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Original Article

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Analysis of Crush Syndrome Patients With and Without Acute Kidney Injury during the 2023 Kahramanmaraş Earthquake: Experience of a Tertiary Referral Center from Türkiye

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ABSTRACT

Background: Early recognition and practical approaches for prevention and rapid treatment of acute kidney injury (AKI) is crucial for decreasing morbidity and mortality in earthquake victims. This study aims to determine various features of hospitalized crush syndrome patients with or without AKI after the Kahramanmaraş (Türkiye) earthquake in February 2023 and provides the knowledge of a tertiary referral center.

Methods: Crush syndrome was described as the existence of crush injury and systemic manifestations. Patients without preexisting chronic kidney disease were diagnosed to have AKI in the presence of azotemia and/or increased creatinine levels (>2 mg/dl) with or without oliguria and hyperkalemia. Patients with crush syndrome were separated into 2 groups: group 1, AKI (+); group 2, AKI (−).

Results: A total of 2300 earthquake wictims were admitted and compared with regards to the outcomes. After excluding 2147 patients, the final evaluation was performed in 153 patients (group 1, n = 56; and group 2, n = 97). Sepsis, hypovolemic shock, need for intensive care unit (ICU), and mortality rates were higher in AKI (+) patients than AKI (−). Thirty-four patients (22.2%) were admitted to the ICU, and 6 were non-survivors. One hundred forty-seven patients were discharged. Amputation, C-reactive protein (CRP), and each 50000 IU/L increase in creatine phosphokinase (CK) levels were risk factors for the development of AKI ($P < .05$).

Conclusion: Acute kidney injury in crush syndrome contributes to morbidity and mortality. Clinicians should be careful about AKI development in patients with amputation, high CRP, and CK levels >50000.

Keywords: Acute kidney injury, crush syndrome, hemodialysis, Kahramanmaraş earthquake

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INTRODUCTION

On February 6, 2023, 2 major earthquakes occurred in Türkiye, with the epicenters in Pazarcık [moment magnitude (M_w) 7.7; focal depth: 8.6 km] and Elbistan (M_w 7.6; focal depth: 7 km) districts of Kahramanmaraş, at 4:17 AM and 1:24 PM local time, respectively (Figure 1). These earthquakes, both of which are unprecedented in recent history in terms of magnitude and covered area, caused great destruction in a total of 11 provinces. Fourteen million people, namely, approximately 16% of the population of Türkiye, were affected. As of June 2023, there are 50 783 non-survivors and 115 353 injured.[1]

The earthquake victims were transferred to the closest hospitals in Adana and Mersin provinces due to the damaged or destroyed hospitals in the earthquake zone.

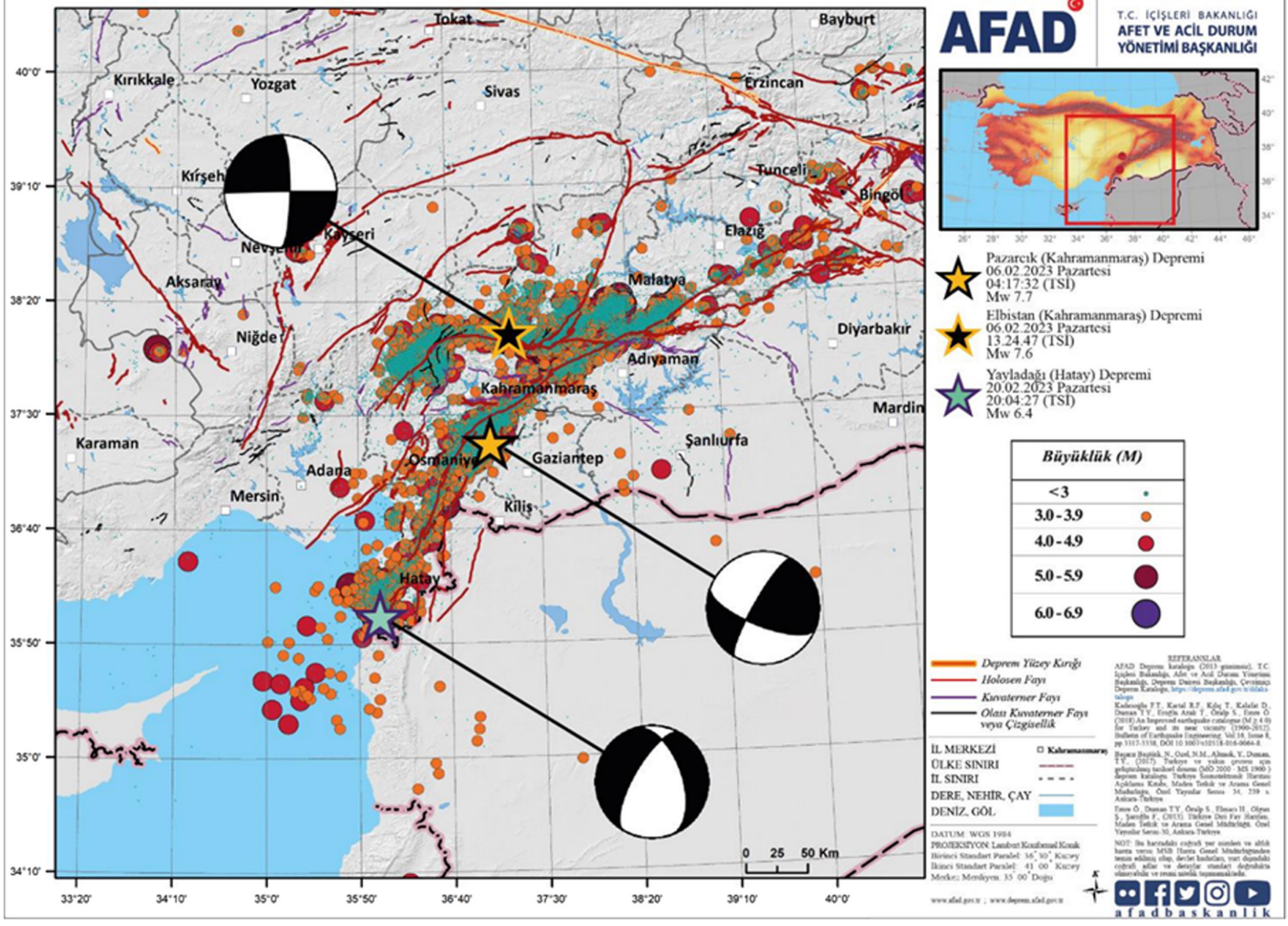

Figure 1. Kahramanmaraş earthquake map[1].

