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ORIGINAL RESEARCH

Crush syndrome outcomes after earthquake

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Abstract

Background: Earthquakes are catastrophic natural disasters that result in complex and severe medical conditions such as the crush syndrome. This study aimed to investigate the association between trauma scores, laboratory findings, mortality, and the development of crush syndrome in patients affected by the Kahramanmaraş Pazarcık earthquake. **Methods**: A retrospective analysis was conducted on trauma cases from the Kahramanmaraş Pazarcık earthquake, which occurred on 06 February 2023, and were treated at the Dicle University Hospital emergency department. Receiver operating characteristic (ROC) curve analysis and logistic regression were used to assess predictors of mortality and crush syndrome. **Results**: Of the 118 patients included, 110 survived and 8 died. The injury severity score (ISS) was the most accurate predictor of mortality (area under the curve (AUC): 0.935; sensitivity: 87.5%; specificity: 90%; positive predictive value (PPV): 38.89%; negative predictive value (NPV): 99%). Potassium level was the most predictive laboratory parameter (AUC: 0.894; sensitivity: 87.5%; specificity: 83.64%; PPV: 28%; NPV: 98.92%). However, multivariate analysis did not identify these variables as independent risk factors for mortality. Crush syndrome developed in 70 patients (59.3%), ISS was identified as the best trauma score for predicting crush syndrome (AUC: 0.822; sensitivity: 87.14%; specificity: 64.58%; PPV: 78.21%; NPV: 77.50%), and among laboratory markers, aspartate aminotransferase (AST) demonstrated the highest predictive ability (AUC: 0.850; sensitivity: 88.57%; specificity: 68.75%; PPV: 80.52%; NPV: 80.49%). Multivariate analysis revealed that C-reactive protein (CRP) (odds ratio (OR): 1.018; 95% confidence interval (CI): 1.005–1.030; p = 0.006), lactate dehydrogenase (LDH) (OR: 0.997; 95% CI: 0.994–1.000; p = 0.030), and ISS (OR: 1.105; 95% CI: 1.019–1.197; p = 0.015) were independent predictors of crush syndrome. **Conclusions**: In conclusion, CRP, LDH, and ISS were identified as independent risk factors for crush syndrome among earthquake victims. In contrast, neither trauma scores nor laboratory parameters independently predicted mortality.

Keywords

Earthquake; Crush syndrome; Mortality; Trauma scores; Injury severity score; C-reactive protein

1. Introduction

Earthquakes are among the deadliest natural disasters worldwide, frequently resulting in substantial loss of life. To date, fatal earthquakes have been documented in 117 countries, with 52 of these experiencing at least one event leading to more than 1000 deaths [1]. Türkiye, located in a seismically active region, has endured more than 100 fatal earthquakes between 1927 and 2022, resulting in approximately 100,000 deaths [1].

On 06 February 2023, two devastating earthquakes struck the southeastern Anatolia region of Türkiye. The first, with a magnitude of Mw 7.7 and a focal depth of 8.6 km, occurred at 04:17 local time with its epicenter in Pazarcık (Kahramanmaraş). The second, registering Mw 7.6 at a focal depth of 7 km, followed later that day at 13:24 with its epicenter in Elbistan (Kahramanmaraş). Subsequently, a triggered earthquake of Mw 6.4 occurred on 20 February 2023, centered in Yayladağı (Hatay). Collectively, these earthquakes caused extensive destruction across 11 provinces, resulting in 50,783 deaths and 115,353 injuries [2], and injured individuals rescued from the rubble received immediate first aid from emergency teams before being transferred to hospitals in less affected provinces, such as Diyarbakır, for further management and treatment.

Crush syndrome is the second leading cause of earthquake-related mortality. The underlying pathophysiology involves ischemia-reperfusion injury, characterized by cellular influx of sodium and water, and efflux of metabolites and toxins such as myoglobin and potassium [3]. Earthquake-related trauma often presents with unique injury patterns and may lead to complications, including hemorrhagic shock, crush syndrome, compartment syndrome, and other serious conditions [3, 4]. Systemic complications such as acute kidney injury (AKI), rhabdomyolysis, sepsis, multiple organ failure (MOF), disseminated intravascular coagulation (DIC), venous thromboembolic events (VTE), acute respiratory distress syndrome (ARDS), and electrolyte imbalances are commonly observed in crush syndrome [5].

Although direct trauma remains the most common cause of death following earthquakes [3], musculoskeletal injuries are widespread, with approximately 70% involving the lower extremities [6]. To evaluate trauma severity, several scoring systems are utilized. The Revised Trauma Score (RTS) is a physiological index incorporating respiratory rate, pulse, and Glasgow Coma Scale (GCS) scores. The Injury Severity Score (ISS) is an anatomical scoring system that assesses injuries based on their distribution across body regions. Furthermore, the Trauma and Injury Severity Score (TRISS) integrates age, ISS, and RTS components to provide a comprehensive assessment of injury severity [7]. While the distribution of trauma scores according to age, treatment modalities, and injury sites in earthquake-related injuries has been previously examined, limited research has investigated their association with mortality [8–11].

We designed this study to assess complications arising in earthquake-injured patients and determine the prognostic value of trauma scores and laboratory findings in predicting mortality and the development of crush syndrome.

2. Materials and methods

2.1 Study design and setting

Dicle University Hospital is located in the southeastern Anatolia region of Türkiye, in Diyarbakır province. The hospital has a total bed capacity of 1226, including 364 intensive care unit (ICU) beds. Diyarbakır was among the 11 provinces affected by the earthquake. During the disaster, the hospital provided medical services to patients from both within its province and from neighboring earthquake-affected regions. The study was conducted following the principles of the Declaration of Helsinki. Ethical approval was obtained from the local ethics committee before the start of the study.

2.2 Diagnostic criteria and definitions

Diagnostic criteria for clinical conditions were defined as follows:

AKI was diagnosed based on the Kidney Disease: Improving Global Outcomes (KDIGO) criteria. AKI was defined as an increase in serum creatinine of more than 0.3 mg/dL within 48 hours, a rise to more than 1.5 times the baseline value within seven days, or a urine output of less than 0.5 mL/kg/h for six hours [12].

Crush syndrome was defined as a serum creatinine phosphokinase (CPK) level of $\geq$1000 IU/L accompanied by systemic complications such as AKI, ARDS, electrolyte disturbances, DIC, hypovolemic shock, arrhythmias, venous thromboembolism (VTE), hemorrhage, or sepsis, resulting from crush injury [5, 13].

