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ORIGINAL RESEARCH

Crush syndrome and mortality predictors in intensive care unit patients after earthquakes

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Abstract

Background: This study aimed to characterize the clinical features, morbidity, and in-hospital mortality of patients admitted to the intensive care unit (ICU) following the Turkey–Syria earthquakes, with particular attention to the prevalence of Crush Syndrome (CS) and the identification of prognostic factors influencing its development and patient outcomes. **Methods**: Clinical data from 108 patients who were admitted to the ICU for earthquake-related trauma were retrospectively reviewed to assess their demographic characteristics, clinical presentation, duration of entrapment under rubble, treatment measures, blood gas parameters, laboratory results, ICU length of stay, occurrence of CS, and hospital mortality. **Results**: Among the 108 patients (mean age, 37 $\pm$ 18 years), the in-hospital mortality rate was 29%. Mortality was found to be significantly associated with higher Acute Physiology and Chronic Health Evaluation (APACHE) II scores, lower Glasgow Coma Scale scores, and increased levels of aspartate aminotransferase, alanine aminotransferase, creatine kinase (CK), peak CK, creatinine, troponin I, and red cell distribution width, as well as with decreased pH and bicarbonate levels ($p < 0.05$ for all). Troponin I exhibited the highest prognostic performance, with an area under the curve of 0.85, sensitivity of 83%, and specificity of 78% at a cut-off value of 257 ng/L. CS was diagnosed in 81 patients (75%), with a median CK level of 44,915 U/L (interquartile range, 15,000–122,250). Male sex and younger age were significantly associated with the development of CS ($p < 0.05$). **Conclusions**: Elevated troponin I levels at admission could be strongly associated with in-hospital mortality among earthquake victims requiring ICU care. CS was highly prevalent, particularly among younger and male patients, indicating the need for early recognition and targeted management strategies in this population.

Keywords

Acute kidney injury; Crush syndrome; Earthquake; Troponin

1. Introduction

On 06 February 2023, a series of catastrophic earthquakes, measuring between 7.3 and 7.8 on the Richter scale, struck southern, central Turkey and northern and western Syria, which represented the most devastating natural disaster in the region over the past century. The earthquake affected 11 provinces across an estimated area of 110,000 km^2 and were generated by ruptures along a fault line extending approximately 350 km. The disaster caused more than 50,500 deaths and over 120,000 injuries [1–3]. Many of the missing victims were presumed to have been crushed or asphyxiated within the confined spaces of collapsed buildings.

One of the most significant medical consequences for individuals trapped under rubble is traumatic rhabdomyolysis, which can progress to crush syndrome (CS) [4, 5]. The prevalence of CS among earthquake victims has been reported to range from 2% to 5% [4]. Importantly, all earthquake victims are at risk of developing CS, regardless of the severity of their injuries. Although the precise pathogenesis remains incompletely understood, ischemia–reperfusion injury and stretch myopathy are widely considered contributing mechanisms. The systemic manifestations of CS result from widespread muscle breakdown, leading to the release of myoglobin, potassium, and phosphorus into the circulation, which can precipitate life-threatening complications such as hyperkalemia and hyperphosphatemia [2, 6, 7]. Clinically, CS is characterized by hypovolemic shock, severe electrolyte disturbances, and acute renal failure [4, 7].

The present study was designed to evaluate morbidity and in-hospital mortality among patients admitted to our intensive care unit (ICU) after the 2023 Turkey–Syria earthquakes, with a particular focus on the prevalence of CS and the prognostic factors associated with both its development and patient out-

comes. The primary outcome was in-hospital mortality, while secondary outcomes included the prevalence of CS, length of ICU stay, and clinical and laboratory predictors of CS and mortality.

