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Characteristics, outcomes, and prognostic factors in patients with penetrating and blunt traumatic diaphragmatic injury: a nationwide retrospective cohort study in Japan

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Abstract

Background Traumatic diaphragmatic injury (TDI) is well-known worldwide as rare and life-threatening. However, because no nationwide cohort study of penetrating and blunt TDI has been conducted in Japan and other countries where penetrating trauma is relatively uncommon, the clinical characteristics of all TDI are unknown. We aimed to describe the characteristics of TDI patients, compare penetrating TDI with blunt TDI, and identify mortality risk factors in Japan.

Methods We retrospectively identified TDI patients between 2004 and 2019 using data from the Japan Trauma Data Bank. We extracted data on patient demographics, type of trauma, cause of trauma, physiological parameters, region of concomitant injury, associated injury, and management. We compared penetrating and blunt TDI for each variable. The primary outcome was mortality. Multivariable logistic regression was performed to identify mortality risk factors.

Results Of the 338,744 patients, 1,147 (0.3%) had TDI, of which 771 were eligible for analysis (excluding 308 in cardiac arrest on arrival). Penetrating TDI represented 29.8% and blunt TDI 70.2%, and comparing penetrating and blunt TDI, the most common cause was self-inflicted (48.7%) vs. accident (85.6%), males were 68.7% vs. 66.0% of the patients ($P = 0.50$), and the mortality rate was 8.3% vs. 26.4% ($P < 0.001$). Multivariable analysis found that age (odds ratio [OR] 1.03, 95% confidence interval [CI] 1.01–1.04), Injury Severity Score (OR 1.03, 95%CI 1.006–1.06), Revised Trauma Score (OR 0.55, 95%CI 0.45–0.67), severe concomitant abdominal injury (OR 2.45, 95%CI 1.32–4.56), severe concomitant upper extremity injury (OR 3.38, 95%CI 1.24–9.17) were independent predictors of mortality, and computed tomography (CT) (OR 0.32, 95%CI 0.15–0.69) and diaphragm repair (OR 0.44, 95%CI 0.25–0.78) were protective factors.

Conclusions In Japan, we found that penetrating TDI was mainly caused by self-injury and the male–female ratio was the same as for blunt TDI, although blunt TDI was much more frequent. TDI was considered highly lethal, with over 25% of patients in cardiac arrest on arrival. Our unique independent predictors were CT, severe concomitant abdominal injury, and severe concomitant upper extremity injury. These findings may help in the management of TDI in countries with less common penetrating trauma.

Keywords Traumatic diaphragmatic injury (TDI), Penetrating TDI (PTDI), Blunt TDI (BTDI), Japan Trauma Data Bank (JTDB), Associated injury, Severe concomitant injury, Independent predictor of mortality, Epidemiology

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Background

Traumatic diaphragmatic injury (TDI) is rare but frequently fatal [1–3]. In the United States, significant differences have been reported between penetrating TDI (PTDI) and blunt TDI (BTDI) in terms of demographics, injury patterns, complications, prognosis, and mortality [1, 4]. PTDI also shows different characteristics from BTDI regarding diagnosis, treatment, and other aspects of practice management [5–7]. The incidence of penetrating trauma varies across countries. Countries in which penetrating trauma is less common include Japan (2.4% incidence of penetrating trauma among all trauma patients) [8], the United Kingdom (4.8%) [9], Germany (3.6%) [10], and Australia and New Zealand (3.8%) [11], while countries in which penetrating trauma is more common include the United States (8.9%) [12], South Africa (40.7%) [13], and Israel (7.4%) [10]. In countries where penetrating trauma is less common, opportunities to treat PTDI are reduced, so familiarity with characteristics of PTDI that differ from those of BTDI is warranted. However, in Japan as well as in other countries with less penetrating trauma, large-scale nationwide studies of all TDI have been lacking, even though large-scale nationwide studies limited to BTDI have been conducted [14–18]. The epidemiology, clinical practice, and prognosis of all TDI in Japan therefore remain unknown. Differences may exist in the clinical characteristics of TDI in Japan compared to countries where penetrating trauma is more common, such as the United States. The purposes of this study were to compare PTDI with BTDI, to elucidate the characteristics of PTDI and BTDI patients, and to identify risk factors for mortality using a nationwide trauma database in Japan.

Methods

Ethics approval

This study was approved by the institutional review board at Jichi Medical University (approval no. RINDAI 21–079). The requirement for informed consent was waived, as all analyses were conducted using anonymized data.

Study design and setting

This multicenter observational retrospective cohort study was conducted using data from patients registered to the Japan Trauma Data Bank (JTDB) between 2004 and 2019. Our findings were reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement for Observational Studies [19].

