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The Effect of Fasciotomy Timing on Limb Vitality and Functionality in Kahramanmaras/Turkey Earthquake

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The earthquakes in Kahramanmaras, Turkey, on February 6, 2023, caused many crush injuries complicated by acute compartment syndrome (ACS). This study assessed how fasciotomy timing (rubble-to-fasciotomy time, RFT) affects survival, limb viability, and functional outcomes.We retrospectively analyzed 145 patients (mean age: 29.2 ± 17.5 years) with crush injuries and ACS who underwent fasciotomy. RFT was grouped as 0–24, 25–48, 49–72, 73–96, and >97 hours. Outcomes were classified as full minor deficits, major deficits, amputation and death. Patients with full recovery or minor deficits were considered to have "good outcome," while those with major deficits or amputation were labeled "poor outcome."Full recovery was observed in 35 patients (24.1%), whereas 110 patients (75.9%) experienced complications. The mean RFT was significantly shorter in the good outcome group (25.1 ± 10.9 hours) compared with the poor outcome group (47.1 ± 23.4 hours, $p < 0.05$). No patients achieved full recovery when fasciotomy was performed after 48 hours. hyperbaric oxygen therapy(HBOT) use was associated with higher rates of good outcomes ($p = 0.006$), whereas dialysis requirement was associated with poorer outcomes ($p = 0.009$). Logistic regression analysis demonstrated that HBOT and dialysis remained statistically significant variables associated with functional outcomes (HBOT: $p = 0.012$; dialysis: $p = 0.010$). Fasciotomy within 24 hours is essential for functional recovery in ACS. Delays beyond 24 hours resulted in worsening outcomes, with no full recovery after 48 hours. Early surgical intervention in disaster settings is crucial to preserve limb function and viability.

Keywords: Earthquake, acute compartment syndrome, fasciotomy, amputation, crush syndrome, hyperbaric oxygen therapy.

INTRODUCTION

Turkey is located on one of the world's major earthquake fault lines. On February 6, 2023, two devastating earthquakes with magnitudes of 7.7 Mw and 7.6 Mw struck the Kahramanmaraş region within a nine-hour interval. As a result of this disaster, more than 50,000 people lost their lives, and over 120,000 were injured[1].

Earthquake-related injuries encompass a broad spectrum, ranging from minor soft tissue damage to fatal trauma due to entrapment under debris. These injuries include open and closed fractures, pelvic, thoracic, and abdominal trauma, amputations, head and spinal injuries, crush injuries, and acute compartment syndrome (ACS)[2,3].

ACS was first described by Volkmann[4]. Following compression, increased compartmental pressure may initially impair lymphatic and venous drainage, leading to elevated capillary pressure. This condition may result in arteriolar collapse, ischemia, and subsequent tissue necrosis[5]. Earthquake-related crush injuries frequently lead to the development of ACS, with or without associated fractures, and can be fatal if left untreated[6]. Timely intervention is crucial, as untreated ACS can result in severe disability, limb loss, or even death, necessitating urgent surgical management[7].

Diagnosis of ACS is primarily based on clinical findings. Key indicators include disproportionate pain, sensory disturbances, pain exacerbated by passive stretching, diminished muscle strength, and palpable swelling in the affected compartment[5,7,8]. While clinical assessment remains the cornerstone of diagnosis, compartment pressure measurements

provide valuable objective support[9]. Fasciotomy is the first-line treatment for ACS, and its success is highly time-dependent[10].

This retrospective study aims to investigate the impact of fasciotomy timing on survival, limb viability, and functional outcomes in patients who developed ACS following entrapment during the earthquake. Additionally, the study evaluates the effects of adjunctive therapies such as hyperbaric oxygen therapy (HBOT) and dialysis on functional recovery.

MATERIALS AND METHODS

A total of 145 patients who sustained crush injuries due to the earthquakes on February 6, 2023, were admitted to our hospital between February 6 and 28, 2023. These patients were retrospectively analyzed after being clinically diagnosed with ACS and undergoing emergency fasciotomy. Ethical approval for this retrospective study was obtained from the Mersin University Ethics Committee on January 10, 2024 (approval number: 2024/024), after the completion of the study period. The ethics committee explicitly approved the retrospective analysis of the patient data included in this study.

Inclusion criteria were: clinical diagnosis of ACS following entrapment under debris during the earthquake and performance of fasciotomy at our institution. Patients who underwent fasciotomy at another facility, died intraoperatively, lacked accessible retrospective records, had no identification data, or failed to attend follow-up outpatient visits were excluded from the study.