Mersin University Faculty of Medicine was among the hospitals that accepted and treated most of the earthquake victims.

Crush syndrome is the second leading cause of mortality, following the direct traumatic effects caused by the earthquake.[2] Permanent disabilities and loss of organ function may also occur in many patients with crush syndrome. Clinical and laboratory findings at admission in these patients are associated with mortality and morbidity.[3,4] Acute kidney injury (AKI) due to crush syndrome has been reported to be related to increased morbidity and mortality compared to victims with crush syndrome without AKI.[5] So, early recognition and practical approaches for prevention and rapid treatment of AKI are crucial.

This study aims to determine the features of hospitalized crush syndrome patients with or without AKI after the Kahramanmaraş (Türkiye) earthquake in February 2023 and provides knowledge of a tertiary referral center.

MAIN POINTS

- AKI in crush syndrome contributes to morbidity and mortality.
- Early recognition and rapid treatment of crush syndrome and practical approaches to prevent the occurrence of acute kidney injury are crucial for decreasing the rate of morbidity and mortality in earthquake victims.
- Amputation, C-reactive protein, and each 50000 IU/L increase in CK levels were risk factors for the development of AKI.

MATERIAL AND METHODS

Study Design and Subjects

This study was authorized by the Mersin University Ethics Committee with an ethics committee approval number of 29-03-2023/199. This was a retrospective, single center, observational study. Data were collected in Mersin University nephrology clinic in Türkiye between March 6 and 12, 2023. The data were received from the hospital's electronic software system.

Inclusion and Exclusion Criteria

The study included earthquake victims diagnosed with crush syndrome. Among these patients, those who were younger than 18 years of age, discharged from the hospital at the time of data collection, or lacked hospital discharge and were still hospitalized during data collection, referred from other hospitals, or referred to other centers were excluded from the study.

Earthquake victims with crush syndrome were divided into groups as AKI (+) and AKI (–) according to the findings at the time of admission.

Definitions of Terminologies

Crush Injury

Crush injury is damage to the muscle cell as a result of a direct and local injury to the muscles. If patients had a creatine phosphokinase (CK) level higher than at least 5 times the normal level, this was accepted as crush injury (CK >725 U/L).[6]

Crush Syndrome

Crush syndrome was described as the systemic manifestation of crush injury, including AKI and/or acute respiratory distress syndrome (ARDS), dyselectrolytemia, disseminated intravascular coagulation (DIC), hypovolemic shock, arrhythmias, and surgical interventions.[7]

Compartment Syndrome

A localized quick increase of tension within a muscle compartment is defined as compartment syndrome.[7,8]

Acute Kidney Injury

Patients with crush injuries and without known preexisting chronic kidney disease who presented with azotemia (urea >85 mg/dL) and/or increased creatinine levels (>2 mg/dL) with or without oliguria and hyperkalemia were considered to be AKI cases as a result of crush injury.[9]

Biochemical, Clinical, and Demographic Data at the Time of Admission

Baseline data at the time of admission included comorbidities, initial laboratory assessments such as serum CK (<145 U/L), myoglobin (25-72 ng/mL), and creatinine. Patients' requirement for intensive care unit (ICU), injury types [compartment syndrome, extremity fracture, limb trauma, cranial trauma, thoracic trauma (hemothorax, pneumothorax), abdominal trauma], surgical interventions (fasciotomy, splint, external fixation of fractures, amputation of extremities), empirical antibiotic therapy given at admission, length of hospital stay, sepsis, microorganisms obtained from blood, wound or urine cultures, number of patients coming from the city of the earthquake, time under the rubble, time from earthquake zone to hospital arrival (hours), and follow-up parameters were also noted.

Crush syndrome-related abnormalities in all included patients during hospitalization were observed.

Hemodialysis (HD) indications were accepted as blood urea nitrogen ≥100 mg/dL or serum creatinine level exceeding 8 mg/dL, serum potassium ≥7 mEq/L, arterial bicarbonate level <10 mEq/L and pH <7.1, hypervolemia, pulmonary edema, and/or any severe uremic symptoms (uremic pericarditis, confusion due to uremia, persistent nausea and vomiting, etc.). Prophylactic dialysis was applied in hypercatabolic cases if this was deemed necessary, e.g., when potassium increased very rapidly, even without hyperkalemia.[10,11] Hemodialysis treatment was scheduled as per the clinical and laboratory parameters necessitated.

Intensive Care Unit Admission Criteria for Patients

Patients with respiratory failure and requiring or likely to require respiratory support, multiorgan dysfunction syndrome, patients at major risk of morbidity and mortality following surgery, patients with cardiopulmonary arrest, life-threatening arrhythmia, DIC, hypovolemic shock, severe head trauma, and the requirement for hemodialysis in an unstable patient were followed in the ICU.[12]

Follow-up

Patients were followed from the date of hospitalization to the time of reaching any of the outcomes, namely, discharge from the hospital or death.

Patients with and without AKI were compared regarding demographic, clinical, and laboratory data. These comparisons were also applied to subgroups of AKI (+) patients who did or did not require HD.