2. Materials and methods

This single-centre retrospective cohort study was conducted in the ICU of Saglik Bilimleri Universitesi (SBU) Adana City Education and Research Hospital, located in Adana, the most populous city in southern Turkey, between 06 February and 21 February 2023. SBU Adana City Education and Research Hospital is one of the leading tertiary referral hospitals in the earthquake-affected region. The study protocol was approved by the Turkish Ministry of Health and the Institutional Review Board (July 2023, Ref: 131-2719) and was carried out following the principles of the Helsinki Declaration [8].

All patients admitted to the ICU with earthquake-related injuries during the study period were eligible for inclusion. However, those with incomplete medical records or who had undergone cardiopulmonary resuscitation before ICU admission were excluded from the study analysis.

Both written and electronic medical records were reviewed. The following data were collected: demographic information (age, sex, comorbidities), clinical scores (Glasgow Coma Scale (GCS) and Acute Physiology and Chronic Health Evaluation II (APACHE II)), need for ventilator support, use of renal replacement therapy, laboratory parameters on admission (hemoglobin, white blood cell (WBC) count, platelet (PLT) count, red blood cell distribution width (RDW), creatine kinase (CK), procalcitonin, lactate dehydrogenase (LDH), alanine aminotransferase (ALT), aspartate aminotransferase (AST), albumin, lactate, glucose, C-reactive protein (CRP), blood electrolytes, and arterial blood gas parameters), peak CK levels during hospitalization, surgical interventions, and in-hospital mortality.

All data were anonymized prior to analysis to maintain patient confidentiality, in accordance with ethical guidelines. Each patient was assigned a unique study code, and no direct personal identifiers were recorded or accessed during the data collection or analysis process.

Acute kidney injury (AKI) was defined according to established consensus criteria as an increase in serum creatinine by at least 0.3 mg/dL within 48 hours, a 50% increase from baseline within 7 days, or urine output below 0.5 mL/kg/hour for at least 6 hours [9]. Since the baseline creatinine values were unavailable for most victims, the lowest creatinine level recorded during hospitalization was taken as the reference baseline for each patient. CS was diagnosed when the blood CK level on the first day of admission was $\geq$1000 IU/L, in combination with systemic complications such as AKI, sepsis, multiple organ failure, or acute respiratory failure [4, 6, 10].

The Shapiro-Wilk test was used to assess the normality of distribution for continuous variables. Normally distributed data were expressed as mean $\pm$ standard deviation (SD), whereas non-normally distributed data were expressed as median with interquartile range (IQR, 25%–75%). Categorical variables are reported as frequencies and percentages. Comparisons between groups were performed using Fisher's exact test for categorical variables, the independent-samples *t*-test for normally distributed continuous variables, and the Mann-Whitney U test for non-normally distributed data. Receiver operating characteristic (ROC) curve analysis was employed to evaluate the predictive performance of admission laboratory parameters for in-hospital mortality and CS. Optimal cut-off values were determined by Youden's index (sensitivity + specificity $-$ 1), and the area under the curve (AUC) was calculated. Sensitivity and specificity were reported for each cut-off point. Correlations between continuous variables were analyzed using Pearson's correlation test. All statistical analyses were performed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA). A two-tailed p-value < 0.05 was considered statistically significant.

3. Results

During the study period, a total of 114 patients were admitted to the ICU. However, 6 patients were excluded from the analysis due to incomplete data (n = 3), pre-hospital cardiac arrest (n = 1), or transfer to another hospital (n = 2). Thus, 108 patients were included in the final evaluation, and of them, 61 (56.5%) were male and 47 (43.5%) were female, with a mean age of 37 $\pm$ 18 years. The median ICU length of stay was 6 days (IQR, 3–8.7). Overall, 77 patients (71%) survived, while 31 patients (29%) died from their injuries. The demographic, clinical, and laboratory characteristics of survivors and non-survivors are summarized in Table 1. Among the laboratory parameters, APACHE II score, GCS, LDH, ALT, AST, CK, peak CK, creatinine, troponin I, RDW, procalcitonin, pH, and bicarbonate levels were significantly different between survivors and non-survivors ($p < 0.05$).

