

Evaluation of critical parameters for optimizing the therapeutic approach in pediatric patients with compartment syndrome during the 2023 Türkiye earthquake disaster

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ABSTRACT

BACKGROUND: The 2023 Türkiye earthquake resulted in a large number of pediatric victims with musculoskeletal trauma, many of whom developed compartment syndrome (CS) and crush-related complications. This study aimed to identify clinical and biochemical parameters associated with disease severity, renal failure, and limb loss in children affected by the disaster.

METHODS: A retrospective analysis was conducted on 103 pediatric patients (0–18 years) admitted after the earthquake. Demographic data, duration of entrapment, laboratory values (creatinine kinase [CK], myoglobin, aspartate aminotransferase [AST], alanine aminotransferase [ALT], urea, potassium), and therapeutic interventions (fasciotomy, negative-pressure wound therapy [NPWT], hyperbaric oxygen therapy [HBOT], hemodialysis, and amputation) were evaluated. Receiver operating characteristic (ROC) analyses were used to determine cut-off values predicting adverse outcomes.

RESULTS: Forty-seven patients (45.6%) developed compartment syndrome involving 68 limbs and underwent fasciotomy. Thirteen patients (12.6%) required limb amputation, and 19 (18.4%) underwent hemodialysis due to acute kidney injury. An entrapment duration exceeding 8 hours (area under the curve [AUC]=0.84, $p<0.001$), CK>10,000 U/L, and myoglobin >4,000 ng/mL were independent predictors of renal failure, fasciotomy, and amputation. NPWT was applied in 66% and HBOT in 85% of patients with necrosis, contributing to an 82% limb salvage rate. No amputations occurred in patients without persistent necrosis. Three patients (2.9%) died from severe crush-related injuries and multi-organ failure.

CONCLUSION: Prolonged entrapment and markedly elevated CK and myoglobin levels are reliable indicators of adverse outcomes in pediatric earthquake victims with compartment syndrome. Early recognition, timely decompression, and structured wound management (NPWT and HBOT) are essential for improving survival and limb salvage when early surgical intervention is not feasible in large-scale disasters.

Keywords: Compartment syndrome; pediatric trauma; earthquake; fasciotomy; crush injury; amputation; negative-pressure wound therapy (NPWT); hyperbaric oxygen therapy (HBOT); renal failure.

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INTRODUCTION

On February 6, 2023, southeastern Türkiye and northern Syria experienced one of the most devastating earthquakes in recent history, measuring 7.8 in magnitude, followed by another significant tremor of 7.5. This catastrophic event affected approximately 15 million individuals, a substantial number of whom were children.^[1] In Türkiye, approximately 21.3% of the country's child population resides in the southeastern regions impacted by the 2023 earthquake. This proportion highlights the considerable pediatric population at risk in the disaster zone, underscoring the need for child-focused medical response strategies.^[2] The earthquake caused extensive structural collapses, trapping many individuals under debris for varying durations—from hours to several days—before rescue efforts reached them. The healthcare infrastructure in the region sustained severe damage, necessitating the transfer of injured patients to medical facilities across the country, including our institution.

This study aims to evaluate the factors influencing the severity of compartment syndrome in pediatric patients affected by the earthquake. Additionally, it assesses the therapeutic interventions provided, including both surgical and non-surgical treatments, and their respective outcomes. By identifying critical determinants of morbidity and treatment efficacy, this analysis seeks to inform future disaster preparedness protocols, optimize emergency response systems, and reduce the risk of amputations and long-term complications in pediatric populations during large-scale disasters.

MATERIALS AND METHODS

This retrospective study reviewed the medical records of pediatric earthquake victims referred to or admitted to at a tertiary referral center following the disaster. Ethical approval for the study was obtained from the institutional ethics committee (number: E2-24-458, date: 10/09/2024), and the study was conducted in accordance with the principles of the Declaration of Helsinki. Pediatric patients aged 0 to 18 years who were referred to or admitted to our institution with earthquake-related musculoskeletal trauma between February 6 and March 31, 2023, were included in the study. Patients with incomplete medical records, those admitted for non-traumatic conditions, or individuals with pre-existing neuromuscular disorders were excluded.

Clinical Setting and Multidisciplinary Management

At our tertiary referral center, all patients were evaluated by a multidisciplinary team dedicated to pediatric surgery, orthopedics, and plastic surgery, supported by surgical intensive care, pediatric intensive care, burn intensive care, and a specialized wound unit. These teams worked in shifts to ensure continuous (24/7) bedside monitoring and serial clinical-laboratory reassessment. Patients were co-managed by pediatric nephrology, cardiology, hematology, and infectious diseases as clinically indicated.

Patients were enrolled starting on the day of the earthquake (February 6, 2023) and followed until discharge or death, with the final date of follow-up being April 15, 2023. The median follow-up duration was 28 days (range: 3–65 days). Of the 107 pediatric patients initially admitted, four were excluded from the analysis due to incomplete clinical data, resulting in a final study population of 103 patients. The variables analyzed included age, gender, city of residence at the time of the earthquake, family health status, duration of entrapment under rubble, type of injury, laboratory values, presence of crush syndrome, fasciotomy status, medical and surgical treatments administered, and the occurrence of acute renal failure.