Patients were assessed for the predicting factors of AKI development and HD requirement.

Statistical Analysis

The frequency counts and percentages were used in categorical variables, while quantitative variables were summarized using means and standard deviations, or medians and interquartile range (IQR) statistics if appropriate. The chi-square and Fisher's exact tests were utilized to analyze qualitative variables, while the Mann–Whitney *U*-test was employed to evaluate non-parametric quantitative variables. The Kaplan–Meier method was used to analyze survival times. Logistic regression analysis was performed to define the odds ratio (OR) and 95% CI associated with AKI and HD requirements. Variables were selected using likelihood ratio tests with forward elimination. Multivariate analyses were performed for variables with $P < .05$ in univariate analyses. Statistical calculations were conducted using Statistical Package for the Social Sciences Statistics software,version 26.0 (IBM SPSS Corp.; Armonk, NY, USA).

Results were noted as statistically significant when *P*-values were equal to or less than .05.

RESULTS

A total of 2300 earthquake victims were admitted. After excluding 2147 patients who had at least one of the exclusion criteria, the final evaluation was performed in 153 patients (AKI (+) group 1, n = 56 and group 2, n = 97) as shown in Figure 2.

The median time period for transfer from the earthquake zone to our hospital was 72.0 (50.3-86.0) hours.

Baseline Clinical Features and Laboratory Values of the Groups at Admission

Table 1 shows the groups' baseline clinical features, laboratory values, and follow-up parameters. Surgical interventions such as amputation, splint, and fixator rates were higher in AKI (+) patients than in AKI (–) patients ($P < .05$).

Follow-up Parameters

All patients received isotonic saline and glucose 5% + 100 mEq bicarbonate as fluids. An average of 300 mL/h of fluid was given to both groups on the first day of hospitalization. On the following days, 3-6 L of fluid was administered per day, depending on the urine output.

Thirty-four (22.2%) of all crush syndrome patients were admitted to the ICU. Of a total of 6 non-survivors (3.9%), all of them had AKI (+) crush syndrome, and all required HD. One hundred forty seven patients were discharged. In both groups, serum creatinine levels and electrolytes returned to the normal biochemical range at discharge.

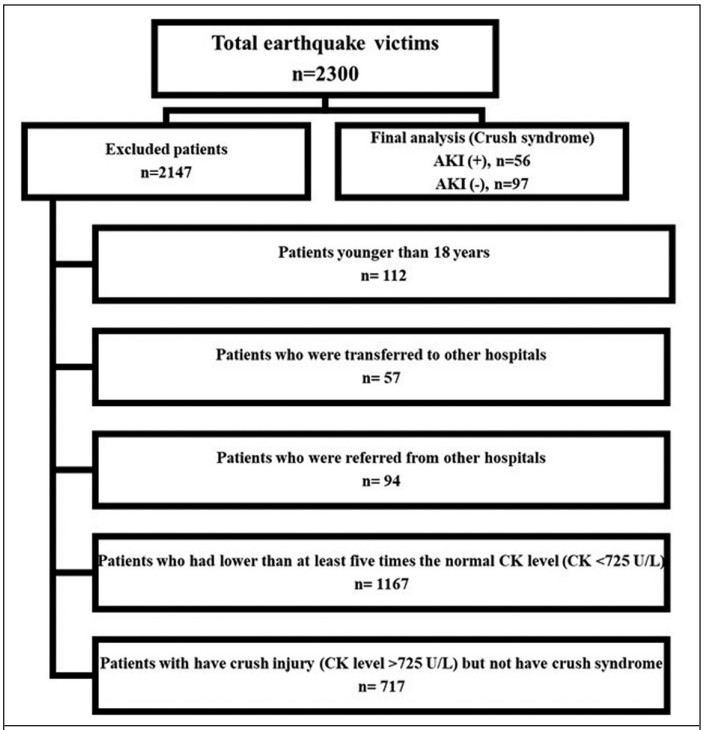

Figure 2. Flowchart illustrating the selection of the study population.

As empirical antibiotic therapy, a combination (70%), ceftriaxone (10.5%), piperacillin/tazobactam (3%), levofloxacin (1%), moxifloxacin (1%), teicoplanin (1%), and others (13.5%) were administered at admission.

Crush syndrome-related abnormalities in all included patients during hospitalization are shown in Table 2.

Acute Kidney Injury Patients Who Required Hemodialysis and Who Did Not Require Hemodialysis

Of the 153 patients with crush syndrome, AKI was detected in 56 (36.6%), 32 of whom required dialysis support. However, 24 of them did not. The most common HD indications were hyperkalemia (71.9%), hypercatabolic states (21.9%), and hypervolemia (6.3%).

The mean number of HD sessions was 5.2 ± 4.8.

Demographic, laboratory, and follow-up parameters of HD requirement and no HD requirement in AKI patients are shown in Table 3.

Predicting Factors of Acute Kidney Injury Development and Hemodialysis Requirement

In the univariate logistic regression analysis, amputation, each 50000 IU/L increase in CK levels, blood glucose level, C-reactive protein (CRP), albumin, ICU requirement, and hemoglobin were the factors predicting for AKI development (Table 4). However, in multivariate analyses, CRP, amputation, and each 50000 IU/L increase in CK levels were risk factors for the development of AKI.

In the univariate logistic regression analysis, each 50000 IU/L increase in CK levels, hemoglobin, and age was a predicting factor for HD requirement (Table 5). But there were no predictive parameters in multivariate analyses.

The Most Important Baseline Demographic, Clinical Characteristics, and Biochemical Features of Non-survivor Earthquake Victims

The number of non-survivors was 6 (4 males and 2 females). The mean age was 50.7 ± 11.4 years.