Compartment syndrome was diagnosed when intramuscular pressure exceeded 30 mmHg and compatible clinical findings were present [14].

MOF was defined as progressive dysfunction in two or more organ systems that was potentially reversible with treatment [15].

Sepsis was defined as life-threatening organ dysfunction caused by a dysregulated host response to infection, identified clinically by a Sequential Organ Failure Assessment (SOFA) score of $\geq$2 [16].

2.3 Patient selection and inclusion criteria

This retrospective study included trauma patients affected by the Kahramanmaraş Pazarcık earthquake on 06 February 2023, who presented to the emergency department of Dicle University Hospital. Patients were included consecutively. A total of 192 earthquake-related trauma cases were initially identified. Exclusion criteria included incomplete data (38 cases), death upon admission (7 cases), leaving the clinic without permission (13 cases), referral to an external center (1 case), and injuries from falls at ground level (15 cases). After applying these criteria, 118 patients were included in the analysis. The causes of trauma in these patients included entrapment under debris, traffic accidents, and falls from a height of 3 meters or more (Fig. 1).

2.4 Emergency department management and initial treatment protocol

Most patients arrived at the emergency department via ambulance, while a smaller proportion presented using private vehicles. Upon arrival, all patients were assessed and treated according to Advanced Trauma Life Support (ATLS) protocols [17]. Electrocardiography, arterial blood gas analysis, and serum electrolyte evaluations were performed immediately. Intravenous (IV) access was established, and urinary catheterization was carried out. Fluid resuscitation was initiated with isotonic saline at a rate of 1 L/h.

Tetanus prophylaxis was administered to all patients, and IV antibiotic prophylaxis was provided for those with open or contaminated wounds. Specialist consultations were obtained as required. Hemodialysis catheters were inserted in patients with uremia, severe hyperkalemia, or severe metabolic acidosis, and hemodialysis was initiated accordingly. Blood transfusions were provided to patients in hemorrhagic shock, while those requiring amputation, surgical management of compartment syndrome, or other urgent surgical interventions were transferred to the emergency operating room. The remaining patients were managed in the ICU with continued fluid replacement to maintain a urine output of at least 1 mL/kg/h.

2.5 Data collection and recorded variables

The following variables were recorded for each trauma case: date and location of presentation, sex, age, vital signs (temperature, heart rate, respiratory rate, and blood pressure), and affected body regions. Trauma severity was assessed using

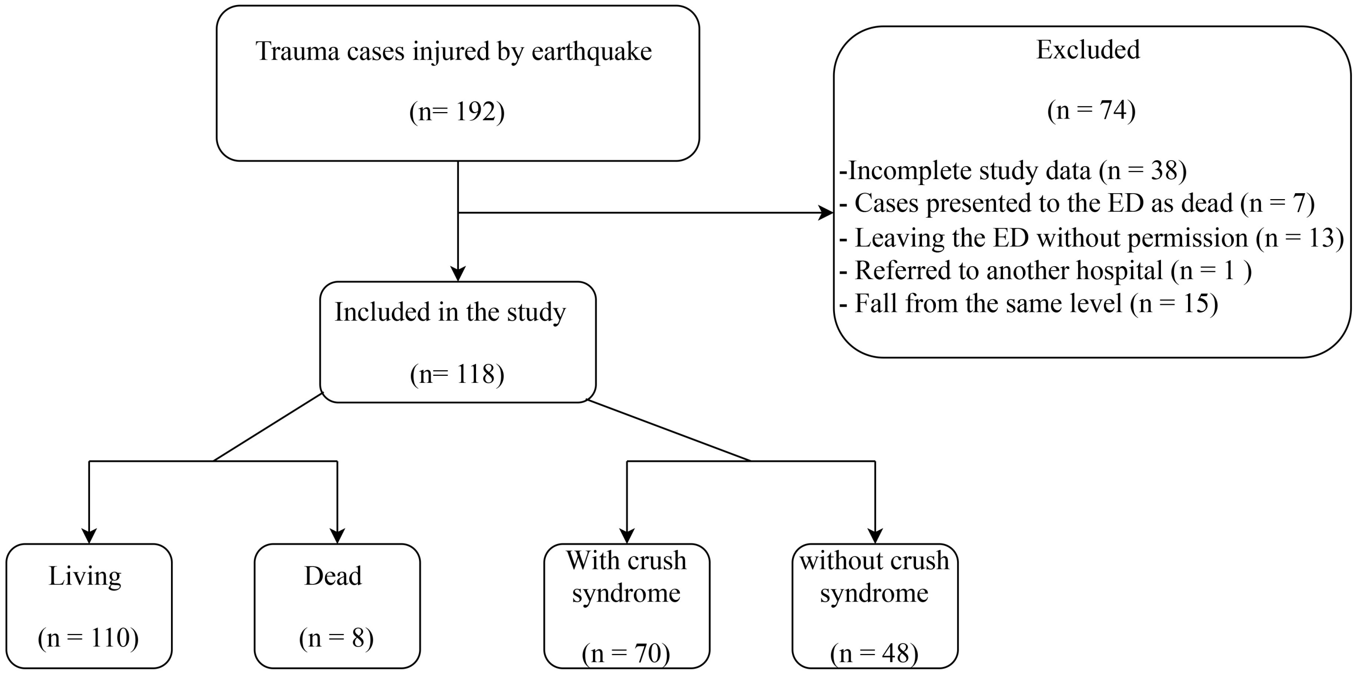

FIGURE 1. Flow chart of the study. ED: Emergency department.

the GCS, RTS, ISS, and TRISS. Surgical interventions, including fasciotomy and amputation, were documented, as were complications such as hemorrhagic shock, crush syndrome, compartment syndrome, AKI, rhabdomyolysis, sepsis, ICU admission, and MOF. Additionally, the length of hospital stay, and survival outcomes (survival or death) were recorded. Laboratory parameters analyzed included whole blood and biochemical markers: urea, creatinine, alanine aminotransferase (ALT), aspartate aminotransferase (AST), lactate dehydrogenase (LDH), creatine kinase (CK), albumin, sodium, potassium, total calcium, C-reactive protein (CRP), pH, lactate, base deficit, hemoglobin, white blood cell (WBC) count, and platelet count.

2.6 Study outcomes

The primary objective of this study was to evaluate the predictive ability of trauma scores and biochemical markers for mortality in trauma patients. The secondary objective was to determine the predictive value of these variables for the development of crush syndrome.