Japan trauma data bank

The JTDB is a nationwide hospital-based trauma registry in Japan, established in 2003 by the Japanese Association for the Surgery of Trauma (Trauma Registry Committee) and the Japanese Association for Acute Medicine (Committee for Clinical Care Evaluations). The JTDB is also managed by the Japan Trauma Care and Research (JTCR). As of March 2019, 280 emergency medical institutions across Japan participated in the registry [8]. The JTDB collected 92 data elements relating to trauma patients such as age, sex, mechanism of injury, Abbreviated Injury Scale (AIS) code (AIS90 update98), Injury Severity Score (ISS), vital signs on hospital arrival, Revised Trauma Score (RTS), medical management, surgical operations, computed tomography (CT), and mortality at discharge. The JTDB included trauma patients who were hospitalized at participating facilities, including patients who were in cardiac arrest on hospital arrival or who died in the emergency department. Physicians and medical assistants who had taken the AIS coding course collected the data and registered it via the Internet at each participating facility. The Trauma Registry Committee cleaned the pooled data and distributed the data set to the participating facilities only each year.

Participants

Among all patients recorded in the JTDB between 2004 and 2019, those with an AIS code (AIS90 update98) indicating diaphragmatic injury (440699.2, 440602.2, 440604.3, and 440606.4) were included in this study. For diaphragmatic injuries, AIS codes 440699.2, 440602.2, 440604.3, and 440606.4 were defined as unspecified, contusion (Organ Injury Scale [OIS] Grade I), laceration (OIS Grade II-IV) [20], and rupture with herniation, respectively. If a patient had more than one AIS code indicating diaphragmatic injury, the maximum AIS code was adopted. Patients with unknown outcomes, those with AIS code 440699.2, meaning TDI of unknown detail, those with unknown mechanism of injury, and those in cardiac arrest (systolic blood pressure = 0 mmHg and/or heart rate = 0 beats/min) on arrival at the hospital were excluded from analyses of in-hospital mortality and its predictive factors. The JTDB instructed that the systolic blood pressure of patients in cardiac arrest should be recorded as 0 mmHg. For this reason, we defined cardiac arrest as systolic blood pressure of 0mmHg. Pulseless ventricular tachycardia, ventricular fibrillation, pulseless electrical activity, or asystole were collectively recorded in the JTDB as cardiac arrest, so we defined these in the same way as the above conditions. In the multivariable regression analysis, patients who had one or more missing values among the explanatory variables were also excluded.

Variables

The following data from the JTDB were analyzed in this study: age (years), sex, type of trauma (penetrating or blunt), cause of trauma (accident, self-injury, assault, or work-related), etiology of trauma (traffic accident, fall, stabbing, or gunshot), TDI classification, prehospital blood pressure (mmHg), prehospital heart rate (beats/min), blood pressure on hospital arrival (mmHg), heart rate on hospital arrival (beats/min), ISS, RTS, severe (AIS ≥ 3) concomitant non-thoracic injury (head, face, neck, abdomen, vertebra, upper extremity, lower extremity including pelvis), any concomitant abdominal injury, associated injury (hemothorax/ pneumothorax, tension pneumothorax, massive hemothorax, flail chest, thoracic aorta injury, cardiac injury, pulmonary injury, trachea/main stem bronchus injury, rib injury, sternum injury, esophagus injury, colon injury, intestine injury, kidney injury, liver injury, mesentery injury, pancreas injury, spleen injury, stomach injury, or duodenum injury), CT of the chest/abdomen, initial therapeutic management (thoracotomy, laparotomy, endoscopic surgery, or non-operative management), performance of diaphragm repair, blood transfusion within 24 h, and mortality. In the AIS90 update98, tension pneumothorax was defined as "a condition associated with a large amount of air leak", as well as a clinically diagnosed condition. In addition, no AIS code was assigned for massive hemothorax, but we included thoracic organ injury "with blood loss > 20% by volume" in massive hemothorax. Hypotension was defined as a systolic blood pressure < 90 mmHg. The Shock Index (SI) was the heart rate divided by the systolic blood pressure, with an SI ≥ 1 denoting a state of shock. Severe concomitant injury was defined as an injury with a maximum AIS ≥ 3.

Outcome measures

The primary outcome measure was in-hospital mortality.

Statistical analysis

Continuous variables were presented as median with interquartile range (IQR), while categorical variables were presented as frequency and percentage. Baseline demographic characteristics, clinical findings, management, and outcomes were analyzed according to the mechanism (penetrating vs. blunt) of diaphragmatic injury. Between-group comparisons were performed using the chi-squared or Fisher's exact test for categorical data and the Wilcoxon test for continuous data.

Multivariable logistic regression analysis was performed with a forced entry procedure to identify factors independently associated with in-hospital mortality. The explanatory variables were selected based on previous studies [2, 16, 21–26] and according to whether they were considered clinically relevant to diaphragmatic injury. The variables selected were age, type of trauma (blunt, penetrating), ISS, RTS, hypotension on hospital arrival, severe concomitant head injury, severe concomitant abdominal injury, severe concomitant upper extremity injury, severe concomitant lower extremity injury including pelvis, flail chest, thoracic aortic injury, cardiac injury, CT of the chest/abdomen, thoracotomy/laparotomy as initial management, diaphragm repair, and blood transfusion within 24 h. Japan has by far the largest number of CT scanners in the world, and access to CT scans is very easy, so it is common practice to perform a CT scan as part of initial trauma care, as long as the patient's general condition allows. To investigate whether trauma CT in Japan contributed to the outcome of TDI, CT of the chest/abdomen was included as an explanatory variable. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were calculated.