Laboratory Assessments

Laboratory parameters including serum creatine kinase (CK), myoglobin, aspartate aminotransferase (AST), alanine aminotransferase (ALT), urea, creatinine, potassium, albumin, and troponin I were routinely measured upon admission and monitored daily during the acute phase of hospitalization (first 7–10 days), or more frequently when clinically indicated. Serial measurements were used to assess trends and guide therapeutic decisions, particularly regarding fasciotomy, renal support, and surgical debridement.

Adjunctive Therapeutic Treatment Options

Negative-pressure wound therapy (NPWT) was employed for open wounds with infected or serous discharge to reduce edema and prevent infection. The frequency of NPWT changes was determined by the presence of infection and the volume of exudate. During follow-up, cultures were obtained from patients who developed wound infections, and appropriate treatments were initiated. Wounds deemed suitable after serial debridement were closed. Hyperbaric oxygen therapy (HBOT) was administered for patients with muscle necrosis, with treatment discontinued once necrotic tissue was no longer present in the fasciotomy wounds.

Clinical Indications for Fasciotomy

Patients presenting with tense, edematous limbs and sensory or motor deficits due to compromised vascular circulation were diagnosed with compartment syndrome. Fasciotomy was indicated for clinically diagnosed acute compartment syndrome in accordance with institutional protocol and prior guidance.^[3] Given the disaster setting, diagnosis was primarily clinical and included: (i) severe pain (often out of proportion) and pain with passive stretch; (ii) tense swelling; (iii) paresthesia or hypoesthesia; (iv) motor weakness; (v) progressive neurovascular compromise; and (vi) absent distal pulses (considered a late sign). When documented, elevated intercompartmental pressures (ICP >30 mmHg) or a perfusion pressure ΔP (diastolic blood pressure – ICP) <30 mmHg supported the diagnosis. Because specific fasciotomy indications were not prospectively coded as discrete variables across referring centers, we report standardized criteria and a narrative description rather than a quantitative breakdown of individual triggers.

Patients who underwent fasciotomy within the first 24 hours were classified as early fasciotomy cases. In instances where fasciotomy had been performed at an outside facility but signs of compromised circulation persisted, fasciotomy revisions or extensions were undertaken.

Clinical Indications for Amputation

Definitive amputation was considered in patients with irreversible ischemia, progressive soft tissue and muscle necrosis, absent distal perfusion despite fasciotomy, severe infection unresponsive to debridement and antibiotics, or systemic deterioration due to sepsis. The decision to amputate was made by consensus within the multidisciplinary team and was delayed when feasible to allow adequate reassessment of tissue viability.

Amputations were performed at the lowest feasible level and reserved for cases in which limb-salvage measures (serial debridement and targeted antimicrobial therapy) failed and there was persistent infection or refractory limb ischemia with progressive osseous or soft-tissue necrosis, motor-sensory dysfunction consistent with irreversible neural compromise and/or systemic sepsis.

Clinical Indications for Hemodialysis

The initiation of hemodialysis was determined in consultation with pediatric nephrologists for patients with uremia, oliguria, resistant electrolyte imbalances (e.g., hyperkalemia), or acidosis. All patients with crush syndrome were closely monitored by pediatric nephrologists and intensive care specialists, and necessary medications were administered to prevent and treat rhabdomyolysis and acute renal failure.

Statistical Analyses

Data analysis was conducted using the Statistical Package for the Social Sciences (SPSS) version 22.0 (IBM Corp., Armonk, New York, USA). Descriptive statistics for continuous variables were presented as median (minimum-maximum) values, while categorical variables were summarized as n (%). The Shapiro-Wilk test was used to assess the normality of continuous variables. For variables that did not conform to a normal distribution, the Mann-Whitney U test was used for group comparisons. A p-value <0.05 was considered statistically significant.

Receiver operating characteristic (ROC) curve analysis was performed to determine cut-off values for key laboratory and clinical parameters associated with poor outcomes. Cut off assessment was conducted using pre specified thresholds for CK and myoglobin, along with exploratory evaluation of other laboratory markers; optimal thresholds were considered only when discrimination was clinically acceptable. Optimal cut off values were determined using Youden's index ($J = \text{sensitivity} + \text{specificity} - 1$), and areas under the curve (AUC) were reported. Two sided p values <0.05 were considered statistically significant.

RESULTS

A total of 103 pediatric patients were referred to our hospital following the earthquake. Of these, 95 were admitted to the pediatric surgery intensive care unit and surgical wards, while eight were treated in the orthopedic ward. The mean age of the patients was 9.47 ± 4.82 years (range: 0.1-17 years), and the male-to-female ratio was 45:58 (44%:66%). Seventy percent (n=72) had lost at least one parent or sibling during the earthquake. The mean duration of entrapment under the rubble was 9.47 hours (range: 0-120 hours). Among these, 59 patients (57.3%) were extricated from the rubble within the first 24 hours following the earthquake. Six patients were intubated upon arrival. The types of injuries sustained by the 103 patients trapped under the rubble are detailed in Table 1. Seven patients had cranial injuries, 21 had facial abrasions and hematomas, four had pneumothorax, four had lung contusions, one had a rib fracture, one had pericardial effusion, two had liver lacerations, two had splenic hematomas, and one had a right adrenal hematoma. Additionally, one patient sustained a urethral injury. A total of 86 patients (83.4%) sustained injuries characterized by crush trauma to either the lower or upper extremities.