2.7 Statistical analysis

Continuous variables were analyzed for normality. If normally distributed, they were presented as mean ± standard deviation (SD) and compared using Student's *t*-test. Non-normally distributed continuous variables were expressed as median and interquartile range (IQR, Q1–Q3) and compared using the Mann-Whitney U-test. Categorical variables were reported as frequencies and percentages, and comparisons were performed using the chi-square (χ^2) test. The diagnostic performance of trauma scores and laboratory markers in predicting mortality and crush syndrome was assessed using receiver operating characteristic (ROC) curve analysis and logistic regression analysis. The discriminative ability of each parameter was expressed as the area under the curve (AUC). The optimal cut-off value, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and odds ratio (OR) were calculated. A p-value of < 0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 21.0 (Armonk, NY, USA).

3. Results

3.1 Patient demographics and baseline characteristics

The mean age of the patients was 35.73 ± 18.28 years, and 66 (55.9%) were female. The basic demographic features of the study population are summarized in Table 1.

3.2 Association of clinical and laboratory parameters with mortality

Of the 118 patients analyzed, 110 survived and 8 died. Significant differences were observed between survivors and non-survivors with respect to trauma scores and several clinical and laboratory parameters. Specifically, AKI, rhabdomyolysis, sepsis, multiple organ failure (MOF), ICU admission, as well as levels of AST, LDH, potassium, and pH, were significantly associated with mortality ($p < 0.001$). Detailed comparisons of the clinics are given in Table 2.

3.3 Association of clinical and laboratory parameters with complications

Complications developed in 38 patients (32.2%), and a statistically significant difference was observed in GCS scores between patients with and without complications; however, this is thought to be due to small differences in minimum and maximum values. However, ISS and TRISS, along with

TABLE 1. Demographic characters.

Variables	N = 118 (%)
Age, yr, mean ± SD	35.73 ± 18.28
Sex, female	66 (55.90)
Distribution of patients by city	
City in the hospital	39 (33.10)
Surrounding cities	79 (66.90)
Time to hospital admission after an earthquake	
First day	28 (23.70)
Second day	22 (18.60)
Third day	15 (12.70)
Fourth day	14 (11.90)
Fifth day	11 (9.30)
Sixth day	10 (8.50)
Other days	18 (15.30)
Trauma causes	
Fall from a height	5 (4.20)
Traffic accident	3 (2.50)
Stay under the debris	113 (95.80)
Injured body region	
Head	91 (77.10)
Chest	95 (80.50)
Abdominal	92 (78.00)
Pelvic	91 (77.10)
Limb	114 (96.60)
Complications	
Hemorrhagic shock	2 (1.70)
Crush syndrome	70 (59.30)
Compartment syndrome	15 (12.70)
Acute kidney injury	26 (22.00)
Rhabdomyolysis	12 (10.20)
Sepsis	10 (8.50)
Multiple organ failure	8 (6.80)
Admission to intensive care	26 (22.00)
Surgical interventions	
Fasciotomy	14 (11.90)
Amputation	12 (10.20)

SD: standard deviation.

laboratory parameters including ALT, AST, LDH, CK, CRP, albumin, and total calcium, differed significantly between patients with and without complications ($p < 0.001$) (Table 3).

3.4 Clinical and laboratory predictors of crush syndrome

Crush syndrome was diagnosed in 70 patients (59.3%), and a statistically significant difference was observed in GCS scores between patients with and without crush syndrome; however, this is thought to be due to small differences in minimum and maximum values. In contrast, ISS, TRISS, and laboratory markers, including ALT, AST, LDH, CK and CRP, were significantly elevated in patients with crush syndrome ($p < 0.001$). A comparative analysis of median (Q1–Q3) values in patients with and without crush syndrome revealed the following: GCS, 15 (15–15) *vs.* 15 (15–15); ISS, 11 (5.25–21.75) *vs.* 26 (19–43.50); TRISS, 99.05 (97.40–99.57) *vs.* 97.20 (84.70–98.70); ALT, 27.45 (20.37–44.70) *vs.* 80.00 (37.22–209.90); AST, 36.45 (20.82–57.40) *vs.* 197.35 (59.52–443.00); LDH,

TABLE 2. Distribution of clinical and laboratory values by mortality.