There was no statistical difference for median time under the rubble between survivors and non-survivors (9 hours versus 6 hours, $P = .77$).

Five patients were hospitalized in the ICU, and 1 patient was admitted to the ward. The mean length of hospital stay was 7.8 ± 7.4 days.

Table 1. Demographic, Laboratory, and Follow-up Parameters of Patients

	AKI (+) (n = 56)	AKI (−) (n = 97)	*P*
Female/male, n %	27/29, (48.2/51.8)	51/46, (52.6/47.4)	.603
Comorbidity, n (%)			.346
No	41 (73.2)	63 (64.9)	
HT	8 (14.3)	10 (10.3)	
DM	3 (5.4)	16 (16.5)	
Heart failure	0 (0)	1 (1.0)	
Malignancy	1 (1.8)	2 (2.1)	
Other	6 (10.7)	5 (5.1)	
Clinical parameters [median, (IQR 25-75)]			
Age (years)	39.0 (26.0-61.0)	40.0 (25.0-50.0)	.683
Time under the rubble (hours)	12.0 (7.0-30.0)	9.0 (6.0-36.0)	.968
Length of hospital stays (days)	19.0 (8.0-26.0)	6.0 (5.0-14.0)	<.001
SBP (mm Hg)	131.0 (120.0-140.0)	131.0 (120.0-135.0)	.362
DBP (mm Hg)	80.0 (75.0-85.0)	78.0 (67.0-85.0)	.102
Heart rate (beats/minute)	96 (80-106)	90 (86-96)	.072
Fever (˚C)	36.0 (36.0-36.2)	36.0 (36.0-36.2)	.202
Oxygen saturation (%)	95 (94-97)	96 (95-98)	.931
Injury type and surgical intervention n (%)			
Limb trauma	23 (41.1)	48 (49.5)	.315
Cranial trauma	7 (12.5)	9 (9.3)	.530
Abdominal trauma	4 (7.1)	6 (6.2)	.817
Thoracic trauma	19 (33.9)	36 (37.1)	.692
Extremity fracture	18 (32.1)	40 (41.2)	.264
Compartment syndrome	10 (17.9)	16 (16.5)	.829
Fasciotomy	6 (10.7)	15 (15.5)	.411
Amputation	14 (25.0)	6 (6.2)	<.001
Splint	15 (26.8)	40 (41.2)	.073
Fixator	8 (14.3)	28 (28.9)	.041
Laboratory parameters at the time of admission [median, (IQR 25-75)]			
FBG (mg/dL)	126.0 (102.0-148.0)	112.0 (98.0-124.0)	.012
Urea (mg/dL)	116.0 (89.0-190.0)	36.0 (26.0-57.0)	.005
Creatinine (mg/dL)	3.9 (2.0-5.1)	0.6 (0.5-0.9)	<.001
Sodium (mmol/L)	130.0 (127.0-136.0)	136.0 (132.0-137.0)	<.001
Potassium (mmol/L)	5.2 (4.7-6.2)	4.0 (3.7-4.4)	<.001
Calcium (mg/dL)	7.8 (7.0-8.4)	8.4 (7.8-8.7)	.004
Phosphorus (mg/dL)	5.1 (3.5-6.8)	2.7 (2.3-3.4)	<.001
AST (IU/L)	649.0 (223.0-1224.0)	152.0 (78.0-314.0)	<.001
ALT (IU/L)	287.0 (142.0-584.0)	79.0 (57.0-228.0)	<.001

(*Continued*)

Table 1. Demographic, Laboratory, and Follow-up Parameters of Patients (*Continued*)

	AKI (+) (n = 56)	AKI (−) (n = 97)	*P*
LDH (IU/L)	1600.0 (688.0-2711.0)	477.0 (312.0-624.0)	<.001
CK (IU/L)	50386.0 (15268.0-136946.0)	7054.0 (3609.0-17615.0)	<.001
Myoglobin (ng/mL)	4007.0 (3692.0-4007.0)	958.0 (385.0-385.0)	<.001
CRP (mg/dL)	167.0 (119.0-215.0)	116.0 (58.0-164.0)	<.001
Albumin (g/dL)	2.5 (2.4-2.8)	2.8 (2.5-3.1)	.006
Leukocyte (10^3/mm^3)	19.2 (14.1-14.1)	12.9 (10.1-17.1)	<.001
Hemoglobin (g/dL)	13.0 (11.5-15.0)	12.0 (9.6-13.5)	.006
Thrombocyte (10^3/mm^3)	217.0 (163.0-313.0)	247.0 (201.0-308.0)	.167
Follow-up parameters [median, (IQR 25-75)]			
Amount of parenteral fluid administered on the first day (mL/h)	300.0 (250.0-300.0)	300.0 (200.0-300.0)	.013
Discharge creatinine (mg/dL)	0.7 (0.4-1.0)	0.5 (0.4-0.6)	<.001
Discharge CK (U/L)	391.0 (119.0-1116.0)	650.0 (185.0-1502.0)	.075
Sepsis, n (%)	22 (39.3)	14 (14.4)	<.001
Hypovolemic shock, n (%)	5 (8.9)	2 (2.1)	.050
ARDS, n (%)	4 (7.1)	5 (5.2)	.615
DIC, n (%)	2 (3.6)	1 (1.0)	.275
Arrhythmia, n (%)	3 (5.4)	0 (0)	.021
ICU need, n (%)	19 (33.9)	15 (15.5)	.008
Mortality, n (%)	6 (10.7)	0 (0)	<.001
Discharge, n (%)	50 (89.3)	97 (100)	<.05

ALT, alanine transaminase; ARDS, acute respiratory distress syndrome; AST, aspartate transaminase; CK, creatine phosphokinase; CKD, chronic kidney disease; CRP, C-reactive protein; DBP, diastolic blood pressure; DIC, disseminated intravascular coagulation; DM, diabetes mellitus; FBG, fasting blood glucose; HT, hypertension; ICU, intensive care unit; IQR, interquartile range; LDH, lactate dehydrogenase; SBP, systolic blood pressure.