Indications for Fasciotomy

Among the 103 patients, 47 were diagnosed with compartment syndrome, affecting a total of 68 extremities. These patients underwent fasciotomy either at the referring hospitals or at our center. A total of 68 fasciotomies were performed in 47 patients. Of these, 40 (58.8%) involved the upper extremities and 28 (41.2%) the lower extremities. Fasciotomy indications included progressive compartment symptoms such as swelling, pain, neurovascular compromise, and motor-sensory dysfunction. In nine patients, fasciotomy extensions were required due to inadequate initial decompression, and in 13 patients, fasciotomies were initiated de novo at our institution based on clinical progression.

Risk Stratification for Fasciotomy Based on Laboratory Cut-Off Values

The comparison between patients who underwent fasciotomy and those who did not is presented in Table 2. Patients who underwent fasciotomy were older, had longer durations of entrapment under the rubble, and experienced longer hospital stays, with significantly higher levels of aspartate

Table 1. Sites of injury (n=103)

Upper extremity	49 (47.5%)
Lower extremity	37 (35.9%)
Head and neck	28 (27.1%)
Thorax	10 (9.7%)
Abdomen	5 (4.8%)
Urogenital	1 (0.9%)

Table 2. Clinical characteristics and laboratory findings of patients undergoing fasciotomy

Parameters	Fasciotomy (+)	Fasciotomy (-)	P value
Age (years)	10.71 (± 4.24)	8.60 (± 5.04)	0.03
Time Trapped in Rubble (hours)	25.94 (± 26.01)	14.32 (± 20.93)	0.02
Length of Hospital Stay (days)	43.38 (± 26.65)	22.60 (± 27.72)	0.001
AST (U/L)	2520	596	0.001
ALT (U/L)	239	187	0.001
Amylase (U/L)	48	76	0.35
Lipase (U/L)	21	24	0.71
Creatinine (mg/dL)	0.36	1.35	0.55
CK (U/L)	123973	13205	0.001
CK-MB (ng/mL)	166.32 (± 532.86)	85.60 (± 338.92)	0.43
Myoglobin (ng/mL)	1171.95	261	0.001
Troponin-I (ng/mL)	40	183	0.01
Albumin (g/dL)	20.04 (± 7.82)	19.83 (± 11.80)	0.95
Uric Acid (mg/dL)	6.28 (± 6.58)	4.91 (± 4.29)	0.23
Urea (mg/dL)	48.77 (± 50.62)	29.06 (± 23.28)	0.01
Potassium (mmol/L)	4.69 (± 1.1)	4.41 (± 0.89)	0.18

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; CK: Creatine kinase; CK-MB: Creatine kinase–myocardial band.

aminotransferase, alanine aminotransferase, creatine kinase, myoglobin, and urea compared with those managed without fasciotomy. Significant differences in laboratory values were also found between patients with and without muscle necrosis. Twenty-three patients with severe muscle necrosis detected during fasciotomy received hyperbaric oxygen therapy. Patients with muscle necrosis were younger, had longer durations of entrapment under the rubble, and required extended hospitalization. They exhibited significantly higher levels of AST, ALT, creatine kinase, myoglobin, troponin-I, urea, and potassium, along with lower albumin levels compared to those without muscle necrosis (Table 3). Among the fasciotomy cohort, 24 patients (34 extremities) presented with persistent soft tissue necrosis and/or severe circulatory compromise and were managed with a stepwise limb salvage protocol (serial surgical debridement under anesthesia, broad spectrum antibiotics, NPWT, and HBOT as indicated). Median NPWT duration was 3.8 days (range 1–5), and the median time to definitive fasciotomy closure was 16.3 days (range 2–28), with 31/47 (66%) achieving primary closure and 16/47 (34%) requiring split thickness skin grafts.

Indications for Amputation

Amputation decisions were made based on comprehensive clinical evaluation, including signs of vascular compromise, irreversible motor-sensory loss, progressive bone and muscle necrosis, and systemic signs of sepsis. These interventions were undertaken despite prior aggressive medical and surgical management.

Despite the aforementioned measures involving fasciotomy, NPWT, and HBOT, 6/34 extremities (17.6%) ultimately required amputation, whereas 28/34 (82.4%) were salvaged. Notably, amputations occurred exclusively within the “persistent necrosis” subgroup; no amputations were recorded in extremities without persistent necrosis (Table 4). A total of 13 patients underwent limb amputation, representing 12.6% of the entire cohort. Of these, seven amputations were performed at the referring hospitals before transfer. After admission to our center, four patients underwent revision amputations due to ongoing infection or tissue necrosis, while six new amputations were performed during follow-up because of progressive ischemia, widespread soft-tissue necrosis, or sepsis. In addition to crush-related ischemia, other causes of amputation included persistent infection (n=2) and progressive necrosis despite decompression (n=1). Furthermore, among patients who received fasciotomy at the referring institution and those who underwent fasciotomy extension at our facility, none required amputation.

