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Traumatic diaphragmatic injury in the American College of Surgeons National Trauma Data Bank: a new examination of a rare diagnosis

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Abstract

BACKGROUND: Traumatic diaphragmatic injury (TDI) is a rarely diagnosed injury in trauma. Previous studies have been limited in their evaluation of TDI because of small population size and center bias. Although injuries may be suspected based on penetrating mechanism, blunt injuries may be particularly difficult to detect. The American College of Surgeons National Trauma Data Bank is the largest trauma database in the United States. We hypothesized that we could identify specific injury patterns associated with blunt and penetrating TDIs.

METHODS: We examined demographics, diagnoses, mechanism of injury, and outcomes for patients with TDI in 2012 as this is the largest and most recent dataset available. Comparisons were made using chi-square or independent samples *t* test.

RESULTS: There were a total of 833,309 encounters in the National Trauma Data Bank in 2012. Three thousand eight hundred seventy-three patients had a TDI (.46%). Of those, 1,240 (33%) patients had a blunt mechanism and 2,543 (67%) had a penetrating mechanism. Patients with blunt TDI were older (44 ± 19 vs 31 ± 13 years, $P < .001$), had a higher injury severity score (33 ± 14 vs 24 ± 15, $P < .001$), and a higher mortality rate (19.8% vs 8.8%, $P < .001$). Compared with patients with penetrating injuries, those with blunt TDI were more likely to have injuries to the thoracic aorta (2.9% vs .5%, $P < .001$), lung (48.7% vs 28.1, $P < .001$), bladder (5.9% vs .7%, $P < .001$), and spleen (44.8% vs 29.1%, $P < .001$). Penetrating TDI was associated with liver and hollow viscus injuries.

CONCLUSIONS: Diaphragmatic injury is an uncommon but significant diagnosis in trauma patients. Blunt injuries may be more likely to be occult; however, a pattern of associated injuries to the aorta, lung, spleen, and bladder should prompt further workup for TDI.

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Although injury remains the leading cause of death in people under age 44, traumatic diaphragmatic injury (TDI) is an infrequent diagnosis in trauma patients with a reported incidence in various series between .8% and 8%.[1,2] Sennertus first described diaphragmatic injury in 1541.[3] Ambroise Pare later described an autopsy case of a gunshot wound to the chest resulting in subsequent death because of strangulation of the colon related to an accompanying left diaphragmatic injury.[4] Although diaphragmatic injury is considered a rare diagnosis, the true incidence of TDI remains unknown. A challenge in the diagnosis of this injury is the poor sensitivity of both chest radiograph and computed tomography.[5–7] Moreover, diagnostic peritoneal lavage is an unreliable test for diagnosis of TDI.[6] In a series of 57 patients with blunt TDI, diagnosis of diaphragmatic injury was not made until laparotomy was performed for associated injuries in 42% of patients.[6] Left-sided diaphragmatic injuries are more commonly reported,[2] but right-sided injuries are more difficult to detect on routine imaging studies because of the presence of the liver, which is less likely to herniate into the chest.[8]

Missed or delayed diagnosis of TDI may result in significant morbidity and mortality. Most early mortality is because of severe associated injuries.[9] However, a diaphragmatic injury with associated hernia may result in compromised cardiopulmonary function via displacement of the mediastinum, impaired venous return, and significantly decreased pulmonary function.[5] Patients may present years after their initial injury with sequelae of herniation, obstruction, incarceration, or strangulation of intra-abdominal contents with potential for significant morbidity and mortality.[10]

Historically, diaphragmatic injuries have been associated with penetrating trauma and the possibility of a TDI should be considered in most patients with a gunshot or stab wound to the chest or abdomen.[10,11] However, the relationship between blunt trauma and diaphragmatic injury is less often apparent. It has been postulated that high-velocity blunt traumatic injuries, particularly motor vehicle collisions, may contribute to blunt diaphragmatic rupture.[12] The mechanism of this injury may involve a shearing injury to the diaphragm at its fixed attachments or a direct anterior blow to the abdomen, resulting in an acute increase in intra-abdominal pressure.[11,13] Given that there are no established patterns or indicators of blunt diaphragmatic injury, the best tool for diagnosis of TDI remains a high index of clinical suspicion.[3,6,10,11,14]

Furthermore, because of the difficulty in diagnosing TDI, few large volume studies have been conducted. Most series published include 10 to several hundred patients over many years. The National Trauma Data Bank (NTDB) is a centralized national trauma registry created by the American College of Surgeons in an effort to provide the trauma community with accessible and "consistent, quality data."[15,16] Therefore, we hypothesized that we could use the NTDB, the largest repository of trauma data available, to identify injury patterns associated with blunt or penetrating diaphragmatic injury.