ROC curve analyses were performed to evaluate the predictive performance of admission parameters for in-hospital mortality (Table 2). Among these, troponin I demonstrated the highest prognostic accuracy, with an AUC of 0.85, a cut-off value of 257 ng/L, sensitivity of 83%, specificity of 78%, and a Youden index of 0.61 (Fig. 1).

AKI was observed in 79 patients (73%), and CS was diagnosed in 81 patients (75%). In the CS group, the median CK level was 44,915 U/L (IQR, 15,000–122,250). The demographic data, clinical features, and laboratory results of patients with and without CS are presented in Table 3. Compared with the non-CS group, the CS group had a higher proportion of male patients (62% *vs.* 41%), a younger median age (31 years (IQR, 21.5–44) *vs.* 43 years (IQR, 30–63), and a lower frequency of cranial trauma (7% *vs.* 37%) (all $p < 0.05$). Although surgical interventions (51% *vs.* 33%) and mortality (32% *vs.* 19%) were more frequent in the CS group, these differences did not reach statistical significance ($p > 0.05$). No differences were observed in CRP, albumin, RDW, or troponin I levels. However, laboratory parameters, including hematocrit, lactate, CK, peak CK, creatinine, LDH, ALT, AST and potassium, were significantly higher in the CS group ($p < 0.05$), whereas pH, bicarbonate, and sodium levels were significantly higher in the non-CS group.

Correlation analyses demonstrated that CK was not significantly correlated with creatinine ($r = 0.170$, $p = 0.81$).

TABLE 1. Comparison of baseline characteristics between survivors and non-survivors among earthquake patients admitted to the intensive care unit.

Variables	Survival	Non-survival	*p* value
Age (yr)	36 ± 18	39 ± 20	0.484[a]
Hematocrit (%)	41.8 ± 10.8	42.9 ± 12.1	0.657[a]
APACHE II score	20.0 (14.0–31.5)	37.0 (24.0–48.0)	***<0.001***[b]
Glasgow Coma Scale	14.0 (10.5–15.0)	5.0 (3.0–13.0)	***<0.001***[b]
LDH (U/L)	1070 (540–2638)	2900 (1103–4250)	***0.005***[b]
ALT (U/L)	147.0 (55.5–300.0)	583.0 (175.0–617.0)	***<0.001***[b]
AST (U/L)	307 (90–855)	848 (367–1640)	***<0.001***[b]
CK (U/L)	16,000 (3675–57,350)	63,045 (8808–132,750)	***0.020***[b]
Peak CK (U/L)	21,260 (4259–94,394)	82,811 (9900–132,000)	***0.029***[b]
Creatinine (mg/dL)	1.8 (0.9–3.0)	2.5 (1.5–3.8)	***0.014***[b]
Troponin I (ng/L)	58.0 (25.5–213.0)	900.0 (285.0–1965.0)	***<0.001***[b]
RDW (%)	14.0 (13.1–14.8)	15.1 (13.8–16.0)	***0.022***[b]
C-reactive protein (mg/L)	123 ± 95	165 ± 115	0.054[a]
Procalcitonin (mcg/L)	3.9 (0.7–13.9)	12.0 (3.1–72.2)	***0.003***[b]
pH	7.24 ± 0.15	7.10 ± 0.19	***0.001***[a]
Lactate (mg/dL)	40 ± 31	53 ± 36	0.055[a]
Bicarbonate (mEq/L)	17.2 ± 5.0	14.0 ± 8.6	***0.018***[a]

ALT: alanine aminotransferase; AST: aspartate aminotransferase; LDH: lactate dehydrogenase; RDW: red cell distribution width; CK: creatine kinase; APACHE II: Acute Physiology and Chronic Health Evaluation II. [a]*Values represent mean (standard deviation) and p values represent Student's t-test results.* [b]*Values are presented as median (interquartile range 25th–75th) and p values represent Mann-Whitney U test results. Significant values are in bold and italics.*

TABLE 2. Receiver operating characteristic curve comparisons of different parameters in predicting in-hospital mortality.