Amputation Versus Non Amputation Comparison

A consolidated analysis is presented in Table 5. In unadjusted comparisons of continuous variables, age, entrapment duration, creatine kinase–myocardial band (CK MB), myoglobin, and troponin I were broadly comparable between groups (all $p>0.05$). By contrast, ALT, CK, urea, and albumin showed nominal between group differences (Table 5). Given the small amputation subgroup and variable level missingness, these findings should be interpreted cautiously and without causal

Table 3. Comparison of laboratory findings and clinical outcomes in patients with and without muscle necrosis

	Muscle Necrosis (+)	Muscle Necrosis (-)	P value
Age (years)	8 (±3.54)	12 (±5.87)	0.01
Time Trapped in Rubble (hours)	28.6 (±22.01)	25.8 (±14.93)	0.008
Length of Hospital Stay (days)	43.38 (±26.65)	22.60 (±27.72)	0.001
AST (U/L)	1271 (1025)	1001 (596)	0.034
ALT (U/L)	514 (241)	284 (187)	0.018
Amylase (U/L)	48	76	0.35
Lipase (U/L)	21	24	0.71
Creatinine (mg/dL)	0.88	0.88	0.55
CK (U/L)	65150.4 (26945)	48847.04 (15032)	0.001
CK-MB (ng/mL)	144.07 (±765.86)	95.72 (±65.92)	0.03
Myoglobin (ng/mL)	1168 (1000)	1000 (1000)	0.032
Troponin-I (ng/mL)	455.2 (300)	239.2 (25)	0.024
Albumin (g/dL)	17.4 (±8.82)	19.33 (±9.80)	0.03
Uric Acid (mg/dL)	7.96 (±7.58)	5.71 (±3.29)	0.57
Urea (mg/dL)	54.8 (±40.62)	51.8 (±18.28)	0.02
Potassium (mmol/L)	5.9 (±1.2)	4.8 (±0.9)	0.04

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; CK: Creatine kinase; CK-MB: Creatine kinase–myocardial band.

Table 4. Surgical interventions and wound management among pediatric patients with compartment syndrome

Domain/Variable	n (%; denominator)
Patients with clinically diagnosed compartment syndrome who underwent fasciotomy	47/103 (45.6%)
Extremities decompressed by fasciotomy	68
Upper extremity fasciotomies	40/68 (58.8%)
Lower extremity fasciotomies	28/68 (41.2%)
Fasciotomy performed de novo at our center	13/47 (27.7%)
Fasciotomy extension/revision at our center	9/47 (19.1%)
Negative-pressure wound therapy (NPWT) after fasciotomy	26
Fasciotomy wound closure – primary	31/47 (66.0%)
Fasciotomy wound closure – split thickness skin graft (STSG)	16/47 (34.0%)
Hyperbaric oxygen therapy (HBOT) in severe intraoperative muscle necrosis	23
Patients undergoing limb amputation	16/103 (15.5%)
Amputation performed prior to transfer	7/16 (43.8%)
New amputation performed at our center	5/16 (31.2%)
Revision amputation at our center	4/16 (25.0%)

inference. Dialysis requirements did not differ by amputation status (2/13 [15.4%] vs. 13/90 [14.4%]; Fisher's exact $p=1.00$).

Indications for Hemodialysis

Nineteen patients with crush syndrome required hemodialysis. The laboratory parameters of these patients are detailed

in Table 6. Patients requiring hemodialysis exhibited significant differences in various clinical parameters compared to those who did not. Specifically, hemodialysis patients had a longer duration of entrapment under the rubble and longer hospital stays. Additionally, laboratory values revealed significantly elevated levels of aspartate aminotransferase and ala-

Table 5. Comparison of clinical and laboratory characteristics by amputation status

Parameter (unit)	Amputation (+) (n=13) Mean±SD	Amputation (-) (n=90) Mean±SD	p value
Age (years)	8.29±2.36	9.87±4.77	0.319
Time trapped under rubble (hours)	28.57±42.77	17.10±21.41	0.673
Length of hospital stay (days)	45.43±31.19	30.00±28.69	0.095
AST (U/L)	879.86±707.10	441.33±818.18	0.057
ALT (U/L)	309.00±229.37	161.85±231.24	0.030
CK (U/L)	27,146.86±22,563.12	18,976.34±54,714.65	0.042
CK MB (ng/mL)	115.00±94.93	167.82±537.54	0.234
Myoglobin (ng/mL)	668.43±457.30	484.95±1,113.50	0.154
Troponin I (ng/mL)	130.14±225.75	145.57±427.65	0.125
Urea (mg/dL)	46.29±22.19	36.93±39.21	0.047
Albumin (g/dL)	18.43±10.81	8.60±11.35	0.026
Dialysis (n, %)*	2 (15.4%)	13 (14.4%)	1.00

*Fisher's exact test.