All tests were two-tailed, and values of $P < 0.05$ were considered statistically significant. All statistical analyses were conducted using JMP Pro 17 software (SAS Institute Japan Co., Minato-ku, Tokyo).

Results

Figure 1 shows patient flow in this study. During the study period, 338,744 patients were registered in the JTDB. Of these, 11,426 (3.4%) were due to penetrating injury and 311,712 (92.0%) were due to blunt injury. Of all patients, 1,147 (0.3%) had TDI and 771 of these patients were enrolled in this study. Penetrating TDI accounted for 230 (29.8%) and blunt TDI accounted for 541 (70.2%). Of the excluded patients, 308 were in cardiac arrest on arrival.

Table 1 shows the baseline characteristics, clinical findings, management, and outcomes of all patients with TDI. Comparisons between PTDI and BTDI are also shown. Patients with PTDI were younger, and self-injury or suicide attempt was the most common cause of injury, followed by assault. The proportion of male patients was not significantly different between the PTDI and BTDI. The mortality rate was significantly lower for PTDI than for BTDI. Patients with prehospital hypotension and SI ≥ 1 were significantly more common in PTDI, while the frequency of patients with hypotension and SI ≥ 1 on hospital arrival did not differ significantly between PTDI and BTDI. Thoracotomy/laparotomy as initial therapeutic management was significantly more common in PTDI, while NOM was significantly more common in BTDI. Diaphragm repair was significantly more common following PTDI. The abdomen was the most common region of severe concomitant injury in PTDI, while

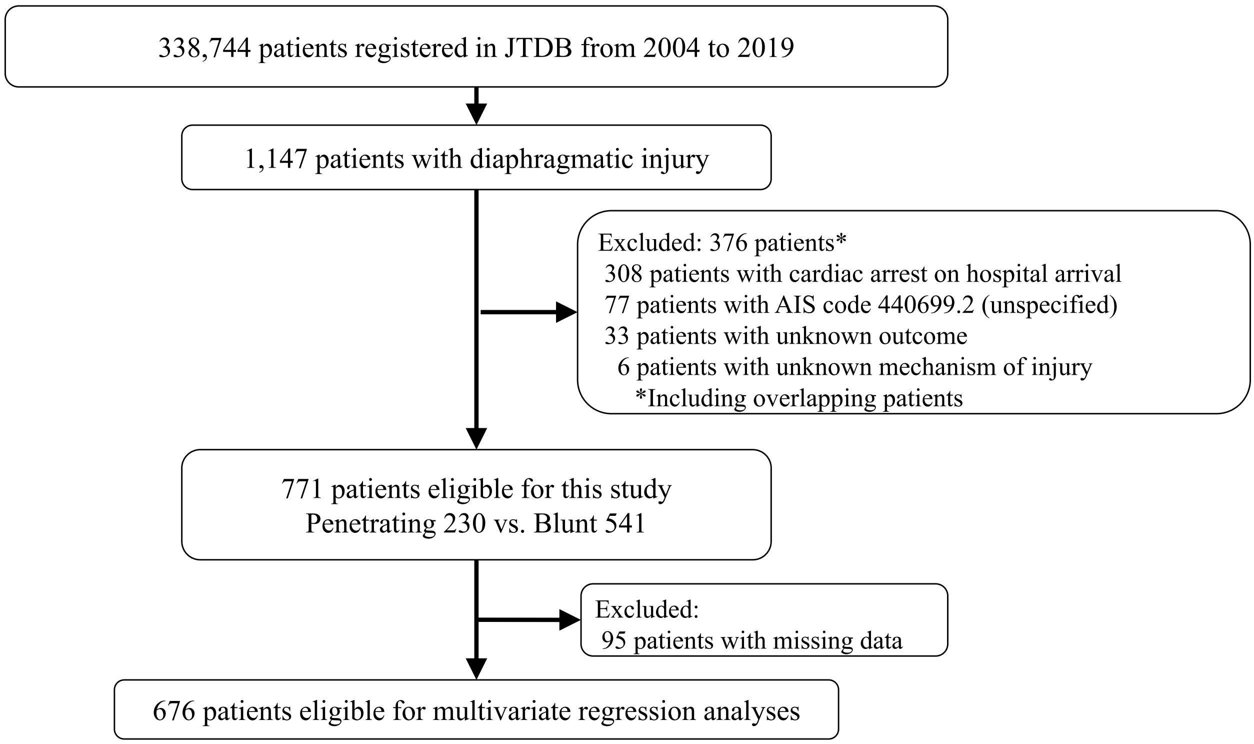

Fig. 1 Flowchart of patient selection

the lower extremity including the pelvis was the most common region of severe concomitant injury in BTDI. Any concomitant abdominal injury was significantly more common in PTDI. In PTDI, liver injury was the most common associated injury, followed by hemothorax/pneumothorax. In BTDI, the most common associated injuries were rib fracture, followed by hemothorax/pneumothorax, lung injury, and spleen injury. CT of the chest and/or abdomen was performed in more than 80% of both PTDI and BTDI.