	AUC	95% CI	Cut-off	Sensitivity (%)	Specificity (%)	*p* value
APACHE II score	0.72	0.61–0.82	22.5	84	54	***<0.001***
GCS	0.73	0.62–0.84	8	78	55	***<0.001***
LDH (U/L)	0.67	0.56–0.73	1018	83	50	***0.005***
AST (U/L)	0.72	0.61–0.82	357	81	55	***<0.001***
ALT (U/L)	0.72	0.61–0.82	173	81	55	***<0.001***
CK (U/L)	0.64	0.53–0.76	346	81	55	***0.020***
Peak CK (U/L)	0.63	0.52–0.74	29,294	58	55	***0.029***
Creatinine (mg/dL)	0.65	0.54–0.75	2.04	67	59	***0.014***
Troponin I (ng/L)	0.85	0.76–0.94	257	83	78	***<0.001***
RDW (%)	0.63	0.51–0.75	14	65	60	***0.027***
pH	0.70	0.59–0.83	7.16	74	65	***<0.001***
HCO_3 (mEq/L)	0.73	0.61–0.84	12.5	80	66	***<0.001***
Procalcitonin (mcg/L)	0.69	0.57–0.81	5.8	72	60	***0.003***

ALT: alanine aminotransferase; AST: aspartate aminotransferase; AUC: area under the curve; CI: confidence interval; CK: creatine kinase; LDH: lactate dehydrogenase; GCS: Glasgow Coma Scale; HCO_3: bicarbonate; RDW: red cell distribution width; APACHE: Acute Physiology and Chronic Health Evaluation. Statistically significant values are shown in bold and italic ($p < 0.05$).