Methods

To perform this study, we used the American College of Surgeons NTDB. The NTDB is the largest available source of trauma registry data in the United States.[15–17] We used the dataset collected and compiled in 2012, as this is both the largest and most recent dataset available currently. It contains 833,309 individual patient records that have been subjected to a quality screening for consistency and validity.

TDIs were identified by International Classification of Diseases 9th Revision codes. All patients with diaphragmatic injury and complete data available were included in the analysis. Variables analyzed included demographic data such as age, sex, and injury severity scores. Mechanism of injury and associated injuries of the vascular system, thoracic, and abdominal organs were determined for all patients with TDI. Outcome data including mortality, length of stay, and complications were examined.

Differences in proportions were tested with a chi-square or Fisher's exact test, while differences in means were tested with independent samples t test. Statistical analysis was performed using SPSS version 22.0 (IBM Corporation, Armonk, NY). Statistical significance was considered a P value less than .05.

Results

There were 833,309 individual patient records available in the 2012 NTDB. Of this cohort, 3,783 patients were diagnosed with TDI, as defined by International Classification of Diseases 9th Revision codes. Of these 3,783 patients, 2,543 patients (67%) were diagnosed with a penetrating TDI, while 1,240 patients (33%) were diagnosed with a blunt TDI. Patient who were diagnosed with blunt TDI were older, less likely to be male, and had a higher overall injury severity score (Table 1).

Of the patients with a penetrating diaphragmatic injury, 66.5% suffered a gunshot wound, while 33.5% suffered a stab wound. Patients with blunt diaphragmatic injuries were most likely to be involved in motor vehicle collisions (63.4%). Other causes of blunt diaphragmatic injury included bicyclist versus auto collisions (10.1%), falls (7.6%), motorcycle collisions (7.7%), and pedestrian versus auto crashes (1.0%).

Mortality was significantly higher in the patients with blunt TDI (19.8%) compared with those with penetrating TDI (8.8%, $P < .001$). In addition, patients with blunt TDI had a significantly longer hospital length of stay, intensive care unit length of stay, and significantly higher number of ventilator days (Table 2).

Regarding in-hospital complications, there were several important differences between the blunt and penetrating diaphragmatic injury groups. Patients with blunt TDI were significantly more likely to have acute respiratory distress syndrome, pneumonia, and deep vein thrombosis, while

Table 1 Demographics

	Blunt TDI	Penetrating TDI	*P* value
Age (years)	44 ± 19	31 ± 13	<.001
Male sex (%)	67.9	91.4	<.001
Injury severity score	33 ± 14	24 ± 15	<.001

Data are expressed as mean ± standard deviation.
TDI = traumatic diaphragmatic injury.

patients with penetrating TDI were more likely to have complications related to deep space infections. There were no significant differences between groups related to pulmonary emboli, myocardial infarctions, superficial space infections, or sepsis (Table 3). Finally, when we examined injury patterns among patients with blunt and penetrating TDI, we identified key distinctions. Patients with blunt TDI were more likely to have associated injuries to the thoracic aorta, lung, spleen, and bladder, while patients with penetrating TDI were more likely to have hollow viscus injuries, hemothoraces, esophageal, stomach, pancreatic, and liver injuries (Table 4).

Comments

Previous authors have established that rupture of the diaphragm because of blunt trauma represents the presence of a significant crush or deceleration force dissipated across the abdominopelvic cavity and blunt TDI has been associated with a higher mortality rate than penetrating TDI.[5,9] Our results confirm these findings, as patients in our cohort with a blunt TDI had both a higher mortality rate and a higher ISS, reflecting their severe associated injuries. Furthermore, the relationship between blunt TDIs and high-velocity mechanism with significant acceleration–deceleration force is demonstrated by the increased incidence of aortic, spleen, and bladder injuries in our population. Alternatively, penetrating TDIs are associated with gastric, bowel, and liver injuries.