At the time of death, 2 patients had ARDS, 2 patients had ARDS + sepsis, 2 patients had sepsis, and 2 patients had DIC.

Cranial, thoracic, or abdominal trauma were not detected in patients who were non-survivors. Compartment syndrome was diagnosed in 3 patients. Fasciotomy was performed in 1 patient while amputation in 3 patients.

The predictive cutoff value of CK for crush injuries was found to be 6967 IU/L. The sensitivity and specificity of these CK levels were found to be 75% and 76.2%, respectively.

Kaplan–Meier plots of patient survival are presented in Figure 3. Of note, the in-hospital mortality rate was significantly different between the AKI (+) and AKI (−) (log-rank $P = .005$).

Figure 4 shows that there was a negative relationship between age and time under rubble ($r = -0.156$, $P = .042$). A significant negative correlation was found between age and CK levels ($r = -0.233$, $P < .001$) (Figure 5).

DISCUSSION

This study evaluates biochemical, clinical, and demographical data in Kahramanmaraş earthqauke victims who have crush syndrome with or without AKI. According to the results of our study presenting the experience of a tertiary referral center, intravenous fluid treatment does not cause any adverse results, such as development of prerenal AKI or hypervolemia, when administered under close monitoring. The major predictors for the development of AKI were detected to be a 50000 IU/L increase in CK levels, CRP levels, and amputation.

It's known that the mortality rate is higher in AKI (+) crush syndrome patients than in AKI (−).[13] In the current study, we could not compare the mortality rates in the study groups. Mortality among the patients with crush syndrome following the Marmara earthquake was reported to be 15.2%,[9] whereas, in our study, it was 10.7% (6/56) in AKI (+) crush syndrome patients. None of the patients with AKI (−) crush syndrome died. More seriously injured victims may have been admitted

Table 2. Crush Syndrome-Related Abnormalities in all Included Patients During Hospitalization

Trauma and surgery intervention	**n (%)**
Limb trauma	71 (46.4%)
Abdominal trauma	65 (42.4%)
Extremities fracture	58 (37.9%)
Compartment syndrome	26 (16.9%)
Fasciotomies	21 (13.7%)
Amputation	20 (13%)
Clinic	**n (%)**
Infection	47 (30.71%)
Sepsis	36 (23.5%)
ARDS	9 (5.8 %)
Hypovolemic shock at admission	7 (4.5%)
DIC	3 (1.9%)
Arrhythmia	3 (1.9%)
Oliguria	6 (3.9%)
Microorganism detected in blood culture	**n (%)**
Enterococcaceae	15 (9.8%)
Actinobacteria	14 (9.2%)
Klebsiella	9 (5.9%)
Escherichia coli	8 (5.2%)
MRSA	3 (2%)
MSSA	2 (1.3%)
Electrolyte disorders at admission	**n (%)**
Hypocalcemia	87 (56.8%)
Hyponatremia	67 (43.7%)
Hyperphosphatemia	31 (20.2%)
Hyperkalemia	20 (13%)
Hypokalemia	14 (9.1%)

ARDS, acute respiratory distress syndrome; CK, creatine phosphokinase; DIC, disseminated intravascular coagulation; MRSA, methicillin-resistant *Staphylococcus aureus*; MSSA, methicillin-sensitive *Staphylococcus aureus*.

to the city hospitals that were closer to the epicenter, and/or most of the patients may have been non-survivors under the rubble. Additionally, Marmara earthquake experiences were applied in our center. These factors may probably be the reasons for the lower mortality rate in our study. Sever et al[3] declared that the mortality percentage of the dialyzed Marmara earthquake victims was 17.2%, significantly higher than that of non-dialyzed patients with kidney problems. This mortality rate in AKI patients that required HD was similar to our study (18.8%).

Two thousand three hundred earthquake victims were admitted to our hospital within a week. Our study included a total of 153 crush syndrome (6%) patients, of whom 56 were AKI (+) patients, 32 of whom required dialysis support, and 97 patients were AKI (–). The incidence of crush syndrome following major earthquakes has not been well described, and 2-5% of the earthquake victims presented with crush syndrome.[10] Also, information regarding the incidence of AKI caused by crush syndrome is scarce. Of the 2702 traumatized victims during the Kobe earthquake, 372 (13.8%) were detected to have crush syndrome, and 202 (7.5%) suffered from AKI.[14]

The optimal fluid management has prime importance to prevent either hypervolemia or prerenal AKI. The Marmara earthquake experience of the investigators has helped us with early, suitable fluid therapy after admission.[14] Due to the damaged or destroyed hospitals in the earthquake zone and the chaotic conditions, it was not known exactly how much fluid was given after the event until their admission to our hospital. Additionally, aggressive fluid treatment was not administered at admission because of the relatively long period of time for arrival at our hospital. Intravenous fluid (isotonic saline and glucose 5% + 100 mEq bicarbonate) was administered to the patients under close monitoring, namely, 300 mL/h on the first day of hospitalization, followed by 3-6 L/day in the following days depending on the volume status and urine output. Hypervolemia constituted 6% of HD indications at the time of hospitalization. During hospital stay, none of the AKI (–) crush syndrome patients developed prerenal AKI and hypervolemia. Although hypovolemic shock was detected in 7 patients at the time of hospitalization, none of our patients developed hypovolemic shock during their hospitalization. None of our patients, who were non-survivors, had hypovolemic shock at the time of mortality. Thus, we believe that controlled fluid treatment can prevent both the development of prerenal AKI and hypervolemia during hospitalization.