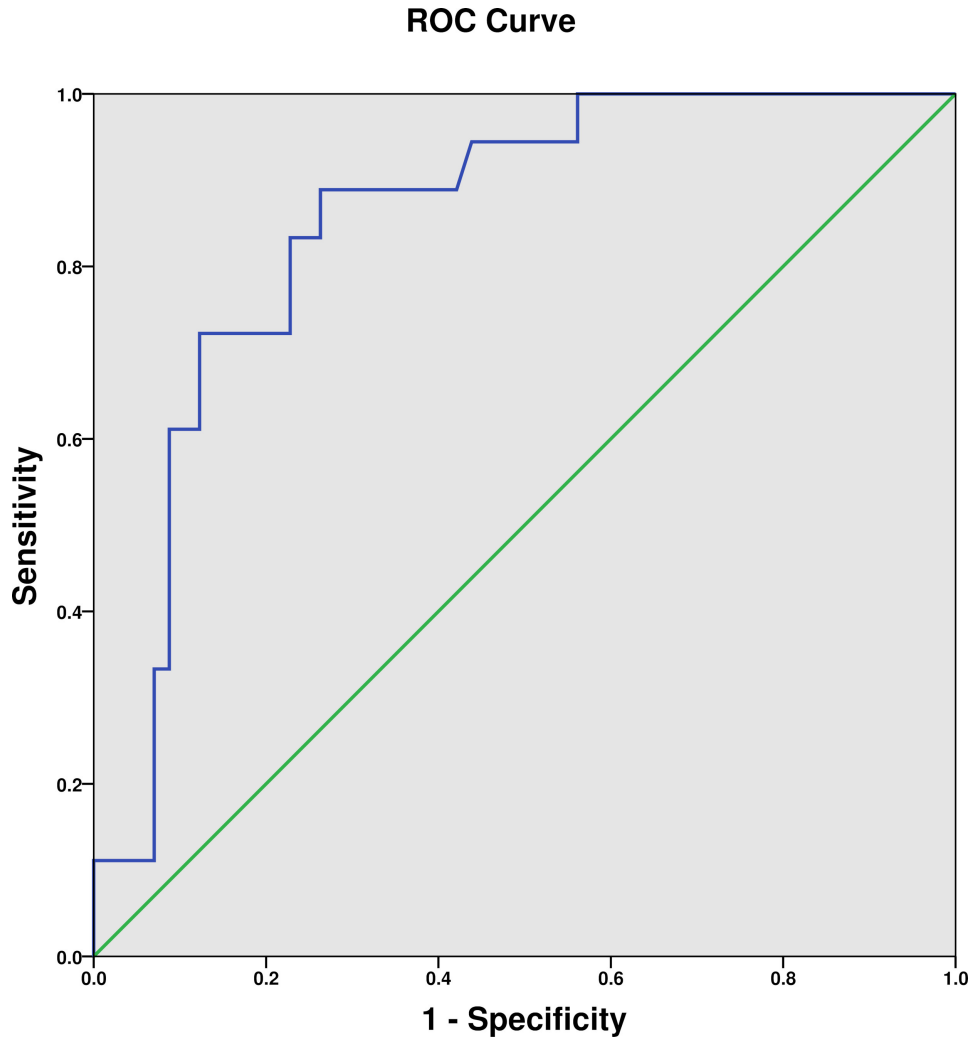

FIGURE 1. Receiver operating characteristic curve of troponin I in predicting in-hospital mortality. ROC: Receiver operating characteristic.

However, CK showed strong positive correlations with LDH ($r = 0.797$, $p < 0.001$), AST ($r = 0.764$, $p < 0.001$), potassium ($r = 0.678$, $p < 0.001$), peak CK ($r = 0.667$, $p < 0.001$), ALT ($r = 0.522$, $p < 0.001$), and hematocrit ($r = 0.358$, $p < 0.001$). Conversely, CK demonstrated significant negative correlations with pH ($r = -0.459$, $p < 0.001$) and sodium ($r = -0.390$, $p < 0.001$).

4. Discussion

This study describes a cohort of critically ill patients who required intensive care following the Turkey–Syria earthquakes, in which a remarkably high incidence of CS at 75% was observed, with troponin I identified as being the most significant laboratory parameter for predicting in-hospital mortality at admission. ROC curve analysis demonstrated that a troponin I cut-off value of 257 ng/L provided good prognostic accuracy for mortality.

Previous research has shown that earthquakes exert both immediate and delayed effects on the cardiovascular system, including an increased risk of coronary mortality and related complications [11–13]. Troponin I is widely recognized as a highly sensitive and specific biomarker of early myocardial injury, primarily reflecting ischemic processes. However, more recent studies have expanded its clinical relevance by demonstrating elevated troponin release in a variety of conditions, such as postoperative states, cardiac surgery, traumatic brain injury, and severe trauma [14, 15]. Crewdson *et al.* [15] reported that elevated troponin levels were associated with mortality in trauma patients, even in the absence of direct cardiac contusion. The underlying mechanisms remain incompletely understood, but proposed explanations include secondary myocardial injury, exaggerated inflammatory responses, trauma-induced physiological stress, catecholamine surges, and oxidative damage [16–19]. Our findings further support the prognostic role of troponin I in trauma-related critical illness, including earthquake victims.

In addition to troponin, recent studies have highlighted the importance of systemic inflammatory and muscle injury markers as predictors of outcomes in earthquake-related CS. Yasar *et al.* [20] demonstrated that hematological and inflammatory indices, including the neutrophil-to-lymphocyte ratio, platelet-to-lymphocyte ratio, monocyte-to-lymphocyte ratio, systemic immune-inflammation index, systemic inflammatory response index, and pan-immune inflammation value, were associated with hospital length of stay and the need for dialysis, reflect-

TABLE 3. Comparison of baseline characteristics between the crush syndrome and non-crush syndrome groups among earthquake victims admitted to the intensive care unit.