Table 6. Comparison of laboratory findings and clinical outcomes in hemodialysis and non-hemodialysis patients

Parameter	Hemodialysis (+) (n=19)	Hemodialysis (-) (n=64)	p
Age	11.12 (±3.54)	11.27 (±5.87)	0.68
Time Trapped in Rubble	29.55 (±22.01)	19.12 (±14.93)	0.028
Length of Hospital Stay	69.5 (±26.65)	41.4 (±27.72)	0.005
AST	2050 (1614)	610 (421)	0.001
ALT	548.4 (490)	230 (175)	0.001
Amylase	116.12	64.66	0.11
Lipase	45.75 (27)	31.05 (19)	0.09
Creatinine	1.93 (1.85)	0.41 (0.36)	0.001
CK-MB	195.45 STD	64.81 STD	0.009
CK	131938 STD	16426.38 STD	0.001
Myoglobin	2125 (3181)	696.55 (377)	0.001
Troponin-I	793.87 (91.02)	52.75 (65.35)	0.001
Albumin	16.5 (±8.82)	20.05 (±9.80)	0.019
Uric Acid	10.47 (±7.58)	4.22 (±3.29)	0.42
Urea	89.75 (101)	35.77 (19)	0.001
Potassium	5.9 (±1.2)	4.8 (±0.9)	0.04

AST: Aspartate aminotransferase; ALT: Alanine aminotransferase; CK: Creatine kinase; CK-MB: Creatine kinase-myocardial band.

nine aminotransferase in the hemodialysis cohort. Creatinine levels were markedly increased, and creatine kinase levels were significantly higher. Myoglobin and troponin-I levels also demonstrated significant differences. Furthermore, albumin levels were lower in the hemodialysis group, and potassium

levels were significantly elevated.

An entrapment duration of more than 8 hours was found to significantly correlate with the development of acute kidney injury (AKI), fasciotomy, and subsequent limb amputation

Table 7. Receiver operating characteristic (ROC) performance and pre specified threshold metrics for hemodialysis

Predictor	AUC	95% CI	Threshold	Sensitivity	Specificity
Creatine kinase (CK), U/L	0.85	0.71-0.98	>10.000	0.80	0.85
Myoglobin, ng/mL	0.89	0.81-0.95	>4.000	0.07	1.00
Entrapment duration (hours)	0.51	0.37-0.66	—	—	—

(AUC=0.84, $p<0.001$). Similarly, creatine kinase levels exceeding 10,000 U/L and myoglobin levels greater than 4,000 ng/mL were associated with a significantly higher incidence of systemic complications and surgical interventions ($p<0.01$).

Risk Stratification for Hemodialysis Based on Laboratory Cut-Off Values

Receiver operating characteristic analyses (primary endpoint: hemodialysis/AKI) showed strong discrimination for CK and myoglobin (AUC=0.85 and 0.89, respectively), whereas entrapment duration had limited discrimination (AUC=0.51) (Table 7). Using pre specified thresholds, CK >10,000 U/L yielded sensitivity/specificity of 0.80/0.85 ($p<0.001$), while myoglobin >4,000 ng/mL was highly specific (1.00) but poorly sensitive (0.07) and did not reach statistical significance (Table 7). AST, ALT, and urea did not demonstrate sufficient discrimination to justify clinically meaningful cutoffs in this cohort.

Among the cohort, patients with serum creatine kinase levels greater than 5,000 U/L and myoglobin levels above 3,000 ng/mL demonstrated significantly higher rates of fasciotomy, muscle necrosis, acute kidney injury, and amputation ($p<0.01$).

All patients were evaluated in their beds by child psychiatrists. Twenty-six patients (25%) required medication, and treatment was provided to 16 patients (41%) who underwent fasciotomy ($p=0.001$). During follow-up, three patients died. Two of these patients, who had crush syndrome, were intubated and transferred from the referring hospital: an eight-year-old boy and a 15-year-old girl. The third patient was a 10-year-old boy with a subarachnoid hemorrhage and compartment syndrome, who underwent fasciotomy but ultimately succumbed to his injuries.

DISCUSSION

Severe earthquakes are associated with substantial morbidity and mortality, with most deaths occurring in the immediate aftermath due to severe trauma and prolonged entrapment under debris.^[4] Crush injury is defined as prolonged compression of muscle tissue, leading to ischemia, cellular disruption, and necrosis. Progression to crush syndrome occurs when intracellular contents such as myoglobin, potassium, and creatine kinase enter the circulation, resulting in systemic complications including acute kidney injury and electrolyte disturbances.

Acute compartment syndrome, in contrast, is a localized condition caused by elevated intercompartmental pressure that impairs tissue perfusion and requires urgent fasciotomy to prevent irreversible damage. In our cohort, 83 patients sustained crush injuries, of whom 22.8% ($n=19$) met the diagnostic criteria for crush syndrome. These patients demonstrated progressive deterioration in key laboratory parameters, characterized by marked increases in creatine kinase, myoglobin, and serum potassium levels, accompanied by a decline in urine output. Crush injuries and crush syndrome present a high risk in these situations.^[5] Musculoskeletal injuries are the most common injuries during earthquakes.^[6,7] However, injuries to critical regions such as the head, abdomen, and thorax frequently lead to fatal outcomes, as many patients succumb before receiving adequate medical attention.^[8] In our study, 83% of patients sustained extremity trauma, while thoracic and abdominal trauma together accounted for 14.5% of cases (Table 1). Data from previous disasters indicate that approximately 80% of trapped victims die quickly from severe injuries, with 10% experiencing crush injuries and another 10% sustaining minor trauma.^[9,10] Of those with crush injuries, 40–70% develop crush syndrome.^[4,11] In our cohort, 22.8% ($n=19$) of the 83 patients with crush injuries developed crush syndrome.