Variables	Survival (n = 110)	Mortality (n = 8)	*p*-value
Age, (yr)	35.83 ± 18.68	34.50 ± 12.30	0.844
Age ≥65, (yr)	8.00 (7.30)	0.00 (0.00)	
Sex, female	63.00 (57.30)	3.00 (37.50)	0.299
Time to hospital admission after an earthquake, (d)	3.00 (2.00–4.75)	3.00 (2.00–5.00)	0.630
Vital signs			
Body temperature (°C)	36.45 (36.20–36.70)	36.50 (35.50–36.70)	0.560
Heart rate, (beats/min)	89.50 (81–104.25)	110.00 (100.00–120.00)	0.013
Respiration rate, (per min)	14.00 (13.00–16.00)	15.00 (14.00–17.00)	0.225
SBP, (mmHg)	123.75 ± 15.77	110.63 ± 31.81	0.039
DBP, (mmHg)	75.47 ± 11.30	65.13 ± 16.36	0.017
Injured body region			
Head	83.00 (75.50)	8.00 (100.00)	0.195
Chest	87.00 (79.10)	8.00 (100.00)	0.352
Abdominal	84.00 (76.40)	8.00 (100.00)	0.197
Pelvic	83.00 (75.50)	8.00 (100.00)	0.195
Limb	106.00 (96.40)	8.00 (100.00)	1.000
Complications			
Hemorrhagic shock	1.00 (0.90)	1.00 (12.50)	0.132
Crush syndrome	62.00 (56.40)	8.00 (100.00)	0.020
Compartment syndrome	12.00 (10.90)	3.00 (37.50)	0.063
Acute kidney injury	19.00 (17.30)	7.00 (87.50)	<0.001
Rhabdomyolysis	6.00 (5.50)	6.00 (75.00)	<0.001
Sepsis	2.00 (1.80)	8.00 (100.00)	<0.001
Multiple organ failure	1.00 (0.90)	7.00 (87.50)	<0.001
Admission to ICU	19.00 (17.30)	7.00 (87.50)	<0.001
Surgical interventions			
Fasciotomy	11.00 (10.00)	3.00 (37.50)	0.053
Amputation	10.00 (9.10)	2.00 (25.00)	0.188
Trauma scores			
GCS	15.00 (15.00–15.00)	13.00 (6.00–15.00)	<0.001
RTS	7.84 (7.84–7.84)	7.84 (5.43–7.84)	<0.001
ISS	26.00 (17.25–34.00)	54.00 (48.00–66.00)	<0.001
TRISS	97.40 (88.60–98.70)	59.40 (36.30–84.70)	<0.001
Laboratory values			
Urea, (mg/dL)	31.50 (22.65–59.47)	89.40 (59.90–141.70)	0.002
Creatinine, (mg/dL)	0.68 (0.51–1.17)	3.46 (0.82–5.08)	0.003
ALT, (U/L)	53.20 (26.77–164.07)	334.10 (76.90–417.10)	0.026
AST, (U/L)	80.05 (33.92–397.10)	546.30 (381.20–1333.60)	0.001
LDH, (U/L)	549.95 (289.42–1010.92)	1727.90 (806.50–6801.80)	0.001
Creatine Kinase, (U/L)	2033.85 (410.20–15,325.75)	40,515.20 (1201.10–181,948.40)	0.158
Albumin, (g/L)	36.00 ± 6.32	31.11 ± 7.36	0.039
Sodium, (mmol/L)	135.45 (132.52–137.20)	129.70 (125.70–141.10)	0.419
Potassium, (mmol/L)	4.26 (3.81–4.87)	5.50 (5.07–6.35)	<0.001
Calcium total, (mg/dL)	8.78 (7.88–9.26)	7.51 (6.88–8.34)	0.003
CRP, (mg/dL)	59.10 (9.48–111.71)	137.61 (119.11–163.26)	0.024
pH	7.38 (7.33–7.41)	7.14 (7.10–7.25)	<0.001
Lactate, (mmol/L)	1.90 (1.32–4.37)	2.00 (1.10–11.30)	0.179
Base deficit, (mEq/L)	−2.00 ((−3.00)–0.00)	−2.00 ((−5.00)–(−1.00))	0.558
Haemoglobin, (g/dL)	12.80 ± 2.70	13.31 ± 4.88	0.628
White blood cell, (10^3/µL)	13.68 (9.28–18.38)	17.73 (6.57–34.08)	0.140
Platelets, (10^3/µL)	269.50 (195.75–335.50)	153.00 (58.00–276.00)	0.054

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; CRP: c-reactive protein; DBP: diastolic blood pressure; GCS: glasgow coma scale; ICU: intensive care unit; ISS: injury severity score; LDH: lactate dehydrogenase; RTS: revised trauma score; SBP: systolic blood pressure; TRISS: trauma score and injury severity score.

TABLE 3. Distribution of clinical and laboratory values by complications.

Variables	Without complications (n = 38)	With complications (n = 80)	*p*-value
Age, (yr)	38.26 ± 18.81	34.53 ± 18.03	0.303
Age ≥65, (yr)	4.00 (10.50)	4.00 (5.00)	0.269
Sex, female	19.00 (50.00)	47.00 (58.80)	0.486
Time to hospital admission after an earthquake, (d)	2.00 (1.00–8.00)	3.00 (2.00–4.00)	0.861
Vital signs			
Body temperature (°C)	36.40 (36.20–36.50)	36.50 (36.20–36.70)	0.373
Heart rate, (beats/min)	93.00 (89.00–105.00)	90.00 (81.00–109.75)	0.301
Respiration Rate, (per min)	14.00 (14.00–16.00)	14.00 (13.00–16.00)	0.433
SBP, (mmHg)	122.92 ± 14.74	122.84 ± 18.64	0.981
DBP, (mmHg)	73.58 ± 11.21	75.34 ± 12.25	0.456
Injured body region			
Head	23.00 (60.50)	68.00 (85.00)	0.006
Chest	23.00 (60.50)	72.00 (90.00)	<0.001
Abdominal	20.00 (52.60)	72.00 (90.00)	<0.001
Pelvic	20.00 (52.60)	71.00 (88.80)	<0.001
Limb	34.00 (89.50)	80.00 (100.00)	0.010
Trauma scores			
GCS	15.00 (15.00–15.00)	15.00 (15.00–15.00)	0.017
RTS	7.84 (7.84–7.84)	7.84 (7.84–7.84)	0.085
ISS	14.00 (9.00–19.00)	32.50 (26.00–49.50)	<0.001
TRISS	98.90 (97.40–99.40)	95.50 (84.70–97.60)	<0.001
Laboratory values			
Urea, (mg/dL)	28.50 (22.10–31.00)	45.95 (25.25–126.60)	0.003
Creatinine, (mg/dL)	0.64 (0.55–0.78)	0.81 (0.51–3.31)	0.239
ALT, (U/L)	27.00 (21.90–36.90)	121.00 (37.00–271.67)	<0.001
AST, (U/L)	23.90 (20.80–66.10)	282.45 (62.32–564.37)	<0.001
LDH, (U/L)	283.80 (193.20–350.00)	832.70 (417.00–1701.47)	<0.001
Creatine Kinase, (U/L)	186.80 (83.70–2104.00)	5448.00 (1268.55–40,339.30)	<0.001
Albumin, (g/L)	38.96 ± 4.66	34.10 ± 6.65	<0.001
Sodium, (mmol/L)	136.10 (134.40–136.90)	134.10 (130.52–138.25)	0.423
Potassium, (mmol/L)	4.12 (3.49–4.61)	4.33 (3.90–5.19)	0.095
Calcium total, (mg/dL)	9.22 (8.79–9.60)	8.37 (7.59–8.91)	<0.001
CRP, (mg/dL)	10.67 (2.53–33.38)	88.22 (25.89–135.84)	<0.001
pH	7.38 (7.33–7.39)	7.37 (7.28–7.42)	0.364
Lactate, (mmol/L)	1.80 (1.30–3.30)	1.95 (1.40–4.77)	0.435
Base deficit, (mEq/L)	0.00 (−2.00–(1.00))	−2.00 (−5.00–(−1.00))	0.001
Haemoglobin, (g/dL)	13.11 ± 2.27	12.70 ± 3.11	0.470
White blood cell, (10^3/µL)	11.96 (9.04–17.00)	14.19 (9.28–19.24)	0.038
Platelets, (10^3/µL)	309.00 (243.00–380.00)	261.00 (177.25–296.25)	0.098

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; CRP: c-reactive protein; DBP: diastolic blood pressure; GCS: glasgow coma scale; ICU: intensive care unit; ISS: injury severity score; LDH: lactate dehydrogenase; RTS: revised trauma score; SBP: systolic blood pressure; TRISS: trauma score and injury severity score.