Variable	Crush Syndrome Group	Non-Crush Syndrome Group	*p* value
Age (yr)	31.0 (21.5–44.0)	43.0 (30.0–63.0)	***0.012***[a]
Gender (male/female)	50/31	11/16	***0.047***[b]
Time under the rubble (d)	2.0 (1.0–2.5)	1.0 (1.0–6.0)	0.783[a]
Trunk trauma, n (%)	23 (28.4%)	7 (25.9%)	0.508[b]
Abdominal trauma, n (%)	10 (12.3%)	3 (11.1%)	0.584[b]
Cranial trauma, n (%)	6 (7%)	10 (37%)	***0.001***[b]
Surgical intervention, n (%)	40 (50.6%)	9 (33.3%)	0.109[b]
CK (U/L)	44,915 (15,000–122,250)	2400 (340–3750)	***<0.001***[a]
Peak CK (U/L)	57,800 (18,757–132,940)	2780 (503–14,259)	***<0.001***[a]
Creatinine (mg/dL)	2.3 (1.5–3.6)	1.1 (0.8–1.6)	***0.014***[a]
LDH (U/L)	2350 (938–4165)	455 (386–754)	***<0.001***[a]
ALT (U/L)	244 (413–515)	48 (28–80)	***<0.001***[a]
AST (U/L)	731 (304–1127)	84 (46–96)	***<0.001***[a]
Hematocrit (%)	44 (37–54)	35 (27–38)	***<0.001***[a]
RDW (%)	14 (13.7–15.5)	14 (12.9–14.8)	0.120[a]
C-reactive protein (mg/L)	120 (53–190)	110 (15–170)	0.080[a]
Procalcitonin (mcg/L)	9.0 (2.3–57.7)	1.5 (0.2–6.0)	***0.001***[a]
pH	7.19 (7.05–7.28)	7.37 (7.28–7.40)	***0.001***[a]
Lactate (mg/dL)	38 (16–74)	27 (12–45)	***0.019***[a]
Bicarbonate (mEq/L)	14 (11–19)	20 (16–23)	***<0.001***[a]
Troponin I (ng/L)	100.0 (35.0–676.0)	89.5 (36.0–393.0)	0.483[a]
Potassium (mEq/L)	5.5 (4.9–6.4)	4.1 (3.7–4.5)	***<0.001***[a]
Sodium (mEq/L)	137 (133–142)	141 (136–144)	***0.015***[a]

ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; CK: Creatine kinase; LDH: Lactate dehydrogenase; RDW: Red cell distribution width.

[a] *Values are presented as median (interquartile range 25th–75th percentiles) and p values were calculated using the Mann-Whitney U test.* [b] *p values were calculated using Fisher's exact test. Statistically significant values are shown in bold and italic ($p < 0.05$).*

ing the role of immune dysregulation in disease progression. Similarly, Aydin *et al.* [2] reported that elevated myoglobin, lactate, and uric acid levels were significantly associated with AKI and increased mortality in critically ill earthquake victims. Data from pediatric earthquake cohorts have shown that CK levels above 25,812 IU/L are linked to severe AKI [10]. Multicenter adult studies have confirmed that CK levels exceeding 50,000 U/L, hypoalbuminemia ≤2.5 g/dL, and multi-region trauma independently predict the need for renal replacement therapy, culminating in the development of a Dialysis Score with excellent discriminative power [21]. In our study, patients with CS exhibited markedly elevated markers of muscle injury and systemic stress, including CK, lactate, potassium, LDH, AST, and ALT, together with lower pH and bicarbonate levels compared with non-CS patients. These findings align with the established pathophysiology of CS, which involves prolonged muscle compression, extensive rhabdomyolysis, massive myoglobin release, electrolyte disturbances, metabolic acidosis, and subsequent renal dysfunction.