It is important to highlight that, due to our hospital's geographic location outside the epicenter, all patients included in this study were admitted no earlier than 24 hours after being extricated from collapsed structures. As such, none of the cases met the criteria for early fasciotomy, which is generally defined in the literature as surgical decompression performed within the first 6 to 12 hours of ischemic insult. This inherent delay limited our ability to evaluate the potential benefits of early intervention on limb salvage and systemic outcomes. Therefore, our findings predominantly reflect the clinical course and complications associated with delayed fasciotomy, offering relevant insights into scenarios where early access to surgical care is not feasible during disaster responses.

In line with prior guidance,^[12] fasciotomy was performed for clinically diagnosed acute compartment syndrome, defined by progressive pain and swelling with neurovascular compromise, motor–sensory deficits, and—when documented—elevated intercompartmental pressures; absent distal pulses were considered a late sign. However, the indication and

timing of fasciotomy remain controversial. Early fasciotomy performed within 6 to 12 hours can prevent muscle necrosis; however, delayed fasciotomy generally results in poorer outcomes.^[13] Some authors have argued that fasciotomy may be less effective in the setting of crush syndrome because irreversible muscle necrosis can precede a rise in compartment pressure, shifting the therapeutic priority toward renal preservation.^[14,15] In our cohort, fasciotomy was performed in 47 patients (68 extremities) with clinically diagnosed compartment syndrome (Table 5).

Previous studies have elucidated the risks associated with fasciotomy in the context of crush syndrome, including uncontrollable hemorrhage, sepsis, and wound infections. Greaves et al.^[16] and Ereke et al.^[17] reported significantly elevated rates of sepsis and increased dialysis requirements among patients undergoing fasciotomy. While fasciotomy in pediatric patients with crush syndrome-related acute kidney injury did not correlate with increased mortality, a strong association was observed between the number of fasciotomy incisions and the onset of sepsis.^[17] In our study, patients who underwent fasciotomy were older, exhibited longer median durations of entrapment and hospital stays, and demonstrated significantly higher levels of transaminases, creatine kinase, urea, and myoglobin compared to those managed without fasciotomy. These differences were statistically significant. Significant differences in laboratory values were also observed between patients with and without muscle necrosis.

Patients with muscle necrosis were younger, had longer durations of entrapment, and experienced longer hospital stays. They exhibited significantly higher levels of aspartate aminotransferase, alanine aminotransferase, creatine kinase, myoglobin, troponin I, urea, and potassium, along with lower albumin levels compared to those without muscle necrosis.

Surgical debridement, antibiotic therapy, and hyperbaric oxygen therapy were performed on 34 extremities with persistent necrosis, but six extremities ultimately required amputation. These findings indicate that limb loss clustered among extremities with persistent soft tissue necrosis and severe circulatory compromise, despite an aggressive salvage pathway (serial debridement, antibiotics, NPWT, HBOT). By contrast, no amputations occurred in extremities without persistent necrosis, suggesting that necrosis status—and the underlying injury severity it reflects—was the principal driver of amputation rather than the wound care modality.

Among the patients with muscle necrosis, 23 (85%) received hyperbaric oxygen therapy, and 17 (63%) were treated with negative-pressure wound therapy. These therapies were primarily administered to individuals exhibiting more severe systemic and local tissue damage. When compared to patients without muscle necrosis, those who received NPWT or HBOT showed significantly higher levels of biochemical markers such as AST, ALT, CK, myoglobin, troponin-I, and urea, as well as elevated potassium levels and prolonged hospital

stays. In contrast, albumin levels were notably lower. These findings suggest that the use of NPWT and HBOT was concentrated among the most critically affected patients and may have contributed to limb salvage in selected cases. Notably, only six patients in the muscle necrosis group required amputation, reflecting a potentially beneficial role of advanced wound management strategies in mitigating irreversible limb damage. Further prospective studies are warranted to evaluate the independent impact of these interventions on functional outcomes in pediatric crush injury victims.

Among these, 24 patients presented with severe circulatory compromise and extensive soft tissue necrosis; six ultimately underwent amputation. Amputation was indicated when limb physiology remained unsalvageable despite decompression and serial debridement—namely, persistent ischemia with non viable muscle, progressive necrosis after fasciotomy, or uncontrolled infection/sepsis (Table 7). Because the decision to perform fasciotomy was driven by the severity of limb ischemia (i.e., confounding by indication) and all cases presented >24 hours after extrication, our observational data cannot establish that fasciotomy per se increased the risk of amputation. Rather, amputation clustered with markers of injury severity, while comparative analyses did not show significant differences in key systemic parameters between amputated and non amputated patients ($p>0.05$).

Additionally, while the majority of amputations were performed in patients with extensive soft tissue necrosis and prolonged entrapment, a subset of cases required limb removal due to progressive ischemia, uncontrolled infection, or sepsis, highlighting the multifactorial nature of limb loss in this context.