283.40 (216.75–387.52) *vs.* 702.80 (415.15–1208.92); CK, 270.70 (121.05–1380.22) *vs.* 6372.00 (1249.00–19,019.12); and CRP, 10.82 (2.64–45.36) *vs.* 84.45 (38.05–136.29) (Table 4).

3.5 Predictive accuracy of trauma scores and laboratory markers for mortality

The predictive ability of laboratory and trauma scores for mortality was evaluated using ROC curve analysis. The AUC, 95% confidence intervals (CI), and p-values for each variable were as follows: albumin (AUC: 0.699, CI: 0.488–0.911, p = 0.060), ALT (AUC: 0.736, CI: 0.507–0.965, p = 0.026), AST (AUC: 0.838, CI: 0.721–0.955, p = 0.001), total calcium (AUC: 0.811, CI: 0.673–0.948, p = 0.003), CK (AUC: 0.650, CI: 0.404–0.896, p = 0.158), CRP (AUC: 0.740, CI: 0.561–0.918, p = 0.024), potassium (AUC: 0.894, CI: 0.809–0.979, $p < 0.001$), LDH (AUC: 0.864, CI: 0.777–0.950, p = 0.001), urea (AUC: 0.830, CI: 0.726–0.933, p = 0.002), GCS (AUC: 0.790, CI: 0.581–0.998, p = 0.006), ISS (AUC: 0.935, CI: 0.853–1.000, $p < 0.001$), RTS (AUC: 0.677, CI: 0.444–0.911, p = 0.095), and TRISS (AUC: 0.913, CI: 0.811–1.000, $p < 0.001$) (Table 5, Fig. 2).

Despite these findings, multivariate logistic regression analysis did not identify any of the studied variables as independent predictors of mortality (Table 6).

3.6 Predictive accuracy of trauma scores and laboratory markers for crush syndrome

The ability of laboratory markers and trauma scores to predict crush syndrome was assessed using ROC curve analysis. The AUC, 95% CI, and p-values for each parameter were as follows: albumin (AUC: 0.648, CI: 0.548–0.748, p = 0.007), ALT (AUC: 0.792, CI: 0.711–0.872, $p < 0.001$), AST (AUC: 0.850, CI: 0.779–0.921, $p < 0.001$), total calcium (AUC: 0.639, CI: 0.540–0.738, p = 0.011), CK (AUC: 0.835, CI: 0.759–0.911, $p < 0.001$), CRP (AUC: 0.812, CI: 0.735–0.889, $p < 0.001$), LDH (AUC: 0.822, CI: 0.744–0.901, $p < 0.001$), urea (AUC: 0.667, CI: 0.570–0.763, p = 0.002), WBC (AUC: 0.618, CI: 0.515–0.722, p = 0.029), GCS (AUC: 0.561, CI: 0.457–0.664, p = 0.265), ISS (AUC: 0.822, CI: 0.744–0.900, $p < 0.001$), and TRISS (AUC: 0.773, CI: 0.687–0.860, $p < 0.001$) (Table 7, Fig. 3).

Multivariate logistic regression analysis demonstrated that CRP (OR: 1.018, 95% CI: 1.005–1.030, p = 0.006), LDH (OR: 0.997, 95% CI: 0.994–1.000, p = 0.030), and ISS (OR: 1.105, 95% CI: 1.019–1.197, p = 0.015) were independent predictors of crush syndrome (Table 8).

4. Discussion

Earthquakes are catastrophic natural disasters that often lead to severe injuries and complications, including crush syndrome, which plays a pivotal role in determining clinical outcomes and prognosis [1–3]. In light of these, our present study investigated the predictive value of trauma scores and laboratory findings for mortality and crush syndrome among patients affected by the Kahramanmaraş Pazarcık earthquake. For assessing mortality, the ISS and TRISS demonstrated the highest sensitivity among trauma scores, while potassium, LDH, and AST were the most sensitive laboratory markers. However, despite their strong predictive performance, multivariate analysis did not identify these variables as independent risk factors for mortality. In contrast, both ISS and TRISS were also the most sensitive trauma scores for predicting crush syndrome, while AST, CK, and LDH emerged as the most sensitive laboratory markers. Notably, multivariate analysis identified CRP, LDH, and ISS as independent risk factors associated with the development of crush syndrome.

Earthquake-related injuries frequently involve multiple organ systems, contributing to considerable morbidity and mortality [18], with extremity injuries being among the most common, followed by head trauma [18, 19]. In the study by Bicakcioglu *et al.* [20], only two cases involved injuries resulting from falls during an earthquake. Consistent with existing literature, extremity trauma was the most commonly observed injury type in the present study. Moreover, most injuries occurred due to entrapment beneath rubbles. Some patients involved in traffic accidents or falls from heights were also subsequently trapped. Notably, patients injured by falls or traffic accidents typically presented to the emergency department in the early hours following the earthquake.

Previous studies have compared ISS and TRISS in predicting mortality among trauma patients, although findings on their relative superiority have varied. Generally, however, TRISS has been reported to outperform ISS [21]. For instance, Sammour *et al.* [22] reported AUC values of 0.8547 and 0.963 for ISS and TRISS, respectively, in mortality prediction. Earthquake-related trauma has historically resulted in high mortality. In a study involving 1028 earthquake-related trauma patients, the mortality rate was 0.5%, with 38 patients (3.7%) exhibiting ISS scores above 25 [19]. Additionally, a previous investigation comparing ISS, TRISS, and New Injury Severity Score (NISS) in relation to hospitalization duration in earthquake trauma patients demonstrated that only NISS was associated with hospital stay. Mortality was not analyzed due to the low number of deaths (n = 2) [9]. In another study, Gao *et al.* [10] reported a mean ISS of 32.1 among patients who died following earthquake-related injuries. Similarly, research evaluating the prognostic value of RTS, ISS, and TRISS scores in mortality prediction found all three to be significant. Among the deceased, the median (IQR) values were RTS 7.84 (4–7.84), ISS 25 (17–33), and TRISS 86 (50–97) [11]. In agreement with previous findings, the present study identified ISS and TRISS as the most sensitive trauma scores for predicting mortality among earthquake-injured patients. However, unlike crush syndrome, none of these trauma scores or laboratory markers were independent predictors of mortality in multivariate analysis.