Table 2 shows the ORs of each variable for in-hospital mortality following TDI. Univariable analysis for in-hospital mortality was conducted. Twenty-one percent of patients died in the hospital. Age, hypotension on hospital arrival, SI ≥ 1 on hospital arrival, ISS, severe concomitant head injury, severe concomitant abdominal injury, severe concomitant upper extremity injury, severe concomitant lower extremity injury including pelvis, flail chest, thoracic aortic injury, cardiac injury, rib injury, NOM, and blood transfusion within 24 h were all significantly associated with higher mortality. Penetrating injury, RTS, CT of the chest and/or abdomen, thoracotomy and/or laparotomy as initial management, and diaphragm repair were significantly associated with lower mortality. TDI classification, presence of any concomitant abdominal injury, and associated injury to each abdominal organ were not significantly associated with in-hospital mortality.

Table 3 shows the multivariate logistic regression analysis for predictors of mortality following TDI. In the multivariable logistic regression analysis, 16 independent variables were used. Age, ISS, RTS, severe concomitant abdominal injury, and severe concomitant upper extremity injury were independent predictors for mortality, whereas CT of the chest and/or abdomen and diaphragm repair were independent protective factors. Hypotension on hospital arrival was not an independent predictor of mortality.

Discussion

We found three important clinical issues for TDI in Japan. First, PTDI was significantly different from BTDI in several respects. Second, TDI was rare but frequently fatal even in Japan, mainly due to blunt injury mechanisms, often with severe injuries in other regions of the body. Third, we identified novel independent predictors of good outcomes and death in TDI.

First, PTDI differed significantly from BTDI in several ways. The most common cause of PTDI in Japan was self-injury or suicide attempt (accounting for half), not assault as in other countries [27, 28]. In Japan, where gunshot wounds are extremely rare, penetrating trauma

Table 1 Characteristics of patients with traumatic diaphragm injury eligible for analysis and their comparisons based on penetrating and blunt injury mechanisms

Variables	overall $n = 771$	Penetrating $n = 230$ (29.8%)	Blunt $n = 541$ (70.2%)	*p* value
Age, years	56 [39–70]	49 [36–64]	59 [41–72]	< 0.001
Male sex	515 (66.8%)	158 (68.7%)	357 (66.0%)	0.50
Cause of trauma				
Accident	482 (62.5%)	19 (8.3%)	463 (85.6%)	< 0.001
Self-injury, suicide	138 (17.9%)	112 (48.7%)	26 (4.8%)	< 0.001
Assault	91 (11.8%)	89 (38.7%)	2 (0.4%)	< 0.001
Work-related	45 (5.8%)	5 (2.2%)	40 (7.4%)	0.003
TDI classification				
Contusion (OIS I)	53 (6.9%)	13 (5.7%)	40 (7.4%)	0.43
Laceration (OIS II-IV)	370 (48.0%)	193 (83.9%)	177 (32.7%)	< 0.001
Rupture with herniation	348 (45.1%)	24 (10.4%)	324 (59.9%)	< 0.001
On-scene cardiac arrest	6 (0.8%)	0 (0%)	6 (1.1%)	0.18
On-scene hypotension*	101 (13.1%)	47 (20.4%)	54 (10.0%)	< 0.001
On-scene Shock Index ≥ 1**	174 (22.6%)	63 (27.4%)	111 (20.5%)	0.038
Hypotension on hospital arrival*	206 (26.7%)	66 (28.7%)	140 (25.9%)	0.42
Shock Index ≥ 1 on hospital arrival**	292 (37.9%)	83 (36.1%)	209 (38.6%)	0.51
ISS	26 [18–38]	18 [13–25]	32 [22–42]	< 0.001
RTS	7.6 [6.0–7.8]	7.6 [6.6–7.8]	7.1 [5.7–7.8]	< 0.001
TRISS Ps, %	88 [55–96]	95 [89–97]	80 [42–93]	< 0.001
Isolated TDI	19 (2.5%)	6 (2.6%)	13 (2.4%)	0.80
Body region of severe**†** concomitant injury				
Head	159 (20.6%)	3 (1.3%)	156 (28.8%)	< 0.001
Abdomen	324 (42.0%)	116 (50.4%)	208 (38.5%)	0.002
Vertebra	36 (4.7%)	2 (0.9%)	34 (6.3%)	< 0.001
Upper extremity	41 (5.3%)	3 (1.3%)	38 (7.0%)	< 0.001
Lower extremity including pelvis	185 (24.0%)	1 (0.4%)	184 (34.0%)	< 0.001
Any concomitant abdominal injury	525 (68.1%)	179 (77.8%)	346 (64.0%)	< 0.001
Associated injury				
Hemothorax or pneumothorax	321 (41.6%)	78 (33.9%)	243 (44.9%)	0.005
Tension pneumothorax	16 (2.1%)	4 (1.7%)	12 (2.2%)	0.78
Massive hemothorax	21 (2.7%)	11 (4.8%)	10 (1.9%)	0.029
Flail chest	36 (4.7%)	0 (0%)	36 (6.7%)	< 0.001
Thoracic aorta	40 (5.2%)	1 (0.4%)	39 (7.2%)	< 0.001
Heart	28 (3.6%)	15 (6.5%)	13 (2.4%)	0.009
Lung	284 (36.8%)	64 (27.8%)	220 (40.7%)	< 0.001
Trachea/main stem bronchus	3 (0.4%)	2 (0.9%)	1 (0.2%)	0.21
Rib	358 (46.4%)	31 (13.5%)	327 (60.4%)	< 0.001
Sternum	18 (2.3%)	2 (0.9%)	16 (3.0%)	0.11
Esophagus	2 (0.3%)	2 (0.9%)	0 (0%)	0.088
Colon	55 (7.1%)	16 (7.0%)	39 (7.2%)	1.00
Intestine	59 (7.7%)	17 (7.4%)	42 (7.8%)	1.00
Kidney	74 (9.6%)	10 (4.4%)	64 (11.8%)	< 0.001
Liver	248 (32.2%)	93 (40.4%)	155 (28.7%)	0.001
Mesentery	84 (10.9%)	14 (6.1%)	70 (12.9%)	0.005
Pancreas	30 (3.9%)	8 (3.5%)	22 (4.1%)	0.83
Spleen	155 (20.1%)	25 (10.9%)	130 (24.0%)	< 0.001
Stomach	66 (8.6%)	42 (18.3%)	24 (4.4%)	< 0.001
Duodenum	8 (1.0%)	2 (0.9%)	6 (1.1%)	1.00

