.5%	1.9	.03
decreased PaO_2/FiO_2	45	48.9%	33.3%	84.6%	74.1%	2.7	.003
decreased SV	64	73.4%	71.2%	88.6%	87.4%	19.2	<<.0001
positive FAST	8	62.5%	7.6%	98.0%	70.5%	4.0	.06
chest/abdominal STI	82	37.8%	47.0%	65.8%	73.7%	1.7	.08
increased BD and/or decreased SV	144	43.8%	95.5%	45.6%	95.8%	17.6	<<.0001

TI, torso injury; NPV, negative predictive value for a negative test; OR, odds ratio; BD, base deficit; SV, spirometric volume; FAST, focused-abdominal sonography for trauma; STI, soft tissue injury (abrasions, ecchymosis, laceration)

Table 3: Rates of torso injuries in 215 stable trauma patients

Risk Factor	Number	TI Rate	95% CI
normal BD and normal SV	71	4.2%	0.0–8.9%
increased BD and normal SV	80	20.0%	12.7–30.0%
normal BD and decreased SV	23	56.5%	36.8–74.4%
increased BD and decreased SV	41	82.9%	71.4–94.4%

TI, torso injury; CI, confidence intervals; BD, base deficit; SV, spirometric volume

base deficit was greater in the ethanol-positive patients (-3.4 ± 2.2) when compared to the ethanol-negative patients (-0.8 ± 2.2, P = 0.0001). Multivariate regression analysis showed that base deficit was independently associated with ethanol status and ISS (r = 0.61, P = 0.0001). The torso injury rate was similar in the ethanol-positive patients (27.3%) and the ethanol-negative patients (26.2%, P = 0.87). Base deficit was greater for patients with highest non-torso injury AIS score 3–4 (-2.6 ± 2.9) when compared to those with highest non-torso injury AIS score 0–2 (-1.1 ± 2.2; P = 0.0005). Base deficit was independently associated with torso injury, ethanol status, and the highest non-torso injury AIS score (r = 0.61; P = 0.0001). The threshold levels selected for increased base deficit were the base deficit values where the odds ratio and sensitivity for torso injury were the greatest for ethanol-negative and ethanol-positive patients. The threshold base deficit values were < 0.0 for ethanol-negative patients and ≤ -3.0 for ethanol-positive patients. The torso injury positive predictive value, sensitivity, specificity, negative predictive value, and risk of increased base deficit are displayed in Tables 2 and 3. Increased base deficit was greater with highest non-torso injury AIS score 3–4 (68.4% [39/57]) when compared to AIS score 0–2 (51.9% [82/158]; OR 2.0, P = 0.03). Increased base deficit was independently associated with torso injury and the highest non-torso injury AIS score (P = 0.006). Torso injury was not associated with the highest non-torso injury AIS score (P = 0.22).

Lactate was greater in the patients with torso injury (2.9 ± 2.2 mmol/L) when compared to the patients without torso injury (2.3 ± 1.1 mmol/L, P = 0.04). Lactate was directly related to ISS (r = 0.26, P = 0.0001). The lactate was greater in the ethanol-positive patients (3.1 ± 1.2 mmol/L) when compared to the ethanol-negative patients (2.3 ± 1.6 mmol/L, P = 0.0001). Multivariate regression analysis showed that lactate was independently associated with ethanol status and ISS (r = 0.33, P = 0.001). The threshold levels selected for increased lactate were the lactate values where the odds ratio and sensitivity for torso injury were the greatest for ethanol-negative and ethanol-positive patients. The threshold lactate values were > 2.5 mmol/L for ethanol-negative patients and ≥ 3.0 mmol/L for ethanol-positive patients. The positive predictive value, sensitivity, specificity, negative predictive value, and risk ratio of increased lactate for torso injury are displayed in Table 2.

The PaO_2/FiO_2 was lower in the patients with torso injury (394 ± 139) when compared to the patients without torso injury (445 ± 102, P = 0.01). The threshold level selected for decreased PaO_2/FiO_2 was the PaO_2/FiO_2 value where the odds ratio and sensitivity for torso injury were the greatest. The threshold PaO_2/FiO_2 value was < 350. The positive predictive value, sensitivity, specificity, negative predictive value, and risk ratio of decreased PaO_2/FiO_2 for torso injury are displayed in Table 2.

The spirometric volume was lower in the patients with torso injury (1,543 ± 620 mL) when compared to the patients without torso injury (2,287 ± 344, P = 0.0001). The threshold level selected for decreased spirometric volume was the volume where the odds ratio and sensitivity for torso injury were the greatest. The threshold spirometric volume was < 1,800 mL (< 25 mL/kg). The positive predictive value, sensitivity, specificity, negative predictive value, and risk ratio of decreased spirometric volume for torso injury are displayed in Table 2.