Hyperkalemia and hyperphosphatemia due to the release of potassium and phosphorus from injured muscle cells,[15] hypercatabolic situations, and hypervolemia are the major causes for the requirement of HD in patients with crush syndrome.[16] In the present study, the requirement of HD among AKI patients was 57.14% (32/56) while it was 61% (123/202) in the Hanshin-Awaji (Kobe) earthquake[4] and 74.6% (477/639) in the Marmara earthquake study.[3] It was reported in the study by Sever et al that the most important and fatal medical complication in crush syndrome patients is hyperkalemia. They found that in hospitalized patients within the first 3 days of the Marmara earthquake, the mean serum potassium level was 5.4±1.3 mEq/L.[17] In our study, we found that median serum potassium levels were higher in AKI (+) compared to AKI (–) patients (5.2 versus 4.0 mEq/L). Serum potassium levels in 2 patients were above 7 mEq/L, while it was 6-7 mEq/L in 18 patients and below 3.5 mEq/L in 14 patients. In earthquake victims, serum potassium levels may vary depending on the trauma severity. However,

Table 3. Demographic, Laboratory, and Follow-up Parameters of Hemodialysis Requirement and No Hemodialysis Requirement in Acute Kidney Injury patients

	Hemodialysis (+) (n = 32)	Hemodialysis (−) (n = 24)	*P*
Female/male, n %	20/12 (62.5/37.5)	15/9 (62.5/37.5)	.064
Comorbidity, n (%)			.100
No	27 (84.4)	12 (50)	
HT	0 (0)	3 (20.8)	
DM	3 (9.4)	5 (20.8)	
Malignancy	1 (3.1)	0 (0)	
Other	2 (6.2)	6 (25)	
Clinical parameters [median, (IQR 25-75)]			
Age (years)	34.5 (23.5-51.2)	47.0 (35.5-66.0)	.019
Time under the rubble (hours)	11.5 (6.0-25.5)	13.0 (7.0-48.0)	.118
Length of hospital stays (days)	20.0 (9.5-25.2)	10.0 (6.5-30.0)	.248
SBP (mm Hg)	134.5 (123.7-141.2)	126.0 (120.0-135.5)	.992
DBP (mm Hg)	79.0 (73.5-87.0)	80.0 (78.0-81.0)	.662
Heart rate (beats/minute)	96.000 (80.0-102.7)	101.0 (82.0-116.0)	.856
Fever (°C)	36.0 (36.0-36.0)	36.0 (36.0-36.0)	.119
Oxygen saturation (%)	96.0 (94.7-99.0)	95.0 (94.0-96.0)	.133
Injury type and surgical intervention n (%)			
Limb trauma	12 (37.5)	11 (45.8)	.530
Cranial trauma	3 (9.4)	4 (16.7)	.414
Abdominal trauma	2 (6.3)	2 (8.3)	.765
Thoracic trauma	11 (34.4)	8 (33.3)	.935
Fracture	9 (28.1)	9 (37.5)	.457
Compartment syndrome	8 (25.0)	2 (8.3)	.107
Fasciotomy	4 (12.5)	2 (8.3)	.618
Amputation	7 (21.9)	7 (29.2)	.533
Splint	7 (21.9)	8 (33.3)	.338
Fixator	5 (15.6)	3 (12.5)	.741
Laboratory parameters at the time of admission [median, (IQR 25-75)]			
FBG (mg/dL)	129.5 (100.0-153.2)	125.0 (106.0-143.5)	.251
Urea (mg/dL)	126.0 (96.2-205.5)	99.0 (55.5-174.5)	.298
Creatinine (mg/dL)	4.2 (3.3-6.3)	2.2 (1.7-3.5)	.001
Sodium (mmol/L)	128.5 (125.0-130.0)	135.0 (131.0-136.0)	.006
Potassium (mmol/L)	5.9 (5.3-6.5)	4.6 (3.9-4.8)	<.001
Calcium (mg/dL)	7.4 (6.8-7.9)	8.2 (7.6-8.6)	.007
Phosphorus (mg/dL)	5.8 (4.3-7.8)	4.9 (2.1-6.3)	<.001
AST (IU/L)	963.5 (509.8-2011.0)	266.0 (128.5-542.5)	<.001
ALT (IU/L)	419.0 (266.2-760.5)	142.0 (72.5-221.5)	.009

(*Continued*)

Table 3. Demographic, Laboratory, and Follow-up Parameters of Hemodialysis Requirement and No Hemodialysis Requirement in Acute Kidney Injury patients (*Continued*)

	Hemodialysis (+) (n = 32)	Hemodialysis (−) (n = 24)	*P*
LDH (IU/L)	2240.0 (1220.5-3783.5)	713.0 (381.5-1377.0)	.014
CK (IU/L)	96227.0 (43763.0-217197.50)	21685.0 (5084.5-31563.5)	.020
Myoglobin (ng/mL)	4007.0 (4007.0-4007.0)	2775.0 (1625.0-4007.0)	.850
CRP (mg/dL)	181.0 (135.5-225.7)	136.0 (108.0-182.0)	.163
Albumin (g/dL)	2.5 (2.4-2.8)	2.5 (2.2-2.7)	.784
Leukocyte (10^3/mm^3)	19.4 (14.8-27.3)	18.9 (13.7-24.0)	.141
Hemoglobin (g/dL)	13.4±3.1	12.0 ± 2.7	.006
Thrombocyte (10^3/mm^3)	222.0 (163.5-301.5)	217.0 (164.5-369.5)	.962
Follow-up parameters [median, (IQR 25-75)]			
Amount of parenteral fluid administered on the first day (mL/h)	300 (225-300)	300 (250-300)	220
Discharge creatinine (mg/dL)	0.7 (0.4-1.1)	0.4 (0.2-0.7)	.007
Discharge CK (U/L)	164.5 (96.0-491.0)	1087.0 (459.0-1412.5)	.235
Sepsis, n (%)	13 (40.6)	9 (37.5)	.813
Hypovolemic shock, n (%)	5 (15.6)	0 (0)	.042
ARDS, n (%)	4 (12.5)	0 (0)	.072
DIC, n (%)	2 (6.3)	0 (0)	.212
Arrhythmia, n (%)	3 (9.4)	0 (0	.123
ICU need, n (%)	14 (43.8)	5 (20.8)	.073
Mortality, n (%)	6 (18.8)	0 (0)	.025