The rare incidence of TDI and the difficultly in diagnosing this injury make it a challenging entity to study prospectively. Thus, previous authors have published retrospective series, often from single centers over several years, in an attempt to identify patterns of injury and associated findings, which may raise the index of clinical suspicion and aid the clinician in making this often elusive diagnosis. Most previous studies are single-center studies from level 1 trauma centers. This may lead to bias, as more severely injured patients may present to these centers. Furthermore, the frequency of blunt or penetrating TDI may depend on geographic and socioeconomic factors relevant to a particular trauma center.[2] There may also be variation over time in the rates of blunt and penetrating trauma over time. As Lopez et al[4] highlighted, there was an increase in the rate of blunt TDI over time, with an associated increase in the mortality rate in this population. Lopez's series of 124 patients with TDIs over a 20-year period demonstrated a rise in mortality from TDI over time from 3% (1986 to 1995) to 17% (1996 to 2005). They attributed this rise in mortality to the concomitant rise in the incidence of blunt trauma at their center over the same time period. Patients in their cohort suffering blunt trauma had a higher ISS and more severe associated injuries.

Our study represents the largest multicenter, single-year series of diaphragmatic injuries ever described, mitigating some of the deficits of single-center or multi-year studies. Additionally, our series is the only descriptive series of diaphragmatic injuries published from NTDB data.

Although diaphragmatic injury itself was unlikely to be an early cause of death in these patients, their increased mortality rate is likely related to their severe associated injuries. Lopez et al[4] concluded that diaphragmatic injury indicates that the patient has sustained a large degree of energy transfer and therefore should be evaluated for other severe life-threatening injuries, particularly in the presence of hemorrhagic shock.

Reiff et al investigated the National Automotive Sampling System to determine which associated injuries and motor vehicle collision characteristics were associated with blunt diaphragmatic injury. This group determined that greater change in velocity and greater occupant compartment intrusion were more likely to be associated with blunt TDI, as were certain patterns of injury, including splenic or hepatic injuries, thoracic aortic injuries, and pelvic fractures. The authors concluded that patients with collision scene data suggestive of high-velocity mechanism might warrant a more invasive diagnostic workup for TDI, such as laparotomy, laparoscopy, or thoracoscopy.[12]

In our cohort, we determined that patients with blunt TDI were more likely to have associated injuries to the thoracic aorta. This finding has not been well described in previous retrospective studies examining diaphragmatic injury. An examination that directly addressed the relationship between diaphragmatic injury and thoracic aortic rupture was published by Rizoli et al in 2004. In a single-center series of 3,886 trauma patients, they found that 69 patients (1.1%) were diagnosed with blunt TDI, and of these 10% (7 patients) had a simultaneous thoracic aortic

Table 2 Outcomes

	Blunt TDI	Penetrating TDI	*P* value
Mortality (%)	19.8	8.8	<.001
Hospital length of stay (days)	15 ± 18	12 ± 15	<.001
ICU length of stay (days)	12 ± 13	8 ± 10	<.001
Ventilator days	9 ± 12	6 ± 9	<.001

Data are expressed as mean ± standard deviation.
ICU = intensive care unit; TDI = traumatic diaphragmatic injury.

Table 3 Complications

Complication	Blunt TDI (%)	Penetrating TDI (%)	*P* value
Acute respiratory distress	7.4	4.1	<.001
Pneumonia	14.8	6.6	<.001
Deep vein thrombosis	4.6	2.6	.011
Pulmonary embolism	2.1	1.6	.248
Myocardial infection	.7	.4	.119
Deep space infection	1.8	3.5	.003
Superficial infection	1.9	2.3	.494
Severe sepsis	2.6	2.3	.570

TDI = traumatic diaphragmatic injury.

injury.[18] In an update published in 2007, this group confirmed that patients with blunt TDI in their cohort of 9,734 trauma patients had a 6-fold increased risk of having a blunt aortic injury. The authors noted that like blunt TDI, blunt aortic rupture represents a significant acceleration–deceleration force. Given this association and the risk of missed diagnosis, the authors note that all patients at their trauma center presenting with blunt diaphragmatic injury also undergo screening for blunt aortic injury with mandatory computed tomography angiography of the chest.[19]

First, our study was limited by the inherent limitations of the NTDB. Although the NTDB is the largest available repository of trauma data in the United States, it lacks detail on several important covariates that may have strengthened our investigation, such as specific imaging obtained or operation performed. Furthermore, the use of the NTDB and other registries allows for only retrospective analyses, which also limits our study.[15,16] There is inherent selection bias in the NTDB, as only those patients admitted to a trauma center contributing data to the NTDB will be included in the database. Furthermore, the NTDB may be subject to survival bias as patients who do not survive to hospital admission, or who die in the emergency department, will not be sufficiently represented in the database. The NTDB is also subject to missing data, which in some cases may be substantial. This may affect the quality of the results published from this database. In our study, we controlled for this factor by excluding patients with missing data.