The diagnosis of ACS was made clinically by orthopedic specialists. To support the diagnosis and assess the severity of the crush injury, the Mangled Extremity Severity Score (MESS) was calculated, providing an objective evaluation of injury severity based on parameters such as injury mechanism, limb ischemia, shock, and patient age[11].

Fasciotomy was performed on patients with a

Fig. 1 — Illustrative Cases of Compartment Syndrome in Disaster Victims Rescued from Rubble. a) 24-year-old female, left cruris, elapsed time: 14 hours; b) 33-year-old male, left hand and fingers, elapsed time: 34 hours; c) 46-year-old female, left foot and fingers, elapsed time: 28 hours; d) 42-year-old female, left cruris and foot, elapsed time: 41 hours; e) 12-year-old female, right thigh and cruris, elapsed time: 18 hours; f) 30-year-old male, both feet and right cruris, elapsed time: 51 hours.

clinical diagnosis of ACS and a MESS score below 7. In cases with a MESS score of 7 or higher, fasciotomy was considered if muscle tissue was deemed viable. Patients with established necrosis in the affected limb, who were unlikely to benefit from fasciotomy, underwent amputation (Figure 1).

All fasciotomy procedures were performed by orthopedic surgeons under sterile operating room conditions (Figure 2). All patients were evaluated after at least one year of follow-up. The mean follow-up duration was 13.2 months, the median follow-up duration was 12 months, and the overall follow-up range was 12 to 18 months (Figure 3). Three orthopedic specialists evaluated functional outcomes at the postoperative follow-up. The majority of assessments were performed through direct, in-clinic examination, while structured telephone interviews were used for patients unable to attend in person. The evaluators were not blinded.

The interval between entrapment and fasciotomy was calculated in hours and defined as Rubble-to-Fasciotomy Time (RFT). RFT was categorized into the following groups: 0–24 hours, 25–48 hours, 49–72 hours, 73–96 hours, and >97 hours. Patients who received adjunctive therapies such as HBOT or dialysis were also recorded.

Post-fasciotomy outcomes were evaluated under four main categories: good outcome, poor outcome, amputation, and death. Neurological deficits were further subdivided into major and minor deficits. Among patients with major deficits, significant functional impairments such as motor-sensory loss, foot drop, and wrist drop were considered. Minor deficits included mild movement restrictions or regional hypoesthesia/hyperalgesia in areas such as the fingers, wrist, or ankle. Patients who achieved full recovery, had minor deficits, and were able to walk independently were classified in the "good outcome" group. In contrast, patients with major deficits resulting in significant limitations in ambulation or upper extremity use, as well as those with amputations, were included in the "poor outcome" group.

Statistical Analysis

Statistical analyses were performed using SPSS for Windows version 25.0. The normality of the variables was assessed both visually and analytically using the Kolmogorov-Smirnov and Shapiro-Wilk tests. A p-value greater than 0.05 in the Kolmogorov-Smirnov test was considered indicative of a normal distribution. When normality could not be established, comparisons between groups were conducted using the Mann-Whitney U test. Categorical variables were compared using the Chi-square test. Logistic regression analysis was employed to evaluate the effect of various parameters on the outcomes. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Between February 6 and February 28, 2023, a total of 12,815 patients (6,898 adults and 5,917 children)

Fig. 2 — Intraoperative fasciotomy images of patients with acute compartment syndrome.
a) Fasciotomy of the forearm and hand; b) Fasciotomy of the thigh and cruris, external fixation was applied to the same patient due to femur fracture; c) Fasciotomy of the thigh through a single lateral incision; d) Lateral incision for leg fasciotomy.

Fig. 3 — Examples illustrating the one-year condition of extremities following fasciotomy.
a) 66 years old female, fasciotomy after 42 hours; b) 22 years old female, fasciotomy after 16 hours; c) 21 years old female, fasciotomy after 30 hours; d) 15 years old male, fasciotomy after 25 hours.