ALT, alanine transaminase; ARDS, acute respiratory distress syndrome; AST, aspartate transaminase; CK, creatine phosphokinase; CKD, chronic kidney disease; CRP, C-reactive protein; DBP, diastolic blood pressure; DIC, disseminated intravascular coagulation; DM, diabetes mellitus; FBG, fasting blood glucose; HT, hypertension; ICU, intensive care unit; IQR, interquartile range; LDH, lactate dehydrogenase; SBP, systolic blood pressure.

Table 4. Logistic Regression Analysis for Parameters Predicting Acute Kidney Injury Development

	Univariate Analysis		Multivariate Analysis	
	OR (95% CI)	*P*	OR (95% CI)	*P*
BGL	1.006 (1.001-1.011)	.011		
CRP	1.011 (1.007-1.016)	<.001	1.009 (1.001-1.017)	.036
Albumin	0.238 (0.105-0.538)	.001		
Hemoglobin	1.174 (1.033-1.333)	.014		
Amputation	6.326 (2.398-16.685)	<.001	33.221 (2.397-460.338)	.009
CK level/50000	11.521 (4.844-27.398)	<.001	10.440 (2.748-39.666)	.001
ICU needs	3.263 (1.569- 6.788)	.002		

CK, creatine phosphokinase; CRP, C-reactive protein; BGL, blood glucose level; ICU, intensive care unit; SBP, systolic blood pressure.

the hyperkalemia risk may persist throughout hospitalization, even if patients are normokalemic at presentation.

In the Kahramanmaraş earthquake, the median time under rubble [8.5 (5.0-24.0) hours] was shorter than the Marmara (11.7 ± 14.3 hours), Kobe (9 ± 13 hours), and Erzincan (9 ± 5 hours) earthquakes.[9,13,14] It was emphasized that a minimum four hours of compression of muscles is necessary for crush injury to develop.[18] Sever et al reported in their article that time under the rubble is not a prognostic factor of mortality or AKI for patients with crush syndrome, probably because only earthquake victims with minimal or modest injuries can survive under the rubble for a longer time. We found that the median time under the rubble was 12 hours in AKI (+) and 9.0 hours in AKI (−) patients. We detected that the shortest period that the patients remained under the rubble was 1 hour, and the longest period was 96 hours. However, the time under the rubble is not a prognostic indicator for AKI and mortality. In the current study, there was no statistical difference in the median time under rubble between survivors and non-survivors.

Bacterial infection and sepsis are common in earthquake victims and are associated with increased mortality. We detected

Table 5. Logistic Regression Analysis for Parameters Predicting Hemodialysis Requirement

	Univariate Analysis		Multivariate Analysis	
	OR (95% CI)	*P*	OR (95% CI)	*P*
Age	0.962 (0.932-0.993)	.016	0.972 (0.937-1.008)	.122
Gender, male	2.500 (0.855-7.314)	.094		
Compartment syndrome	3.667 (0.701-19.168)	.124		
Hemoglobin	1.310 (1.064-1.613)	.011		
ICU	3.111 (0.934-10.364)	.065		
CK level >50000	1.647 (1.021-2.657)	.041	1.214 (0.812-1.814)	.344

CK, creatine phosphokinase; ICU, intensive care unit.

sepsis in 36 (23.5%) patients. This rate was similar to that reported with Marmara earthquake victims (18.9%).[19] The Marmara earthquake study found that sepsis was associated with increased mortality.[19] However, sepsis was present in 3 out of 6 of our earthquake victims who were non-survivors. Sepsis rate and CRP levels were quite higher in our AKI (+) crush syndrome patients than in AKI (–) patients. This study found that CRP levels are a major risk factor for AKI.

In the present series, low serum albumin reflects a poor prognosis for kidney function. Serum albumin levels were lower in AKI (+) crush syndrome patients than in AKI (–) patients. Furthermore, hypoalbuminemia was a risk factor for AKI development (Table 4). The most common reason for reduced plasma albumin levels is an acute-phase response. Hemodilution, loss of extravascular area, increased consumption by injured muscle cells, malnutrition, capillary leakage, and decreased synthesis are among the other causes of hypoalbuminemia.[20]

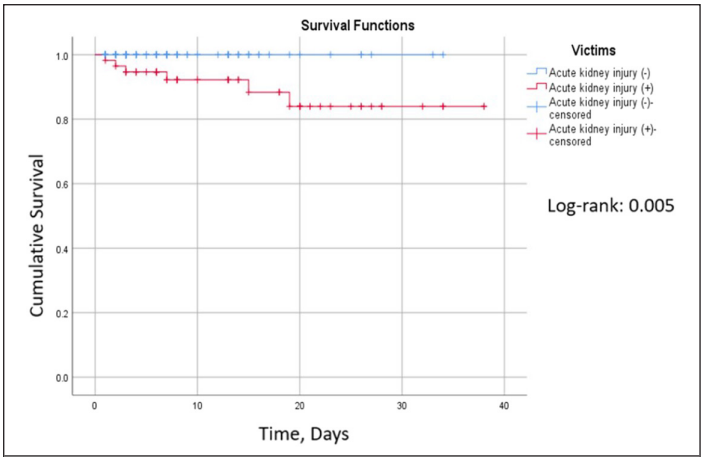

Figure 3. Kaplan–Meier plots of patient survival.