Table 1 (continued)

Variables	overall $n=771$	Penetrating $n=230$ (29.8%)	Blunt $n=541$ (70.2%)	*p* value
CT of chest/abdomen	656 (85.1%)	187 (81.3%)	469 (86.7%)	0.060
Initial therapeutic management				
Thoracotomy/laparotomy	549 (71.2%)	187 (81.3%)	362 (66.9%)	< 0.001
Thoracotomy alone	99 (12.8%)	36 (15.7%)	63 (11.7%)	0.12
Laparotomy alone	314 (40.7%)	86 (37.4%)	228 (42.1%)	0.23
Endoscopic surgery alone	30 (3.9%)	9 (3.9%)	21 (3.9%)	1.00
Non-operative management	192 (24.9%)	34 (14.8%)	158 (29.2%)	< 0.001
Diaphragm repair	392 (50.8%)	133 (57.8%)	259 (47.9%)	0.011
Blood transfusion within 24 h	535 (69.4%)	156 (67.8%)	379 (70.1%)	0.60
Mortality	162 (21.0%)	19 (8.3%)	143 (26.4%)	< 0.001

Data are presented as number (percentage) or median [IQR]

TDI traumatic diaphragmatic injury, *OIS* organ injury scale, *ISS* injury severity score, *RTS* revised trauma score, *TRISS* trauma-injury severity score, *Ps*probability of survival

[*] Systolic blood pressure < 90 mmHg, excluding cardiac arrest

[**] Excluding cardiac arrest

[†] maximum Abbreviated Injury Scale ≥ 3

is almost always from a stab wound, and over 70% of abdominal stab wounds are reportedly self-inflicted, with TDI present in just under 4% of these [29]. Further, while the proportion of male patients with PTDI has been reported as around 90% in other countries [1, 2, 24], no sex difference was evident in Japan. A strong correlation has been reported between assault as a cause of penetrating injury and male patients [30]. As with other organ injuries, a clear difference was noted between most PTDIs resulting from self-injury, suicide, or assault and most BTDI resulting from accidents. These findings have not been well described in previous studies of TDI.

The mortality rate of PTDI was significantly lower than that of BTDI in Japan, similar to countries like the United States [1, 2, 4]. In the present study, despite worse prehospital hemodynamics than BTDI, PTDI showed a higher RTS (better physiological severity) on hospital arrival and consequently a lower mortality rate. This would indicate that PTDI is evaluated as more severe than BTDI in the prehospital setting, but actually has a good prognosis. More thoracotomy and/or laparotomy and less NOM as initial therapeutic management and more diaphragm repair may be associated with lower mortality in PTDI than in BTDI. In principle, all diaphragmatic injuries require surgical repair, but NOM is only acceptable under certain conditions for PTDI [5, 6]. Thoracoabdominal stab wounds are suspected to result in PTDI and NOM may be recommended as initial management of the injury in the United States and elsewhere. In Japan, however, poor experience with penetrating trauma may make the decision for NOM difficult, and laparotomy or thoracotomy may be performed more often. PTDI was associated with a significantly higher prevalence of concomitant severe abdominal injury than BTDI. Associated injuries to abdominal organs were most common in the order of liver, stomach and spleen, similar to the study using the National Trauma Data Bank (NTDB) by Fair et al. [1].