Complications such as crush injury, crush syndrome, compartment syndrome, hemorrhagic shock, AKI, and MOF frequently develop following earthquakes [3, 5, 18]. Additionally, interventions, including fasciotomy and amputation, are more commonly required in earthquake-related trauma [18, 23]. Early mortality is predominantly attributable to hypovolemia and hyperkalemia, whereas late mortality typically results from sepsis and MOF [18]. In the present study, complication rates were notably higher among patients who

TABLE 4. Distribution of clinical and laboratory values by crush syndrome.

Variables	Without crush syndrome (n = 48)	With crush syndrome (n = 70)	*p*-value
Age, (yr)	37.64 ± 18.59	34.42 ± 18.10	0.350
Age ≥65, (yr)	5.00 (10.40)	3.00 (4.30)	0.268
Sex, female	24.00 (50.00)	42.00 (60.00)	0.376
Time to hospital admission after an earthquake, (d)	2.00 (1.00–7.75)	3.00 (2.00–5.00)	0.348
Vital signs			
Body temperature (°C)	36.50 (36.20–36.70)	36.50 (36.20–36.70)	0.349
Heart rate, (beats/min)	89.00 (78.00–98.75)	89.50 (81.00–104.25)	0.514
Respiration Rate, (per min)	15.00 (13.25–16.00)	14.00 (13.00–15.00)	0.201
SBP, (mmHg)	124.94 ± 13.90	121.44 ± 19.43	0.286
DBP, (mmHg)	75.10 ± 11.69	74.54 ± 12.13	0.803
İnjured body region			
Head	29.00 (60.40)	62.00 (88.60)	0.001
Chest	30.00 (62.50)	65.00 (92.90)	<0.001
Abdominal	28.00 (58.30)	64.00 (91.40)	<0.001
Pelvic	27.00 (56.30)	64.00 (91.40)	<0.001
Limb	44.00 (91.70)	70.00 (100.00)	0.025
Complications			
Hemorrhagic shock	0.00 (0.00)	2.00 (2.90)	
Compartment syndrome	1.00 (2.10)	14.00 (20.00)	0.010
Acute kidney injury	2.00 (4.20)	24.00 (34.30)	<0.001
Rhabdomyolysis	0.00 (0.00)	12.00 (17.10)	
Sepsis	0.00 (0.00)	10.00 (14.30)	
Multiple organ failure	0.00 (0.00)	8.00 (11.40)	
Admission to ICU	8.00 (16.70)	18.00 (25.70)	0.348
Surgical interventions			
Fasciotomy	1.00 (2.10)	13.00 (18.60)	0.015
Amputation	2.00 (4.20)	10.00 (14.30)	0.119
Trauma scores			
GCS	15.00 (15.00–15.00)	15.00 (15.00–15.00)	0.027
RTS	7.84 (7.84–7.84)	7.84 (7.84–7.84)	0.211
ISS	11.00 (5.25–21.75)	26.00 (19.00–43.50)	<0.001
TRISS	99.05 (97.40–99.57)	97.20 (84.70–98.70)	<0.001
Laboratory values			
Urea, (mg/dL)	28.30 (18.97–35.37)	35.35 (23.25–83.70)	0.002
Creatinine, (mg/dL)	0.64 (0.53–0.78)	0.78 (0.49–1.43)	0.054
ALT, (U/L)	27.45 (20.37–44.70)	80.00 (37.22–209.90)	<0.001
AST, (U/L)	36.45 (20.82–57.40)	197.35 (59.52–443.00)	<0.001
LDH, (U/L)	283.40 (216.75–387.52)	702.80 (415.15–1208.92)	<0.001
Creatine Kinase, (U/L)	270.70 (121.05–1380.22)	6372.00 (1249.00–19,019.12)	<0.001
Albumin, (g/L)	37.43 ± 6.30	34.46 ± 6.36	0.014
Sodium, (mmol/L)	135.50 (133.22–136.55)	134.30 (131.17–137.87)	0.387
Potassium, (mmol/L)	4.06 (3.64–4.52)	4.24 (3.82–4.95)	0.050
Calcium total, (mg/dL)	9.02 (8.59–9.38)	8.71 (7.68–9.22)	0.011
CRP, (mg/dL)	10.82 (2.64–45.36)	84.45 (38.05–136.29)	<0.001
pH	7.38 (7.34–7.41)	7.40 (7.34–7.43)	0.104
Lactate, (mmol/L)	1.75 (1.30–3.17)	1.70 (1.37–3.32)	0.941
Base deficit, (mEq/L)	−1.00 (−2.00–0.00)	−2.00 (−5.00–(−1.00))	0.016
Haemoglobin, (g/dL)	12.80 ± 2.61	12.85 ± 3.05	0.924
White blood cell, (10^3/µL)	10.93 (8.14–15.30)	13.96 (9.31–18.51)	0.029
Platelets, (10^3/µL)	256.50 (220.50–336.00)	261.00 (190.50–305.00)	0.475

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; CRP: c-reactive protein; DBP: diastolic blood pressure; GCS: glasgow coma scale; ICU: intensive care unit; ISS: injury severity score; LDH: lactate dehydrogenase; RTS: revised trauma score; SBP: systolic blood pressure; TRISS: trauma score and injury severity score.

TABLE 5. Efficacy of laboratory and trauma scores in determining mortality with ROC analysis.

Predictor	Optimal Cut Point	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC
Albumin	31.80	75.00	74.55	17.65	97.62	0.699
ALT	259.60	62.50	90.00	31.25	97.06	0.736
AST	192.50	87.50	70.91	17.95	98.73	0.838
Ca	8.37	87.50	70.00	17.50	98.72	0.811
CK	40,515.20	50.00	91.82	30.77	96.19	0.650
CRP	119.11	75.00	79.09	20.69	97.75	0.740
K	4.81	87.50	83.64	28.00	98.92	0.894
LDH	646.40	100.00	68.18	18.60	100.00	0.864
Urea	59.90	75.00	82.73	24.00	97.85	0.830
GCS	5.00	62.50	94.55	45.45	97.20	0.790
ISS	48.00	87.50	90.00	38.89	99.00	0.935
RTS	5.97	37.50	99.09	75.00	95.61	0.677
TRISS	84.70	87.50	86.36	31.82	98.96	0.913

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; AUC: area under the curve; Ca: calcium total; CK: creatine kinase; CRP: c-reactive protein; GCS: glasgow coma scale; ISS: injury severity score; K: potassium; LDH: lactate dehydrogenase; NPV: negative predictive value; PPV: positive predictive value; RTS: revised trauma score; TRISS: trauma score and injury severity score.