Here, we have used a large database to identify injury patterns associated with diaphragmatic injury. Given that this diagnosis is frequently occult, injury patterns may aid the clinician in making the diagnosis of TDI. In particular, patients presenting with blunt TDI were found to have associated injuries of the thoracic aorta. The finding of diaphragmatic injury should result in the consideration of additional studies to evaluate for missed injury to the thoracic aorta, such as computed tomography angiography.

However, many unanswered questions remain. Given the poor sensitivity of routine imaging used for trauma patients, the best test for detection of TDI is currently unknown.[6,20] In a series of 108 stable trauma patients presenting with

Table 4 Injury patterns

Injury	Blunt TDI (%)	Penetrating TDI (%)	*P* value
Thoracic aorta	2.9	.5	<.001
Pulmonary injury	48.7	28.1	<.001
Pneumothorax	30.0	20.4	<.001
Cardiac injury	8.0	9.9	.060
Hemothorax	21.5	26.2	<.001
Esophagus	.2	1.1	.003
Bronchus	.2	0	.211
Abdominal aorta	.2	.4	.243
Spleen	44.8	29.1	<.001
Bladder	5.9	.7	<.001
Duodenum	3.0	3.9	.176
Kidney	17.3	18.0	.633
Pancreas	5.7	9.8	<.001
Stomach	4.5	26.6	<.001
Liver	39.7	53.6	<.001
Small bowel	7.8	12.1	<.001
Large bowel	6.0	11.9	<.001

TDI = traumatic diaphragmatic injury.

penetrating thoracoabdominal trauma who underwent diagnostic laparoscopy, 20% were diagnosed with diaphragmatic injury. Preoperative chest radiographs were normal in 68% of the patients who underwent diagnostic laparoscopy.[7] As nonoperative management of both blunt and penetrating trauma increases, additional use of diagnostic laparoscopy may be required to avoid missing this important injury.

Conclusions

Diaphragmatic injury is a rare but significant entity in trauma patients. The NTDB provides the largest single series of patients described with this entity to date, allowing for analysis of patterns of injury on a larger scale and among multiple trauma centers. Clinicians should be beware of TDI in bluntly injured patients with specific injury patterns, specifically injuries to the thoracic aorta, lung, spleen, and bladder, and consider additional diagnostic workup or clinical intervention in these patients to avoid untoward complications related to TDI.

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References

1. Stewart RM, Myers JG, Dent DL, et al. Seven hundred fifty-three consecutive deaths in a level I trauma center: the argument for injury prevention. J Trauma 2003;54:66–70; discussion 70–1.
2. Zarour AM, El-Menyar A, Al-Thani H, et al. Presentations and outcomes in patients with traumatic diaphragmatic injury: a 15-year experience. J Trauma Acute Care Surg 2013;74:1392–8. quiz 1611.
3. Mihos P, Potaris K, Gakidis J, et al. Traumatic rupture of the diaphragm: experience with 65 patients. Injury 2003;34:169–72.
4. Lopez PP, Arango J, Gallup TM, et al. Diaphragmatic injuries: what has changed over a 20-year period? Am Surg 2010;76:512–6.
5. Shah R, Sabanathan S, Mearns AJ, et al. Traumatic rupture of diaphragm. Ann Thorac Surg 1995;60:1444–9.
6. Guth AA, Pachter HL, Kim U. Pitfalls in the diagnosis of blunt diaphragmatic injury. Am J Surg 1995;170:5–9.
7. Powell BS, Magnotti LJ, Schroeppel TJ, et al. Diagnostic laparoscopy for the evaluation of occult diaphragmatic injury following penetrating thoracoabdominal trauma. Injury 2008;39:530–4.
8. Matsevych OY. Blunt diaphragmatic rupture: four year's experience. Hernia 2008;12:73–8.
9. Hanna WC, Ferri LE, Fata P, et al. The current status of traumatic diaphragmatic injury: lessons learned from 105 patients over 13 years. Ann Thorac Surg 2008;85:1044–8.
10. Scharff JR, Naunheim KS. Traumatic diaphragmatic injuries. Thorac Surg Clin 2007;17:81–5.
11. Lewis JD, Starnes SL, Pandalai PK, et al. Traumatic diaphragmatic injury: experience from a level I trauma center. Surgery 2009;146:578–83; discussion 583–4.
12. Reiff DA, McGwin Jr G, Metzger J, et al. Identifying injuries and motor vehicle collision characteristics that together are suggestive of diaphragmatic rupture. J Trauma 2002;53:1139–45.
13. Kearney PA, Rouhana SW, Burney RE. Blunt rupture of the diaphragm: mechanism, diagnosis, and treatment. Ann Emerg Med 1989;18:1326–30.
14. Chughtai T, Ali S, Sharkey P, et al. Update on managing diaphragmatic rupture in blunt trauma: a review of 208 consecutive cases. Can J Surg 2009;52:177–81.
15. Haider AH, Saleem T, Leow JJ, et al. Influence of the National Trauma Data Bank on the study of trauma outcomes: is it time to set research best practices to further enhance its impact? J Am Coll Surg 2012;214:756–68.
16. Research Data Set Admission Year 2012 User Manual. National Trauma Data Bank. p. 62. Available at: https://www.facs.org/~/media/files/quality%20programs/trauma/ntdb/ntdbmanual2012.ashx. Accessed October 20, 2014.
17. Barmparas G, DuBose J, Teixeira PG, et al. Risk factors for empyema after diaphragmatic injury: results of a National Trauma Databank analysis. J Trauma 2009;66:1672–6.
18. Rizoli SB, Brenneman FD, Boulanger BR, et al. Blunt diaphragmatic and thoracic aortic rupture: an emerging injury complex. Ann Thorac Surg 1994;58:1404–8.
19. Chughtai TS, Sharkey P, Brenneman F, et al. Blunt diaphragmatic rupture mandates a search for blunt aortic injury: an update. Ann Thorac Surg 2007;83:1234–5.
20. Brasel KJ, Borgstrom DC, Meyer P, et al. Predictors of outcome in blunt diaphragm rupture. J Trauma 1996;41:484–7.