were transferred from the earthquake zone to our hospital. Of these, 1,272 patients (958 adults and 314 children) were evaluated by the Department of Orthopedics and Traumatology. Fasciotomy was performed in 145 patients, involving a total of 243 anatomical compartments. Among these patients, 81 (55.8%) were female and 64 (44.1%) were male. The mean age was 29.2 ± 17.5 years (range: 2–76 years). The demographic and clinical characteristics of the fasciotomy group are summarized in Table I. In terms of functional outcomes, 35 patients (24.1%) achieved full recovery, while 110 patients (75.9%) experienced complications such as neurological deficits, amputations, or death. Specifically, 64 patients (44.1%) had major neurological deficits, 13 patients (9.0%) had minor deficits, 21 patients (14.5%) required amputations, and 12 patients (8.3%) died. Fasciotomy timing played a critical role in clinical outcomes. Patients who underwent surgery within the first 24 hours had the highest full recovery rate (31 patients, 21.4%) and the lowest complication rates. As the time to fasciotomy (RFT) increased, the rates of neurological deficits and amputations rose significantly. No patients who underwent fasciotomy after 48 hours achieved full recovery. The mean RFT in the good outcome group (48 patients, 33.1%) was 25.12 ± 10.9 hours, while it was 47.13 ± 23.4 hours in the poor outcome group (85 patients, 58.6%), a statistically significant difference ($p < 0.05$). Notably, all fasciotomies performed after 48 hours were associated with neurological deficits or worse outcomes ($p = 0.04$).

Regarding supportive treatments, 54 patients (37.2%) received HBOT. Of these, 36 were in the good outcome group, whereas only 12 of the 91 patients who did not receive HBOT achieved good outcomes. HBOT use was associated with a higher likelihood of good functional results ($p = 0.006$). In contrast, 39 patients (26.9%) required hemodialysis, and these patients showed higher rates of major deficits, amputations, and mortality compared with those who did not require dialysis ($p = 0.009$). Logistic regression analysis indicated that HBOT and dialysis were statistically significant variables associated with functional outcomes ($p = 0.012$ and $p = 0.010$, respectively). Age and gender were not significantly associated with outcomes ($p = 0.77$ and $p = 0.678$, respectively) (Table II). Clinical results according to RFT are presented in Table III.

Table I. — Demographic and Clinical Characteristics of Patients.

Variable	Values [n, (%)]
Number of fasciotomized patients	145
Age (years), mean±SD	29.2±17.5 (min-max: 2-76)
Gender, n(%)	
Male	64 (44.1)
Female	81 (55.8)
RFT (hours), mean±SD	43.2±22.7 (min-max: 9-116)
Number of fasciotomy procedures, n(%)	243
Hand	6 (2.5)
Forearm	29 (11.9)
- Unilateral	27 (11.1)
- Bilateral	1 (0.4)
Arm	6 (2.5)
Foot	14 (5.8)
Leg	146(60.1)
- Unilateral	84 (34.6)
- Bilateral	31 (12.8)
Thigh	42 (17.3)
- Unilateral	34 (14.0)
- Bilateral	4 (1.6)
Thigh + Leg	35 (14.4)
Leg + Foot	11 (4.5)
Forearm + Hand	4 (1.6)
Timing of Fasciotomy, n(%)	
0-24 hours	42(28.9)
25-48 hours	56(38.6)
49-72 hours	36(24.8)
73-96 hours	7 (4.8)
>96 hours	4 (2.8)
Functionality and Deficits, n(%)	
Fully recovered	35 (24.1)
Major deficits	64 (44.1)
Minor deficits	13 (9.0)
Amputation	21 (14.5)
Death	12 (8.3)
Dialysis, n(%)	39 (26.9)
HBOT, n(%)	54 (37.2)
Outcomes, n(%)	
Good	48 (33.1)
Poor	85 (58.6)

RFT: Rubble to fasciotomy time, HBOT: Hyperbaric Oxygen Therapy.

DISCUSSION

In this study, we investigated the effect of RFT on functional outcomes in patients who developed ACS following entrapment due to an earthquake. Our findings indicate that increased RFT was associated with poorer outcomes. As RFT increased, the rate of full recovery decreased, while the likelihood of developing neurological deficits rose. Fasciotomies performed within the first 24 hours were associated with favorable outcomes, whereas those performed after 48 hours correlated with poor outcomes. The results of fasciotomies performed between 24 and 48 hours were variable but generally worsened with time.

We also found that patients who received HBOT had a higher rate of full recovery, indicating that HBOT use was associated with more favorable functional outcomes. Conversely, patients who required hemodialysis exhibited higher rates of neurological deficits, amputations, and mortality, suggesting that dialysis requirement was associated with poorer outcomes. Although both HBOT and dialysis appeared as statistically significant variables associated with functional outcomes in the regression

Table II. — Results of a regression analysis of the factors influencing functionality.