FAST and torso injury relationships

A positive abdominal/pelvic ultrasound result was found in seven patients (3.3%). All patients with fluid-positive FAST had an abdominal/pelvic CT scan. The positive predictive value for abdominal/pelvic injury was 57.1% and the sensitivity was 11.4%. The risk ratio for abdominal/pelvic injury with a positive ultrasound result was 7.6 (P = 0.01). A positive pericardial ultrasound result was present in 1 patient (0.5%). The positive predictive value for thoracic injury was 100.0% and the sensitivity was 2.3%. The risk ratio for thoracic injury with a positive ultrasound result was 4.1 (P = 0.2). The positive predictive value, sensitivity, specificity, negative predictive value, and risk ratio of a positive thoracic/abdominal/pelvic ultrasound result for torso injury are displayed in Table 2.

Truncal soft tissue injury and torso injury relationship

The positive predictive value, sensitivity, specificity, negative predictive value, and risk ratio of chest or abdominal soft tissue injury for torso injury are displayed in Table 2.

Torso injury relationships with decreased spirometric volume or increased base deficit

Multivariate logistic regression analysis indicated that torso injury was independently and inversely related to base deficit and spirometric volume (P = 0.0001). Regression analysis also showed that torso injury was independently related to increased base deficit status and decreased spirometric volume status (P = 0.004). Increased lactate, decreased PaO_2/FiO_2, and positive FAST each had an insignificant relationship with torso injury (P >> 0.05) when increased base deficit and decreased spirometric volume status were included in the logistic regression analysis. Base deficit was increased and/or spirometric volume was decreased in 144 patients (67.0%) (see Tables 2 and 3). The positive predictive value of increased base deficit and/or decreased spirometric volume for torso injury was 43.8% (95% CI, 35.7–51.9%) and the sensitivity for torso injury was 95.5% (95% CI, 92.1–98.9%). The risk ratio for torso injury was 17.6 (P << 0.0001). A normal base deficit and spirometric volume was found in 71 patients (33.0%) (see Table 3). Three of these patients had a torso injury (negative predictive value 95.8% [95% CI, 91.1–100.0%]). The sensitivity of increased base deficit and/or decreased spirometric volume for abdominal/pelvic injury was 94.3%; the sensitivity for thoracic injury was 97.7%.

The torso injury rates for the four combinations of base deficit and spirometric volume are described in Table 3 (Chi-square 87.5; P < 0.0001). The rates for the four combinations are significantly different (P < 0.05) from each other. Of the 46 patients with a negative FAST and a normal base deficit, lactate, PaO_2/FiO_2, and spirometric volume, there were no torso injuries identified (positive predictive value 95% CI, 0.0–3.5%).

The three patients with a torso injury and a normal base deficit and normal spirometric volume also had a normal FAST exam. The lactate was increased in two patients, and the PaO_2/FiO_2 was decreased in the third patient. One patient had an isolated sternal fracture and was discharged within 3 days with a spirometric volume of 2,000 mL at discharge. The only torso injury in the other two patients was a hip fracture.

Discussion

Spirometric volume and base deficit provide a probability for the presence of torso injury in stable patients. The literature is miniscule relative to chest wall mechanical assessment in acutely injured patients. Patients with increased base deficit or lactate, decreased spirometric volume, impaired PaO_2/FiO_2, or a positive FAST were found to have substantial risk for torso injury. Trauma patients with normal base deficit and spirometric volume are unlikely to have a torso injury. Conversely, increased base deficit and/or decreased spirometric volume indicate that there is a markedly enhanced risk for torso injury. An increased base deficit and/or decreased spirometric volume were highly sensitive for detecting patients with torso injury.

The trauma surgeon is frequently confronted with a plethora of injuries in a diverse cohort of patients. However, our aim was to evaluate the typical 30–40 year old stable, trauma patient with a significant mechanism of injury and determine the risk for torso injury using readily available, objective tests. We excluded extremes of age to optimize cohort homogeneity. Also, patients with severe pre-existing pulmonary conditions were excluded because we were concerned that it would alter the relationship between spirometric volume and torso injury. Additionally, these patients commonly have a metabolic alkalosis, which may modify the association of base deficit with torso injury. Unconscious patients would not be able to perform a spirometric volume. Patients undergoing immediate tracheal intubation or with persistent hemodynamic instability typically need a comprehensive diagnostic evaluation for torso injury. Patients falling from a standing height have variable risk for serious injury, are often elderly, and frequently have pre-existing medical conditions.

The association between base deficit and torso injury was highly significant. Base deficit was independently associated with ethanol status, torso injury, and highest non-torso injury AIS score. Patients with an increased base deficit had a substantial increase in torso injury risk. Three-quarters of patients with torso injury had an increased base deficit.