It is well established that CS and its complications, particularly AKI, are major contributors to mortality in earthquake-affected regions. Reported incidences of CS vary widely, ranging from 2% to 64% depending on the population and circumstances studied [4, 22]. These discrepancies are likely related to differences in climate, building structure and materials, duration of entrapment, efficiency of rescue and medical response, distance to referral centers, and challenges in data collection under disaster conditions. The high incidence of CS in our series (75%) is consistent with the fact that our cohort consisted exclusively of ICU patients, who represent the most severely affected subgroup.

Elevated CK has long been recognized as an effective marker of muscle injury and has been shown to be strongly associated with the risk of AKI and dialysis [10, 21, 22]. Hatice *et al.* [5] reported that CS was a major risk factor for mortality among earthquake victims requiring surgical intervention, with 72% of non-survivors presenting with CS and a median CK level of 31,856 U/L. In our series, the median CK level among CS patients was even higher at 44,915 U/L, and 79 patients overall developed AKI. Interestingly, CS

patients in our study were more often male, younger, and had less cranial trauma than those without CS. Although mortality and surgical intervention rates were more frequent higher in the CS group, these differences did were not reach statistical significance, possibly because due to the higher prevalence of severe cranial trauma, associated with poor outcomes, was more prevalent in the non-CS group.

This study has several limitations. First, its retrospective single-center design limits the generalizability of the findings, as local clinical practices, healthcare resources, and patient demographics in the post-earthquake context may not be representative of other settings. Second, the sample size was relatively small, which reduces statistical power and limits the robustness of the conclusions. Third, despite careful data collection, missing information remained unavoidable due to the extraordinary conditions following the earthquake. Finally, the chaotic environment of disaster response reduced adherence to standardized treatment protocols, and variability in therapeutic approaches may have influenced patient outcomes. Despite these limitations, our findings contribute important insights into the prognostic value of troponin I and the clinical burden of CS among critically ill earthquake victims, and they may help inform management strategies in future disaster scenarios.

5. Conclusions

CS and its renal complications represent major clinical challenges following earthquake disasters. In this study, CS was identified in 75% of patients admitted to the ICU, with a higher prevalence among male and younger patients. Elevated troponin I levels at admission were associated with in-hospital mortality, suggesting its potential role as a prognostic biomarker in critically ill earthquake victims. Nevertheless, this association should be interpreted with caution, and further prospective studies are required to confirm the prognostic utility of troponin I in this setting.

ABBREVIATIONS

AUC, Area under the curve; ALT, Alanine transaminase; AKI, Acute kidney injury; AST, Aspartate aminotransferase; CK, Creatine kinase; CRP, C-reactive protein; CS, Crush syndrome; GCS, Glasgow Coma Score; HCO_3, Bicarbonate; LDH, Lactate dehydrogenase; PLT, Platelets; RDW, Red blood cell distribution width; ROC, Receiver operating characteristic; WBC, White blood cells; ICU, Intensive care unit, APACHE II, Acute Physiology and Chronic Health Evaluation II; IQR, Interquartile range; CI, Confidence interval; SD, standard deviation.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and/or analyzed during the current study are not publicly available due to Turkish Personal Data Protection Law no 6698. However, de-identified or anonymized data may be available upon reasonable request from the corresponding author, subjects to institutional ethics approval and a data sharing agreement in compliance with applicable legal and ethical standards.

AUTHOR CONTRIBUTIONS

BA, ÜK, HKÖ—concept; critical revision. ZB, ÜK, NÜ, KGG—design. BA, HKÖ, NÜ—supervision. ÜK, KGG—data. BA, ZB—analysis. KGG, NÜ, ZB—literature search. ZB, ÜK, BA—writing. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Turkish Ministry of Health and Ethics Committee of SBU Adana City Training and Research Hospital (July 2023, Ref: 131-2719) and waived the need for informed consent from participants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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