Second, TDI was rare but often fatal even in Japan, where penetrating trauma was much less common than in the United States. However, it was found that TDI in Japan was mainly due to blunt trauma mechanisms and often accompanied by severe injuries to the abdomen, lower extremities including the pelvis, and head. Previous reports have shown that the incidence of TDI is less than 0.5% of all trauma [1, 26], with a mortality rate of 7–21% [1, 2, 4, 26, 31], and the results of the present study were almost the same. In this study, the in-hospital mortality rate was 21.0%, but 26.9% (308/1,147) of patients with cardiac arrest on hospital arrival were excluded from the study. The "true mortality" of all cases of TDI, including cardiac arrest on hospital arrival, would therefore certainly be higher. The fact that more than a quarter of the patients with TDI in this study were in cardiac arrest on hospital arrival may mean that TDI itself is extremely lethal, as suggested by several case reports [32–34]. However, no previous investigations have reported that such a high proportion of TDI cases were in cardiac arrest on hospital arrival. Excluding those in cardiac arrest on hospital arrival, just under 30% of TDI patients showed hypotension and just under 40% had an SI ≥ 1 in this study. This also suggests that TDI is likely to be severe. In two cohort studies limited to BTDI using the JTDB [14, 15],

Table 2 Odds ratios of in-hospital mortality following TDI according to patient characteristics

Variables	Death *n* = 162 (21.0%)	Survived *n* = 609 (79.0%)	OR (95%CI)	*P* value
Age, years	62 [44–75]	54 [38–68]	1.02 (1.01–1.03)	< 0.001
Sex, Male	104 (64.2%)	411 (67.5%)	0.86 (0.60–1.24)	0.45
Type of trauma				
Penetrating injury	19 (11.7%)	211 (34.6%)	0.25 (0.15–0.41)	< 0.001
Blunt injury	143 (88.3%)	398 (65.4%)	1 (reference)	-
TDI classification				
Contusion (OIS I)	12 (7.4%)	41 (6.7%)	1 (reference)	-
Laceration (OIS II-IV)	75 (46.3%)	295 (48.4%)	0.86 (0.43–1.73)	0.71
Rupture with herniation	75 (46.3%)	273 (44.8%)	0.93 (0.46–1.87)	0.85
Hypotension on hospital arrival*	85 (52.5%)	121 (19.9%)	4.45 (3.08–6.42)	< 0.001
Shock Index ≥ 1 on hospital arrival**	92 (56.8%)	200 (32.8%)	2.68 (1.88–3.82)	< 0.001
ISS	41 [28–50]	25 [18–34]	1.07 (1.06–1.09)	< 0.001
RTS	5.1 [2.8–6.6]	7.6 [6.6–7.8]	0.48 (0.42–0.55)	< 0.001
Body region of severe concomitant injury				
Head	56 (34.6%)	103 (16.9%)	2.59 (1.76–3.82)	< 0.001
Abdomen	87 (53.7%)	237 (38.9%)	1.82 (1.28–2.58)	< 0.001
Vertebra	8 (4.9%)	28 (4.6%)	1.07 (0.48–2.41)	0.83
Upper extremity	18 (11.1%)	23 (3.8%)	3.18 (1.67–6.05)	< 0.001
Lower extremity including pelvis	73 (45.1%)	112 (18.4%)	3.63 (2.51–5.27)	< 0.001
Associated injury				
Hemothorax or pneumothorax	68 (42.0%)	253 (41.5%)	1.01 (0.71–1.44)	0.92
Tension pneumothorax	4 (2.5%)	12 (2.0%)	1.25 (0.40–3.95)	0.75
Massive hemothorax	6 (3.7%)	15 (2.5%)	1.52 (0.58–3.98)	0.41
Flail chest	14 (8.6%)	22 (3.6%)	2.52 (1.26–5.05)	0.011
Thoracic aorta	14 (8.6%)	26 (4.3%)	2.12 (1.08–4.16)	0.043
Heart	12 (7.4%)	16 (2.6%)	2.96 (1.37–6.40)	0.007
Lung	60 (37.0%)	224 (36.8%)	1.01 (0.70–1.44)	1.00
Rib	90 (55.6%)	268 (44.0%)	1.59 (1.12–2.25)	0.010
Sternum	6 (3.7%)	12 (2.0%)	1.91 (0.70–5.17)	0.23
Colon	12 (7.4%)	43 (7.1%)	1.05 (0.54–2.04)	0.86
Intestine	10 (6.2%)	49 (8.1%)	0.75 (0.37–1.51)	0.50
Kidney	19 (11.7%)	55 (9.0%)	1.33 (0.76–2.32)	0.29
Live	61 (37.7%)	187 (30.7%)	1.36 (0.94–1.95)	0.10
Mesentery	22 (13.6%)	62 (10.2%)	1.38 (0.82–2.33)	0.25
Pancreas	7 (4.3%)	23 (3.8%)	1.15 (0.48–2.73)	0.81
Spleen	35 (21.6%)	120 (19.7%)	1.12 (0.73–1.71)	0.58
Stomach	8 (4.9%)	58 (9.5%)	0.49 (0.23–1.05)	0.080
CT of chest/abdomen	112 (69.1%)	544 (89.3%)	0.26 (0.17–0.40)	< 0.001
Initial therapeutic management				
Thoracotomy/laparotomy	96 (59.3%)	453 (74.4%)	0.50 (0.34–0.71)	< 0.001
Endoscopic surgery alone	1 (0.6%)	29 (4.8%)	0.12 (0.01–0.91)	0.010
Non-operative management	65 (40.1%)	127 (20.9%)	2.54 (1.75–3.68)	< 0.001
Diaphragm repair	37 (22.8%)	355 (58.3%)	0.21 (0.14–0.31)	< 0.001
Blood transfusion within 24 h	134 (82.7%)	401 (65.8%)	2.74 (1.72–4.37)	< 0.001