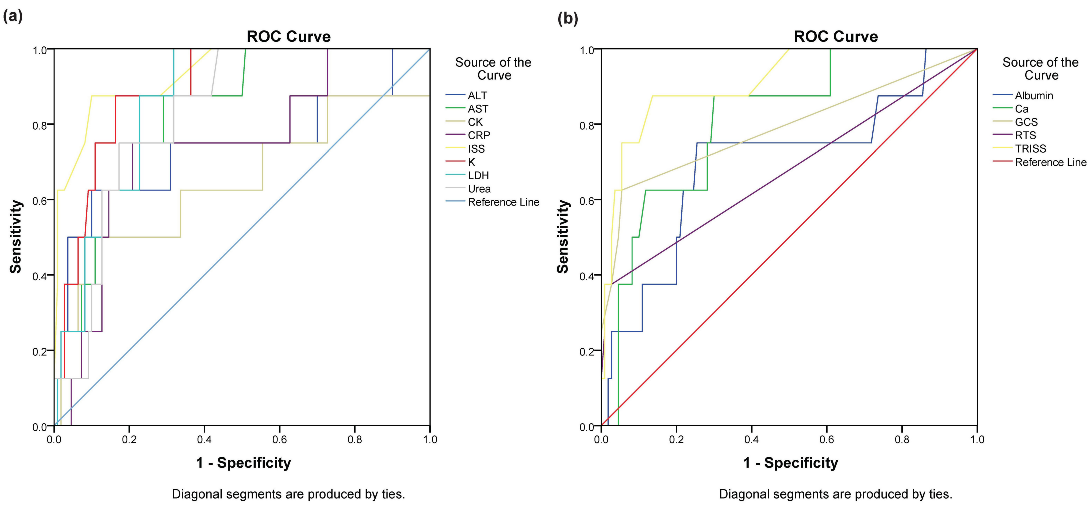

FIGURE 2. ROC curve of laboratory and trauma scores by mortality. (a) ROC curve of ALT, AST, CK, CRP, ISS, K, LDH, Urea. (b) ROC curve of Albumin, Ca, GCS, RTS, and TRISS. ROC: receiver operating characteristic; ALT: alanine aminotransferase; AST: aspartate aminotransferase; CK: creatine kinase; CRP: c-reactive protein; ISS: injury severity score; K: potassium; LDH: lactate dehydrogenase; Ca: calcium total; GCS: glasgow coma scale; RTS: revised trauma score; TRISS: trauma score and injury severity score.

TABLE 6. Logistic regression analysis for mortality.

Variables	Univariate		Multivariate	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
Albumin	1.105 (1.000–1.221)	0.049		
ALT	0.995 (0.992–0.998)	0.003		
AST	0.998 (0.997–0.999)	0.003		
Ca	1.821 (1.065–3.115)	0.029		
CK	1.000 (1.000–1.000)	0.014		

TABLE 6. Continued.

Variables	Univariate		Multivariate	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
CRP	0.990 (0.980–1.000)	0.041		
K	0.318 (0.158–0.640)	0.001		
LDH	1.000 (0.999–1.000)	0.006		
Urea	0.992 (0.986–0.998)	0.015		
GCS	2.627 (1.316–5.245)	0.006		
ISS	0.871 (0.806–0.941)	<0.001		
RTS	5.342 (1.953–14.614)	0.001		
TRISS	1.078 (1.039–1.118)	<0.001		

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; Ca: calcium total; CK: creatine kinase; CI: confidence interval; CRP: c-reactive protein; GCS: glasgow coma scale; ISS: injury severity score; K: potassium; LDH: lactate dehydrogenase; RTS: revised trauma score; TRISS: trauma score and injury severity score.

TABLE 7. Efficacy of laboratory and trauma scores in determining crush syndrome with ROC analysis.

Predictor	Optimal Cut Point	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC
Albumin	31.90	40.00	85.42	80.00	49.40	0.648
ALT	76.90	54.29	95.83	95.00	58.97	0.792
AST	48.70	88.57	68.75	80.52	80.49	0.850
Ca	8.98	71.43	54.17	69.44	56.52	0.639
CK	395.60	97.14	60.42	78.16	93.55	0.835
CRP	70.96	65.71	87.50	88.46	63.64	0.812
LDH	411.40	77.14	77.08	83.08	69.81	0.822
Urea	45.90	45.71	89.58	86.49	53.09	0.667
WBC	12.01	62.86	62.50	70.97	53.57	0.618
GCS	5.00	14.29	97.92	90.91	43.93	0.561
ISS	18.00	87.14	64.58	78.21	77.50	0.822
TRISS	98.80	88.57	54.17	73.81	76.47	0.773

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; AUC: area under the curve; Ca: calcium total; CK: creatine kinase; CRP: c-reactive protein; GCS: glasgow coma scale; ISS: injury severity score; LDH: lactate dehydrogenase; NPV: negative predictive value; PPV: positive predictive value; TRISS: trauma score and injury severity score; WBC: white blood cell.