Furthermore, in a comparative analysis of patients who underwent amputation versus those who did not, no statistically significant differences were observed regarding dialysis requirements, mean age, duration of entrapment, and laboratory parameters, including AST, ALT, troponin I, myoglobin, CK, CK-MB, urea, creatinine, and potassium levels ($p>0.05$). Additionally, none of the patients who underwent fasciotomy at the referring hospital or received fasciotomy extension at our institution required subsequent amputation. These findings suggest that although severe tissue damage is a major contributor to limb loss, fasciotomy—when appropriately indicated and executed—may not independently predict amputation risk in delayed-access disaster scenarios.

The likelihood of limb salvage is lower in cases involving significant bone loss, extensive soft tissue damage, distal sensory and motor function loss due to peripheral nerve injury, and major vascular damage requiring reconstruction. Guidelines recommend limiting amputation to cases where the limb is unsalvageable or when injuries result in uncontrollable bleeding, sepsis, or severe systemic inflammation. If amputation is indicated, it should be performed as promptly as possible.^[18,19] We performed amputation in 25% of patients with crush

syndrome. These patients had a prolonged duration of entrapment under the rubble, exhibited no circulation, or had severe muscle necrosis.

Furthermore, our analysis identified specific thresholds for clinical and biochemical risk factors associated with adverse outcomes. In particular, entrapment durations exceeding 8 hours, serum creatine kinase levels greater than 10,000 U/L, and myoglobin levels above 4,000 ng/mL were significantly correlated with an increased risk of acute kidney injury, need for fasciotomy, and limb amputation ($p < 0.01$). These cut-off values, determined by receiver operating characteristic curve analysis, provide valuable guidance for early risk stratification in similar disaster settings. Additionally, while the majority of amputations were performed in patients with extensive soft tissue necrosis and prolonged entrapment, a subset of cases required limb removal due to progressive ischemia, uncontrolled infection, or sepsis, underscoring the multifactorial nature of limb loss in this context.

Fasciotomy has been associated with increased dialysis requirements in some studies, with Kantarci et al.^[20] identifying it as a strong indicator of dialysis need. Sever et al.^[21] reported that dialysis was required in 83.9% of fasciotomy patients compared to 65.2% of those who did not undergo the procedure. Matsuoka et al.^[22] however, found no significant difference in hemodialysis requirements between patients with or without fasciotomy. In our study, patients requiring hemodialysis showed significant differences in clinical parameters compared to those who did not. Specifically, the hemodialysis group experienced a longer duration of entrapment under the rubble and an extended hospital stay. Laboratory analyses revealed markedly elevated levels of aspartate aminotransferase and alanine aminotransferase, along with increased creatinine and creatine kinase levels. Myoglobin and troponin I levels also differed significantly, while albumin levels were lower and potassium levels were significantly elevated in the hemodialysis cohort ($p < 0.05$).

Consistent with prior reports,^[5] dialysis requirement did not differ significantly by amputation status in our cohort (amputation 2/7 [28.6%] vs. no amputation 13/88 [14.8%]; $p > 0.05$). In unadjusted comparisons, age, duration of entrapment, AST, CK MB, myoglobin, and troponin I did not differ significantly between amputated and non amputated patients (all $p > 0.05$) (Table 5). By contrast, ALT, CK, urea, and albumin showed nominal between group differences ($p = 0.030, 0.042, 0.047$, and 0.026 , respectively) (Table 5); these findings should be interpreted cautiously given the small amputation subgroup ($n = 7$) and variable missingness.

Oda et al.^[23] reported a mortality rate of 13.4% among patients with crush syndrome, with a significantly elevated rate of 50% in those with abdominal injuries. Sever et al.^[21] observed a 30.5% mortality rate among amputated patients, highlighting thoracic and abdominal trauma as significant predictors of mortality. Overall, the mortality rate for crush syndrome

approaches 20%, increasing further in cases of multi-organ failure.^[24,25] In our study, three patients died during follow-up, including two intubated patients with crush syndrome transferred from the referring hospital—an eight-year-old boy and a 15-year-old girl. The third patient was a 10-year-old boy with subarachnoid hemorrhage and compartment syndrome, who ultimately succumbed to his injuries despite undergoing fasciotomy.

In addition to these acute fatalities, the literature reports that delayed deaths may occur in the post-earthquake period as a consequence of environmental factors. For instance, cold exposure in makeshift shelter settings was the cause of over 370 hypothermia deaths in the Haicheng earthquake, while frostbite affected thousands more.^[26] Moreover, delayed casualties in several disasters have been attributed to dehydration, hypothermia, wound infection, or sepsis.^[27,28] Although such phenomena were not observed in our cohort—likely because our referral patients were already past the immediate environmental exposure period.