Crude odds ratios were calculated for 771 patients. Data are presented as number (percentage) or median [IQR]

TDI traumatic diaphragmatic injury, *OIS* organ injury scale, *ISS* injury severity score, *RTS* revised trauma score, *IQR* interquartile range, *OR* odds ratio, *CI*, confidence interval

* Systolic blood pressure < 90 mmHg, excluding cardiac arrest

** Excluding cardiac arrest

† maximum Abbreviated Injury Scale ≥ 3

Table 3 Multivariate logistic regression analysis for predictors of mortality

Variables	OR	95%CI	*P* value
Age, years	1.03	1.01-1.04	< 0.001
Type of trauma (penetrating vs. blunt)	0.44	0.19-1.007	0.052
ISS	1.03	1.006-1.06	0.017
RTS	0.55	0.45-0.67	< 0.001
Hypotension on hospital arrival*	1.13	0.57-2.22	0.71
Body region of severe† concomitant injury			
Head	0.62	0.29-1.30	0.20
Abdomen	2.45	1.32-4.56	0.004
Upper extremity	3.38	1.24-9.17	0.016
Lower extremity including pelvis	1.25	0.64-2.41	0.50
Associated injury			
Flail chest	0.73	0.27-1.95	0.53
Thoracic aorta	0.94	0.34-2.56	0.90
Heart	2.28	0.47-11.0	0.30
CT of chest/abdomen	0.32	0.15-0.69	0.003
Thoracotomy/laparotomy as initial management	0.56	0.30-1.03	0.066
Diaphragm repair	0.44	0.25-0.78	0.004
Blood transfusion within 24 h	1.83	0.77-4.31	0.16

OR odds ratio, *CI* confidence interval, *ISS* injury severity score, *RTS* revised trauma score

*Systolic blood pressure < 90 mmHg, excluding cardiac arrest

†maximum Abbreviated Injury Scale ≥ 3

the proportion of shock was calculated without excluding cardiac arrest on arrival, so the proportion of shock included cardiac arrest. Such a methodology does not accurately represent the rate of shock.

The present study revealed that in Japan, patients with PTDI accounted for only 29.8% of TDI, relatively similar to the situations in Australia (37.5%) [16] and Germany (8.6%) [35], but the exact opposite of the United States (67–75%) [1, 2, 4] and South Africa (94%) [31], where penetrating trauma is more common [9–13]. The PTDI proportion may offer a direct reflection of the incidence of penetrating trauma in a country or region.

Regarding concomitant injuries, very few cases showed isolated TDI, and the most common regions of severe concomitant injury were the abdomen, lower extremities including the pelvis, and head, in that order, and most TDIs involved some concomitant injury to the abdomen. The results were similar to findings from previous studies [2, 22, 26, 36]. In another study by Benhamed et al. [37], the frequency of severe concomitant injury to the head, vertebrae, upper extremities, and lower extremities in road traffic accident-related thoracic trauma was similar to the results of this study, but the severe concomitant injury to the abdomen was only 9.5%, which was significantly different from the 42.0% in this study, and it was suggested that a high frequency of severe concomitant abdominal trauma was one of the characteristics of TDI.