	B	SE	OR (95% CI)	P-value
Age	0.026	0.015	1.03(0.99-1.05)	0.77
Gender	0.22	0.52	1.2(0.45-3.4)	0.678
RFT	0.42	0.68	1.1(1-1.18)	0.010
Dialysis	2.05	0.81	7.7(1.6-38)	0.010
HBOT	1.82	0.52	0.17(0.06-0.5)	0.012
B: Regression coefficient, CI: Coefficient Interval, HBOT: hyperbaric oxygen therapy, OR: Odds Ratio, RFT: Rubble to fasciotomy time, SE: Standard error.				

Table III. — Clinical Outcomes and Supportive Treatments Based on RFT.

	0–24	25–48	49–72	73–96	>97	Total
Number of Patients n,(%)	42(28.9)	56(38.6)	36(24.8)	7 (4.8)	4(2.8)	145(100)
Full Recovery n,(%)	31(21.4)	4 (2.8)	0 (0.0)	0 (0.0)	0 (0.0)	35 (24.1)
Minor Deficit n,(%)	3 (2.1)	10(6.9)	0 (0.0)	0 (0.0)	0 (0.0)	13(9.0)
Major Deficit n,(%)	8 (5.5)	33(22.8)	20(13.8)	2(1.4)	1(0.7)	64(44.1)
Amputation n,(%)	0 (0.0)	7 (4.8)	10(6.9)	3 (2.1)	1(0.7)	21(14.5)
HBOT n, (%)	20(13.8)	29(20.0)	4(2.8)	0 (0.0)	1(0.7)	54 37.2)
Dialysis n,(%)	2(1.4)	11(7.6)	21(14.5)	2(1.4)	2(1.4)	39(26.9)
Good Outcome n,(%)	34(23.4)	14(9.7)	0(0.0)	0 (0.0)	0 (0.0)	48(33.1)
Poor Outcome n,(%)	8(5.5)	40(27.6)	30(20.7)	5(3.4)	2(1.4)	85(58.6)
Death n,(%)	0 (0.0)	2(1.4)	6(4.1)	2(1.4)	2(1.4)	12(8.3)
RFT: Rubble to Faciotomy Time, HBOT: Hiperbaric oxygen therapy.						

analysis, these relationships reflect associations rather than causal effects.

Fasciotomy is a surgical procedure that reduces elevated intracompartmental pressure by incising the fascia surrounding muscles, tendons, vessels, nerves, and other soft tissues. Literature supports its effectiveness in reducing compartment pressure[12-14]. However, when fasciotomy is performed after irreversible ischemic damage—such as paralysis or sensory loss—functional recovery tends to be limited, and the risk of infection is higher[15-18]. Experimental studies have demonstrated that irreversible damage to muscle and nerve tissues begins within 6–8 hours of complete ischemia[19]. In our study, the more favorable outcomes observed in fasciotomies performed within 24 hours align with this evidence.

Sheridan and Matsen reported that 68% of patients who underwent fasciotomy within 12 hours of symptom onset regained normal function, compared to only 8% in those treated after 12 hours. Their study also documented a 46% infection rate and a 21% amputation rate, with complications occurring in 54% of patients treated after the 12-hour threshold[20]. As one of the earliest studies in the literature, it did not stratify RFT into subgroups or provide detailed analysis of functional outcomes. In comparison, our study reported a 14.4% full recovery rate and a 13.2% amputation rate, and offers additional insight through RFT stratification and functional classification.

Nerlich et al. analyzed 134 compartments treated with fasciotomy, reporting no late complications in 59% and poor outcomes in 12% of cases. They found a significant correlation between fasciotomies performed after 23 hours and negative outcomes21. Similarly, our findings showed that fasciotomies performed beyond 24 hours were more frequently associated with poor outcomes.

Some studies suggest that conservative treatment in ACS can result in favorable outcomes and may prevent complications such as bleeding, sepsis, infection, and reperfusion injury that are associated with fasciotomy[22-24]. Intravenous mannitol has been shown to reduce intracompartmental pressure and preserve renal function[22,25,26]. However, these studies lack detailed evaluations of limb function following conservative management without fasciotomy. Our study did not include patients treated conservatively, and thus we are unable to provide data on this approach. Future prospective studies comparing long-term outcomes of conservative versus surgical management are needed to better inform clinical practice.