The literature indicates that there are several relationships that have been previously established between injury severity and base deficit. Base deficit has been found to be associated with trauma patient mortality [35,36] and ISS[28,35,37]. Base deficit has also been associated with the trauma score[35,38]. Additionally, base deficit has been linked to hypotension and resuscitation [28,36] and the presence of an abdominal injury[28,39]. Similar to the current study, base deficit level has been found in other investigations to be increased in patients with ethanol [28,37,40].

Similar to base deficit, there was an association between lactate and torso injury. Patients with torso injury had a greater lactate when compared to those without torso injury. Lactate was directly related to ISS and was greater in ethanol-positive patients when compared to ethanol-negative patients. Lactate was also found to be independently associated with ethanol status and ISS. The patients with increased lactate had a substantial risk for torso injury when compared to those with normal lactate. Several other studies provide evidence that lactate is associated with injury severity. Lactate has been shown to have a positive relationship with mortality[29,41] and injury severity[29,37,41]. Additionally, lactate has been associated with the need for resuscitation[38]. Similar to base deficit, others have found lactate to be increased in patients who have consumed ethanol[37].

Patients with torso injury had a lower PaO_2/FiO_2 than those without torso injury. When the PaO_2/FiO_2 was < 350, the torso injury risk was substantially increased. One-third of the patients with torso injury had a decreased PaO_2/FiO_2. Other investigators have noted that trauma patients with a decreased PaO_2/FiO_2 had increased mortality [30,31] and a need for prolonged mechanical ventilation[30,42]. Other investigators have also noted a reduction in PaO_2/FiO_2 in patients with pulmonary contusion [30,43,44] and acute chest trauma[31,45].

Torso injury patients had a lower spirometric volume than those with no torso injury. A spirometric volume < 1,800 mL (< 25 mL/kg) was associated with increased torso injury risk. Three-quarters of the patients with a decreased spirometric volume had a torso injury and three-quarters of the patients with torso injury had a decreased spirometric volume. The only literature identified regarding spirometric volume assessment in trauma patients described patients with rib fractures[32]. This study showed a decrease in spirometric volume prior to the institution of a regimen to mitigate chest wall pain. Rib fractures are associated with torso pain and are likely to cause a decrement in chest wall mechanics [32,46-48].

A reduction in vital capacity following operative torso trauma has been documented in other studies. Upper abdominal surgery has been associated with a postoperative vital capacity 45–55% that of the preoperative value[33,49,50]. Postoperative vital capacity has been found to have a greater reduction with open cholecystectomy (48%) when compared to laparoscopic cholecystectomy (26%)[34]. Other studies have shown that stable patients undergoing median sternotomy had a marked reduction in postoperative vital capacity[51]. These studies suggest that significant trauma to the chest or abdomen may cause a clinically significant reduction in spirometric volume.

The patients with a positive FAST had a substantial torso injury risk. However, the 95% confidence band was quite large due to the small number of patients. Less than 10% of the patients with torso injury had a positive FAST. The latter is due to the fact that FAST is not likely to detect most retroperitoneal, pelvic, or chest injuries[11,52]. The variable sensitivity of FAST for detecting abdominal injuries is a concern. Amoroso found in 13 studies that the abdominal injury sensitivity for FAST ranged from 81–99%[52]. In six of these studies, the abdominal injury sensitivity was ≤ 90%. Pearl has also described variation in FAST sensitivity depending on the clinical endpoint[11]. An examination of four studies revealed a sensitivity of 87–98% for detecting intraperitoneal fluid. The sensitivity for identifying organ injury was 69–96% in six studies. A review of four studies showed that the sensitivity for therapeutic laparotomy ranged from 84–93%. The current study and the literature suggest that FAST has substantial limitations for identifying torso injuries.

Patients with chest or abdominal abrasions, ecchymosis, or lacerations had a substantial torso injury risk. However, the odds ratio was insignificant. Only one-half of the patients with torso injury had a truncal soft tissue injury. The relationship between spirometric volume and torso injury was superior. Others have shown an important association between intrathoracic injuries and chest ecchymosis [53,54] and abrasions[55]. Similarly, intra-abdominal injuries have been linked to abdominal ecchymosis, [54,56-58] abrasions, [55,58] and lacerations[59]. Data from the current study suggest that spirometric volume assessment may be more reliable for detecting torso injuries. Others have shown that physical examination has a modest sensitivity for detecting abdominal injuries (60–87%) [60-62]. The above literature suggests that an objective appraisal for torso injury may be needed to complement the physical exam.