Third, in our multivariate logistic analysis, independent predictors of TDI survival were younger age, CT of the chest/abdomen, and diaphragm repair, while independent predictors of death were higher ISS, lower RTS, concomitant severe abdominal injury, and concomitant severe upper extremity injury. Previous studies have also reported similar independent predictors to this study [2, 16, 23, 24, 26]. Penetrating injury was not a significant independent predictor of TDI survival. The unique independent predictors in the present study were CT, severe concomitant abdominal injury, and severe concomitant upper extremity injury. Severe upper extremity injuries suggest that a strong external force may also have been applied to the trunk. As long as permitted by the general condition of the patient, CT is recommended to carefully explore for diaphragmatic injuries and any diaphragmatic injuries identified should be surgically repaired. Even if TDI cannot be detected by CT or other imaging during initial trauma care, and even if management is initiated with NOM without thoracotomy or laparotomy, it is necessary to have a high index of suspicion for TDI in patients with high physiological and anatomical severity and concomitant severe injuries to the abdomen or upper extremity, and the survival rate of TDI patients can be improved by performing diaphragm repair surgery as soon as possible after diagnosis.

Because of the various significant differences between PTDI and BTDI, they may not be treated as the same injury. In PTDI, in addition to definitive diaphragm repair, intervention for associated thoracic and abdominal injuries may be important, and under certain conditions, NOM or endoscopic surgery may be an option. To improve the higher mortality rate of BTDI, multidisciplinary trauma management will be important, with aggressive diagnosis and surgical repair of diaphragmatic injuries in the initial management, as well as definitive care for multiple severe injuries to the abdomen and extremities.

The significance of the present study lies in its position as the only nationwide study of PTDI and BTDI from a country with a relatively low incidence of penetrating trauma, and this study was second in size only to the nationwide cohort study by Fair et al. [1] using the NTDB. We expect that the present results will contribute to trauma care worldwide, particularly in countries with low rates of penetrating trauma.

Limitations

We acknowledge that there are several limitations in this study. First, the present study was limited by the inherent constraints of the JTDB. Because the JTDB is a hospital-based registry, not a population-based registry, selection bias is present in that only patients who visited and were admitted to JTDB-registered facilities are registered in the JTDB. The use of registries such as the JTDB also allows only retrospective analysis. Second, the JTDB data did not allow us to determine how or when the TDI was diagnosed. We could not evaluate whether surgery was performed after obtaining a radiographic or CT imaging diagnosis, or whether the diagnosis was made intraoperatively rather than preoperatively. One issue for future investigation may be to consider the factors that led to a higher-than-expected rate of NOM for TDI, since surgical repair is supposed to be the principle of treatment. Third, during the observation period of this study, the JTDB did not register whether the diaphragmatic injury was on the left or right side as a variable, and no data were available on any organs that prolapsed in diaphragmatic hernia. The characteristics of TDI reportedly differ significantly between the left and right sides, and differences also exist in the recommendations for therapeutic management [2, 6, 7]. With data on whether TDI is left, right, or bilateral available in the revised JTDB from 2019, future studies will now be able to compare left- and right-sided TDI in Japan. In addition, in the case of diaphragmatic hernia, the prolapsed organs are also now being registered in the revised JTDB. We would like to conduct further research on TDI using the revised JTDB in the future.

Conclusion

In Japan, PTDI was much less common than BTDI, but PTDI was mainly due to self-injury, and the male-to-female ratio was the same as for BTDI. TDI had a high mortality rate, and the proportion of patients in cardiac arrest on hospital arrival was found to be over 25%. Independent predictors of TDI survival were younger age, CT of the chest/abdomen, and diaphragm repair, while independent predictors of death were higher ISS, lower RTS, concomitant severe abdominal injury, and concomitant severe upper extremity injury. These findings may be helpful in the diagnosis and management of TDI not only in Japan, but also in other countries with less penetrating trauma.

Abbreviations

TDI	Traumatic diaphragmatic injury
PTDI	Penetrating traumatic diaphragmatic injury
BTDI	Blunt traumatic diaphragmatic injury
JTDB	Japan Trauma Data Bank
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
JTCR	Japan Trauma Care and Research
AIS	Abbreviated Injury Scale
ISS	Injury Severity Score
RTS	Revised Trauma Score
TRISS	Trauma-Injury Severity Score
Ps	Probability of survival
OIS	Organ Injury Scale
CT	Computed tomography
SI	Shock Index
IQR	Interquartile range
OR	Odds ratio
CI	Confidence interval
NOM	Non-operative management
NTDB	National Trauma Data Bank

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Authors' contributions

All authors contributed to the study conception and design. TS drafted and wrote the manuscript. YI substantively revised the manuscript. TS, YI, CY, and Tomohiro, M interpreted the data. Takashi, M supervised the study. All authors read and approved the final manuscript.

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Data availability

The data that support the findings of this study are available from the Japan Trauma Care and Research (JTCR) but restrictions apply to the availability of these data, which were used under license for the current study and so are not publicly available.

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of Jichi Medical University. The need to obtain informed consent was waived because all analyses used anonymized data (approval no. RINDAI 21–079).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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