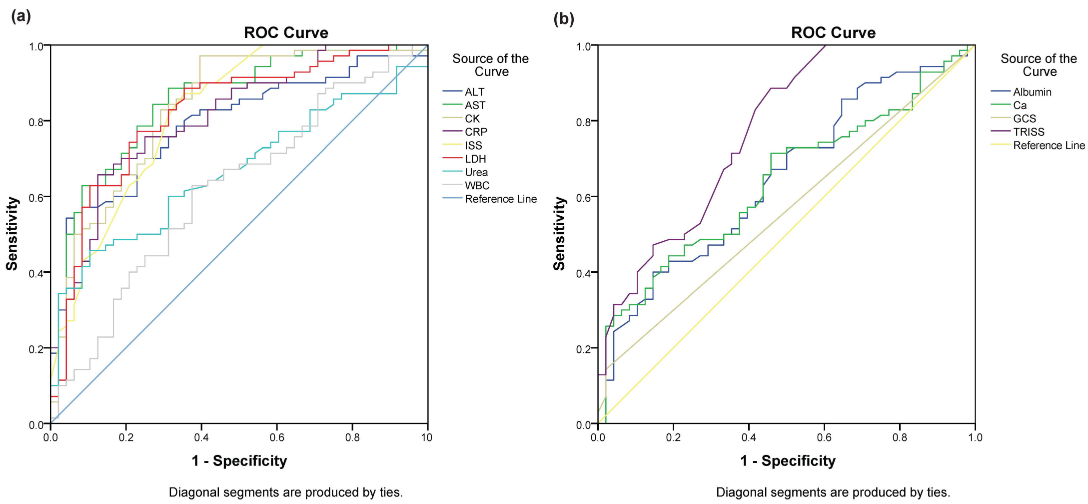

FIGURE 3. ROC curve of laboratory and trauma scores by crush syndrome. (a) ROC curve of ALT, AST, CK, CRP, ISS, K, LDH, Urea, WBC. (b) ROC curve of Albumin, Ca, GCS, TRISS. ROC: receiver operating characteristic; ALT: alanine aminotransferase; AST: aspartate aminotransferase; CK: creatine kinase; CRP: c-reactive protein; ISS: injury severity score; LDH: lactate dehydrogenase; WBC: white blood cell; Ca: calcium total; GCS: glasgow coma scale; TRISS: trauma score and injury severity score.

TABLE 8. Logistic regression analysis for crush syndrome.

Variables	Univariate		Multivariate	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
Albumin	0.924 (0.867–0.986)	0.016		
ALT	1.017 (1.008–1.027)	0.001		
AST	1.007 (1.003–1.011)	<0.001		
Ca	0.639 (0.416–0.982)	0.041		
CK	1.000 (1.000–1.000)	0.010		
CRP	1.023 (1.014–1.033)	<0.001	1.018 (1.005–1.030)	0.006
LDH	1.002 (1.001–1.003)	0.001	0.997 (0.994–1.000)	0.030
Urea	1.019 (1.005–1.034)	0.009		
WBC	1.046 (0.993–1.102)	0.088		
GCS	0.538 (0.239–1.215)	0.136		
ISS	1.108 (1.062–1.156)	<0.001	1.105 (1.019–1.197)	0.015
TRISS	0.908 (0.847–0.974)	0.007		

Abbreviations: ALT: alanine aminotransferase; AST: aspartate aminotransferase; Ca: calcium total; CK: creatine kinase; CI: confidence interval; CRP: c-reactive protein; GCS: glasgow coma scale; ISS: injury severity score; LDH: lactate dehydrogenase; TRISS: trauma score and injury severity score; WBC: white blood cell.

died. Late deaths were primarily caused by sepsis and MOF, while one early death was due to hemorrhagic shock.

Crush injury leads to cellular destruction and myonecrosis [5]. During revascularization, calcium, sodium, and water enter necrotic muscle tissue, whereas potassium, phosphorus, lactic acid, myoglobin, and intracellular enzymes such as CK, ALT, AST and LDH are released into the bloodstream [5, 18, 24]. Previous studies have explored the relationship between serum enzyme and electrolyte levels and mortality in earthquake-related injuries [25, 26]. Consistent with the literature, the present study demonstrated that potassium, LDH, and AST were the most sensitive laboratory markers associated with mortality. These findings suggest that elevated potassium, LDH, and AST levels during initial emergency department evaluation may serve as important indicators for early ICU admission, even in patients not requiring immediate surgical intervention.

Crush syndrome occurs in approximately 2–15% of patients following major earthquakes [27]. This syndrome is characterized by systemic complications, including AKI, rhabdomyolysis, sepsis, MOF, DIC, VTE, ARDS, and electrolyte imbalances [5]. In the present cohort, patients with crush syndrome demonstrated a higher incidence of complications, consistent with prior observations.

Extremity trauma is the most frequent injury pattern among patients with crush syndrome resulting from earthquake-related injuries [26]. Furthermore, in patients with multiple trauma, an ISS score of ≥25 has been associated with the development of AKI [28]. In this study, extremity injuries were most prevalent, and ISS was the most significant trauma score in predicting crush syndrome. Given that ISS is an anatomical scoring system, it may better reflect the extent of muscle damage, which likely explains its superior performance in predicting crush syndrome compared to other trauma scores.

Previous research has assessed the diagnostic utility of serum enzymes and electrolytes in predicting AKI, crush syndrome, fasciotomy, and amputation [13, 23, 29, 30]. Hu *et al.* [29] identified CK as the most effective predictor of AKI, while Omrani *et al.* [30] found CK, LDH, AST, and uric acid to be the most relevant biomarkers. Similarly, Feng *et al.* [26] reported that CK had the highest diagnostic value for crush injury and crush syndrome (AUC: 0.994; sensitivity: 99.4%; specificity: 100%). Consistent with these findings, the present study identified AST, CK, and LDH as the most sensitive laboratory markers for predicting crush syndrome.

This study has several limitations. First, it was conducted at a single center with a relatively small sample size, which may limit the generalizability of the findings, particularly to hospitals with different triage or trauma care protocols. Future multicenter investigations are necessary to validate and extend these results. Second, the retrospective design may introduce inherent biases. However, conducting prospective studies during natural disasters such as earthquakes poses considerable logistical and ethical challenges. Finally, long-term outcomes, including functional status and psychological sequelae, were not assessed in this study.

5. Conclusions

This cross-sectional study provides a comparative evaluation of trauma scores and laboratory markers in predicting mortality and crush syndrome among patients with earthquake-related injuries. The findings underscore the clinical relevance of these parameters in determining prognosis and guiding management decisions in such settings. Among the trauma scores, ISS and TRISS demonstrated superior performance in predicting both mortality and crush syndrome. Similarly, among serum biomarkers, AST, CK, and LDH were the most sensitive indicators. Furthermore, multivariate analysis identified CRP, LDH, and ISS as independent risk factors for crush syndrome. These results highlight the potential utility of trauma scores and laboratory markers as early triage tools to facilitate timely risk stratification in earthquake-induced trauma. In addition, the findings may provide a foundation for the development of advanced predictive models, including machine learning algorithms, to support real-time prognostic assessment and optimize clinical decision-making in disaster scenarios.

AVAILABILITY OF DATA AND MATERIALS

The data generated and analysed during the study can be obtained from the corresponding author.

AUTHOR CONTRIBUTIONS

Mİ—writing–original draft, methodology, investigation, data curation, conceptualization, formal analysis, validation, supervision. TB—methodology, investigation, data curation, conceptualization, formal analysis.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Permission to study was obtained from The Ethics Committee of Dicle University Faculty of Medicine with registration number 14.06.2023-205. Due to the retrospective nature of the study, informed consent was waived by The Ethics Committee of Dicle University Faculty of Medicine.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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