Following the 1995 Kobe earthquake in Japan, Matsuoka et al. conducted a comprehensive study involving 42 ACS patients, categorized into fasciotomy and non-fasciotomy groups. Of these, 17 underwent fasciotomy and 25 were managed conservatively. Severe lower extremity dysfunction was observed in 47% of the fasciotomy group and 16% of the non-fasciotomy group. The authors highlighted a strong association between delayed fasciotomy and poor prognosis due to infection, debridement, and prolonged healing[27]. This study stands out in the literature for its detailed evaluation of extremity function. However, factors affecting fasciotomy outcomes were not clearly defined, and the pre-2000 context likely limited access to modern therapies such as HBOT, vacuum-assisted closure (VAC), negative pressure wound therapy (NPWT), and potent intravenous antibiotics. In contrast, we believe that, with current infection control and supportive treatment modalities, timely fasciotomy may yield better outcomes.

HBOT is a widely accepted modality for treating musculoskeletal injuries. It enhances oxygenation of damaged tissues, protects against infection, promotes cellular regeneration, and reduces reperfusion injury. A double-blind, placebo-controlled study by Bouachour et al. demonstrated HBOT's effectiveness in accelerating wound healing and reducing the need for repeat surgeries in crush injuries[28]. However, HBOT use in earthquake-related injuries remains underreported in the literature. In our study, a positive association was observed between HBOT use and full recovery, although session number, duration, and pressure parameters were unavailable. Future studies are needed to clarify which HBOT parameters may be associated with improved functional outcomes in ACS.

Paul et al. reported that severe limb trauma and crush injuries frequently lead to rhabdomyolysis, myoglobin release, and subsequent acute renal failure, with higher rates observed in lower limb injuries and in patients with elevated MESS scores. Their study emphasized that early resuscitation and prompt management are critical to preventing renal deterioration[29].

Hemodialysis plays a critical role in managing renal failure secondary to ACS. It is essential in preserving renal function and preventing irreversible damage following muscle injury[30]. In our study, patients requiring hemodialysis showed poorer functional outcomes, which may reflect the severity of their underlying crush-related muscle damage rather than a direct effect of dialysis itself. The association observed between dialysis requirement and worse outcomes may therefore be influenced by indication bias and underlying injury severity.

Given the retrospective nature of the study, the associations observed between HBOT, dialysis, and functional outcomes should be interpreted cautiously. Residual confounding from unmeasured clinical factors (such as the extent of muscle ischemia or severity of crush injury) may have influenced our findings. Furthermore, indication bias is likely, as patients requiring dialysis typically presented with more severe systemic involvement, while HBOT was more frequently administered to patients with better preserved tissue viability.

The limitations of this study include its retrospective design; the lack of detailed evaluation of critical factors such as sepsis, infection, and nutritional status, which could significantly influence recovery and functional outcomes in patients with ACS who underwent fasciotomy; the fact that all patients were evaluated after at least one year of follow-up, while longer-term follow-up data were not available; the inability to compare outcomes with a conservatively treated patient group; the lack of information regarding HBOT session parameters; and the unrecorded number and duration of dialysis sessions.

Strengths of this study include a relatively large patient sample compared to existing literature, subgroup analysis of RFT, evaluation of limb functionality, and exploration of the relationships between HBOT, dialysis, and outcomes. While many previous studies have focused on systemic complications such as sepsis or renal failure, our study places special emphasis on functional outcomes of the extremities, which is a notable contribution to the field.

Our findings are specific to earthquake-related ACS in a disaster-stricken, resource-limited setting. Extrapolation of these results to non-disaster scenarios or regions with more robust healthcare infrastructure may require further validation. Future studies comparing fasciotomy with conservative management and examining recovery-influencing parameters such as nutritional status and infection markers are warranted.

In earthquake-related cases of ACS, the timing of fasciotomy often extends beyond conventional standards due to the chaotic conditions in disaster zones and the challenges patients face in accessing healthcare facilities. These circumstances make it difficult to clearly define precise indications and timing criteria for fasciotomy. Our study demonstrated

that fasciotomies performed within the first 24 hours resulted in significantly better functional outcomes.

Even in well-equipped medical centers with access to advanced resources such as HBOT, dialysis units, VAC/NPWT systems, and robust infection and sepsis control, fasciotomies performed between 24 and 48 hours showed a trend toward poorer outcomes over time. Furthermore, all fasciotomies performed after 48 hours were associated with poor results. These findings underscore the critical importance of performing fasciotomy as early as possible, particularly in disaster settings where time and resources are limited.

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