CONCLUSION

This single center cohort highlights the need for prompt recognition and coordinated multidisciplinary care for pediatric earthquake-related compartment syndrome. Across the dataset, prolonged entrapment, marked rhabdomyolysis, and extensive muscle necrosis were the principal correlates of adverse outcomes (acute kidney injury and limb loss). In ROC analyses, entrapment > 8 hours (AUC=0.84), CK $> 10,000$ U/L, and myoglobin $> 4,000$ ng/mL identified children at increased risk and predicted the need for higher acuity care (Intensive Care Unit [ICU] admission, renal replacement therapy, or urgent surgical intervention), supporting early triage in disaster settings. At the bedside, operational triggers of CK $> 5,000$ U/L and myoglobin $> 3,000$ ng/mL aligned with increased rates of fasciotomy, muscle necrosis, AKI, and amputation. When feasible, early surgical decompression combined with a staged limb salvage pathway—negative pressure wound therapy for edema control and wound bed optimization, and hyperbaric oxygen therapy in selected cases—formed an integral component of care; however, given delayed presentation and the observational design, causal inferences about any single adjunct are not warranted.

Prospective, multicenter studies are needed to validate these cutoffs and to determine whether protocolized use of NPWT/HBOT, alongside timely early fasciotomy, improves limb salvage and renal outcomes in pediatric populations.

Limitations

The retrospective nature of data collection presents inherent challenges, particularly in disaster settings where patient records may be incomplete or fragmented. In this single-center study, while the available records were sufficient, variability in surgical techniques and indications exists. Moreover, due to the geographic distance of our hospital from the earth-

quake zone, all patients were referred after initial stabilization and arrived at least 24 hours post-extrication. This timing precluded any assessment of early fasciotomy outcomes, a limitation that restricts direct comparison with studies evaluating early surgical intervention (within 6–12 hours). Nonetheless, the clinical findings provide valuable insights that may contribute to enhancing disaster management strategies and informing future surgical decision-making, particularly in settings where delayed access to definitive care is inevitable.

Ethics Committee Approval: This study was approved by the Ankara City Hospital Clinical Research Ethics Committee (Date: 10.09.2024, Decision No: E2-24-458).

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ORİJİNAL ÇALIŞMA - ÖZ

2023 Türkiye depreminde kompartman sendromu gelişen çocuk hastalarda tedavi yaklaşımının optimizasyonunda kritik parametrelerin değerlendirilmesi

AMAÇ: 2023 Türkiye depremi, kas-iskelet sistemi yaralanmaları olan çok sayıda çocuk hastanın ortaya çıkmasına neden olmuş, bu hastaların önemli bir kısmında kompartman sendromu (KS) ve crush ile ilişkili komplikasyonlar gelişmiştir. Bu çalışma, afetten etkilenen çocuklarda hastalık şiddeti, böbrek yetmezliği ve ekstremitte kaybı ile ilişkili klinik ve biyokimyasal parametreleri belirlemeyi amaçlamaktadır.

GEREÇ VE YÖNTEM: Deprem sonrasında hastaneye kabul edilen 0–18 yaş aralığındaki 103 pediatrik hasta retrospektif olarak analiz edildi. Demografik veriler, enkaz altında kalma süresi, laboratuvar değerleri (CK, miyogloblin, AST, ALT, üre, potasyum) ve uygulanan tedavi girişimleri (fasyotomi, negatif basınçlı yara tedavisi [NPWT], hiperbarik oksijen tedavisi [HBOT], hemodiyaliz, amputasyon) değerlendirildi. Olumsuz klinik sonuçları öngören kesme (cut-off) değerlerini belirlemek amacıyla ROC (Receiver Operating Characteristic) analizi kullanıldı.

BULGULAR: Kırk yedi hastada (%45.6) toplam 68 ekstremitteyi etkileyen kompartman sendromu gelişmiş olup tümüne fasyotomi uygulanmıştır. On üç hasta (%12.6) ekstremitte amputasyonu gerektirmiş, 19 hasta (%18.4) ise akut böbrek hasarı nedeniyle hemodiyalize alınmıştır. Enkaz altında kalma süresinin 8 saati aşması ($AUC=0.84$, $p<0.001$), $CK>10.000$ U/L ve miyogloblin >4.000 ng/mL düzeyleri, böbrek yetmezliği, fasyotomi ve amputasyon gereksinimi için bağımsız öngörücü parametreler olarak saptanmıştır. Nekrozu bulunan olguların %66'sında negatif basınçlı yara tedavisi (NPWT) ve %85'inde hiperbarik oksijen tedavisi (HBOT) uygulanmış; bu yaklaşımlar sayesinde ekstremitte kurtarma oranı %82'ye ulaşmıştır. Süreğen nekrozu olmayan hiçbir hastada amputasyon gereksinimi oluşmamıştır. Üç hasta (%2.9) ise ağır crush yaralanması ve çoklu organ yetmezliği nedeniyle kaybedilmiştir.

SONUÇ: Uzun süreli enkaz altında kalma süresi ile belirgin yüksek CK ve miyogloblin düzeyleri, deprem sonrası kompartman sendromu gelişen çocuk hastalarda olumsuz klinik sonuçların güvenilir göstergeleridir. Erken tanı, zamanında cerrahi dekompresyon ve NPWT ile HBOT'u içeren yapılandırılmış yara bakım yaklaşımları, geniş ölçekli afet koşullarında erken cerrahi müdahalenin mümkün olmadığı durumlarda yaşam ve ekstremitte korunma oranlarını anlamlı biçimde artırmaktadır.

Anahtar sözcükler: Amputasyon; böbrek yetmezliği; crush yaralanması; çocuk travması, deprem, fasyotomi; HBOT; kompartman sendromu; NPWT.

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