Torso soft tissue injury can be considered a clinical standard for which to compare the other torso injury risk factors. Sensitivity of increased base deficit and sensitivity of decreased spirometric volume for torso injury was greater than the other risk factors. Sensitivity for increased base deficit and/or decreased spirometric volume for torso injury approached 100%. Decreased spirometric volume had a superior specificity when compared to torso soft tissue injury. The specificity of increased base deficit and the specificity of increased base deficit and/or decreased spirometric volume were inferior to torso soft tissue injury. In other words, the false-positive rates were increased. The decreased specificity of increased base deficit and the decreased specificity of increased base deficit and/or decreased spirometric volume are, in part, explained by the association between base deficit and the highest non-torso injury AIS score value. Specifically, increased base deficit is present with either torso injury or complex non-torso injuries. The negative predictive value for normal base deficit and the negative predictive value for normal spirometric volume were greater than the rate for no torso soft tissue injury. The negative predictive value for normal base deficit and normal spirometric volume was nearly 100%. Torso soft tissue injury was not a significant risk for torso injury, however, increased base deficit was. Decreased spirometric volume and increased base deficit and/or decreased spirometric volume performed well as risk factors for torso injury. Decreased spirometric volume had the highest positive predictive value for torso injury.

There were no torso injuries in the patients with a negative FAST and a normal base deficit, lactate, PaO_2/FiO_2, and spirometric volume. When base deficit and spirometric volume were normal, the probability for torso injury was low. When base deficit was increased and spirometric volume was normal, there was a 20% torso injury rate. The relatively low torso injury rate is likely due to the influence of complex non-torso injuries on base deficit. When spirometric volume is normal and base deficit is increased, the clinician should evaluate the patient for evidence of torso and non-torso injuries and determine the need for a torso CT scan. When spirometric volume is decreased, a comprehensive evaluation of the torso is indicated. Because the clinical objective is to minimize risk for missing potentially life threatening injuries, the high sensitivity and relatively low specificity of increased base deficit and/or decreased spirometric volume are reasonable.

There were study weaknesses that need to be addressed in future investigations. Patients falling from a standing height need to be studied in the future to determine the potential relevance of base deficit and spirometric volume in assessing risk for torso injury. The study focus was to detect clinically significant torso injuries and describe risk relationships using readily available, objective tests. The standard for determining the presence or absence of a torso injury was a routine chest x-ray on admission, select chest or abdominal CT scans on admission, and daily evaluation with additional appropriate diagnostic studies until hospital discharge. A torso injury was determined to be present or absent at hospital discharge. During the pilot-study, patients discharged within 72 hours of injury were also evaluated by post-discharge telephone call and/or clinic visit. Eighty-eight patients were in the pilot-study and 26 torso injuries were detected (29.5%). One injury was detected after discharge. If this injury had not been detected or two more had been identified the torso injury rate would have been 28.4–31.8%. The 30.7% torso injury rate for the 215 patients was strikingly similar to that in the pilot-study. Routine chest, abdominal, and pelvic CT scans may have been more elucidating. However, CT scans may divulge clinically insignificant injuries. Our study should provide an impetus to perform a future investigation with routine CT scans, as well as a description of the clinical import of each identified torso injury. Such a study would help to better define the rate of clinically significant torso injuries and the ability to assess risk during the patient's initial evaluation. A cost analysis comparing routine CT scans with potential discharge home to the cost and ability of arterial blood gas analysis, spirometric volume, lactate, and FAST to indicate the need for admission or discharge or torso CT scans is important and needs to be studied. Future studies should routinely obtain an ethanol test.

Conclusions

This is the only study to describe the use of bedside spirometric volume assessment in a wide spectrum of stable trauma patients during the early postinjury period. Patients with decreased spirometric volume have a high torso injury rate and the majority of patients with a torso injury have a decreased spirometric volume. Spirometric volume and base deficit are two simple objective measures that indicate the probability of torso injury in stable patients. Trauma patients with normal base deficit and spirometric volume are unlikely to have a torso injury. An increased base deficit and/or a decreased spirometric volume are highly sensitive for torso injury. An increased base deficit is associated with torso and complex non-torso injuries. Base deficit and spirometric volume may be useful complements to the ATLS secondary survey to risk stratify the likelihood for torso injury. The physician may find that the objective and clinical information can be used to determine the need for a more comprehensive evaluation of the trauma patient.

Abbreviations

ABG arterial blood gas; ATLS Advanced Trauma Life Support; BD base deficit; CT computed tomography; DPL diagnostic peritoneal lavage; FAST focused abdominal sonography for trauma; ISS Injury Severity Score; LUQ left upper quadrant; RUQ right upper quadrant; SV spirometric volume

Competing interests

None declared.

Authors' contributions

CMD conceived the study, supervised the study, participated in the design, acquired the data, performed the statistical analysis and interpretation of data, drafted the manuscript, participated in the critical revision, and provided the funding. ES conceived the study and participated in the design, acquired the data, and performed the statistical analysis and interpretation of data. LAP acquired the data, performed the statistical analysis and interpretation of data, drafted the manuscript, and participated in the critical revision. All authors read and approved the final manuscript.

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