Discussion

Hugh Foy, M.D.: The authors present their analysis of diaphragmatic injuries extracted from the American College of Surgeons (ACS) National Trauma Data Bank (NTDB) in 2012. Indeed this is a very large series that reinforces the rare nature of this injury at $<1\%$. Both blunt and penetrating mechanism are reported: with 67% due to penetrating and 33% from blunt mechanism. No mention is given of the denominator in the NTSB of penetrating vs blunt patients, but generally speaking, penetrating injuries comprise a small fraction of all trauma patients, 10-30% depending on the center. If one assumes that diaphragm injuries were 2 times higher in penetrating mechanism in this series, then TDI from penetrating injuries are 10 times more likely than from blunt trauma. Not surprising given the size of the target that the diaphragm affords a penetrating knife or bullet. A gunshot fired in a horizontal plane commonly will injure the diaphragm in addition to injuring the liver, spleen and the hollow viscera nestled in its' concavity.

Despite the lower incidence overall, the authors report that blunt TDIs were associated with a greater mortality, ISS, and ICU length of stay compared to penetrating TDI. It is a well recognized phenomenon that penetrating injuries present a more defined scenario compared to the blunt injured patients who suffer TDI. These patients incur a myriad of other injuries, particularly thoracic and musculoskeletal (pelvic) due to the high energy anterior compression that typically ruptures the diaphragm. The authors correctly discuss the known association with Blunt TDI, aortic tears and pelvic fracture, reinforcing previous authors' recommendation to perform routine CT angiogram of the aorta whenever a blunt TDI is diagnosed.

Correspondingly, blunt TDI are likely to be larger compared to the discrete punctate violation typical of a penetrating weapon. Variation in the incidence of blunt TDI parallels the improvement in vehicle safety and better patient survival in motor vehicle collisions (MCVs) over the decades raising the suspicion that more patients survive to reach the hospital in MVCs that previously would have died at the scene. Diagnosis is now much improved with the advent of faster, higher resolution CT scanning with 3-D, coronal and sagittal reconstruction to increase the sensitivity of diagnosis of blunt TDI.

The authors admit to the limitations of their retrospective study, which include its lack of detail of the injury, the specific imaging employed, and inherent selection bias of including only admitted patients. It may be illustrative to examine their local coroners data to compare field and hospital mortality, given the well known early mortality with associated traumatic aortic injury. Like penetrating cardiac injuries, the survival bias in many studies is unmasked by inclusion of coroner's data to arrive at a realistic survival statistics. The challenge of accurate and timely diagnosis is also addressed. Particularly in field intubated patients, TDI can be occult due to reduction of the hernia. Catastrophic failure of spontaneous breathing trials despite excellent gas exchange should raise the suspicion of an occult TDI.