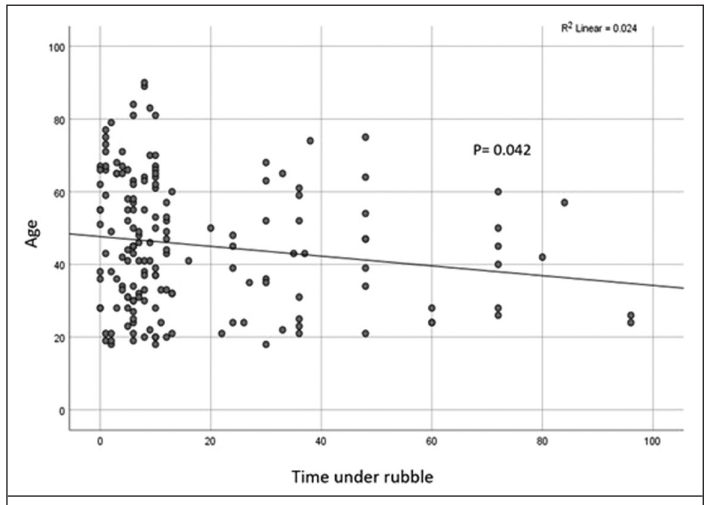

Figure 4. Correlation between age and time under rubble.

In the Marmara earthquake, the mean age of victims with AKI was 33 ± 14 and 31 ± 15 years for male and females, respectively.[21] Like the victims of the Marmara earthquake, both our AKI (–) and AKI (+) patients were young (40.0 vs. 39.0 years). The median age of AKI patients that required HD was significantly lower than that of AKI patients that did not require HD. The univariate analysis showed that the HD requirement increased with decreased age (OR, 95% CI, 0.932-0.993, *P* = .016). In our study, we found the sensitivity and specificity of CK levels (6967 IU/L) for crush injury were 75% and 76.2%, respectively. A negative correlation was found between age and time spent under rubble. Most of our patients with both AKI (+) and AKI (–) crush syndrome did not have comorbidities (73.2% vs. 64.9%), and the patients were relatively young. It may be commented that

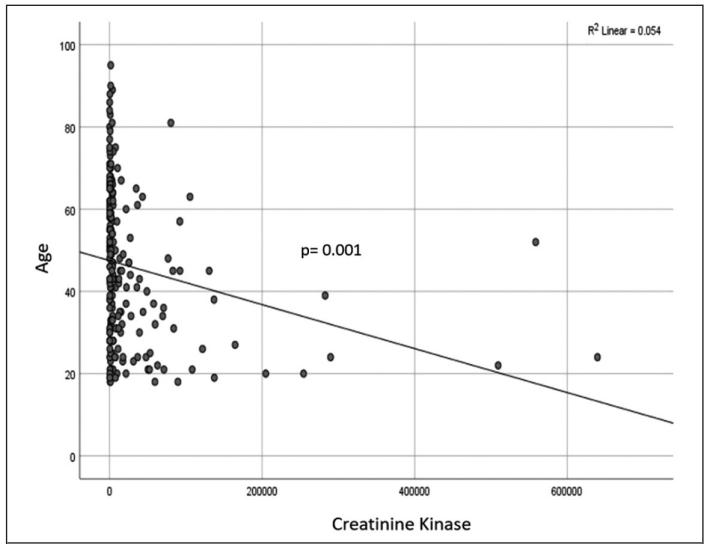

Figure 5. Correlation between age and CK levels.

many elderly patients may have been non-survivors under the rubble, while younger patients remained longer under the rubble and were more affected by the intensity of the earthquake. These results may explain why young age is a risk factor for HD requirements.

In earthquakes, most hospital admissions happen within the first 3 days after the event.[22] Compatible with this conjecture, only 2.4% of the 902 patients were admitted 7 days or more after the Armenian earthquake.[23] In the Marmara earthquake study, a similar result was observed: earthquake patients were admitted the most 3-7 days after the earthquake.[24] In our series, a similar trend was observed. The median time from the earthquake zone to hospital arrival of all included study patients was found to be 72.0 (50.3-86.0) hours. Patients with AKI came to the hospital from the earthquake zone in a shorter time than AKI (−) patients (62.36 ± 27.1 vs. 75.68 ± 34.1 hours; $P < .05$). Due to the violence of the trauma, AKI (+) patients may have been brought to the hospital in a shorter time than AKI (−) patients by their relatives or 112 emergency services.

Amputation has some additional risks for AKI, such as hypotension and bleeding during surgery. Amputation was performed on 20 patients (20/153, 13%) in our hospital, and it was more frequent in patients with AKI. We found that amputation was a risk factor for AKI.

Low values of hemoglobin may indicate either blood loss or hemodilution in patients who received large amounts of fluid. In contrast, a high hemoglobin value in crush syndrome victims showed severe dehydration.[25] In our AKI (+) patients, hemoglobin values were higher than in AKI (−) patients at the time of hospitalization. The hemoglobin value was a risk factor for AKI development in our study.

Median CK levels were quite high in both AKI (+) and AKI (−) patients, probably related to the severity of the trauma. In most of our patients, blood glucose level was found to be above the normal value. In these patients, that may be related to the stress due to trauma. CK > 50000 IU/L levels, ICU requirement, and blood glucose level were independent risk factors for AKI.

Limitations

First, our study was conducted at a single center. Second, we were unable to perform a mortality analysis due to our mortality rate.

Acute kidney injury in crush syndrome contributes to morbidity and mortality. Clinicians should be careful about the development of AKI in patients with amputation, high CRP, and CK level > 50000 IU/L. Patients should be closely followed for controlled fluid administration at the time of hospitalization. This approach can prevent both the development of prerenal AKI and hypervolemia.

Kahramanmaraş Earthquake Study Group

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