Clinical Features and Outcome of Crush Syndrome Caused by the Chi-Chi Earthquake

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Background and Purpose: Few reports exist concerning the peak serum concentration of creatine kinase (CK) and the severity of crush syndrome, and the efficacy of fasciotomy in crush syndrome patients remains controversial. This study aimed to analyze and assess the clinical features, treatment, and outcome of patients with crush syndrome sustained in the Chi-Chi earthquake in September 21, 1999.
Methods: Pertinent data were collected from major hospitals in central Taiwan via questionnaire. Patients with a peak serum CK concentration of more than 1,000 U/L within 2 weeks following the earthquake were included in the study. Eight hospitals responded and a total of 95 patients were included for the analysis.
Results: Forty-four patients (46.3%) with acute renal failure were found to have a serum creatinine level of more than 159 μmol/L (1.8 mg/dL) or daily urine output of less than 400 mL. Thirty patients (31.6%) required hemodialysis, which completely restored renal function. The incidence of acute oliguria, acute renal failure, and the need for hemodialysis were significantly increased if the peak CK concentration was more than 50,000 U/L ($p < 0.01$). Thirty-five patients underwent fasciotomy to treat compartment syndrome caused by crush syndrome. Among these, 31 patients (88.6%) had a peak CK concentration higher than 10,000 U/L. The incidence of acute renal failure ($p < 0.01$) and the need for hemodialysis ($p < 0.01$) were significantly higher in the fasciotomy group than in the non-fasciotomy group. Eight patients developed superficial infection and 16 developed deep infections after fasciotomy. Six patients underwent amputations and one patient died of sepsis due to uncontrolled infection of the fasciotomy wound.
Conclusion: CK concentration is a good indicator of the occurrence of acute renal failure and the need for dialysis. The high infection rate and amputation rate after fasciotomy may be due to inadequate debridement. Fasciotomy in crush syndrome patients with high serum CK concentrations should be deliberated.

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Key words:
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At 1:47 AM on September 21, 1999, a catastrophic earthquake registering 7.3 on the Richter scale hit the central part of Taiwan. This earthquake, subsequently known as the Chi-Chi earthquake, caused 2,329 deaths and 8,722 casualties. Most of the dead were crushed or suffocated in collapsed houses.

The 'crush syndrome' was first reported by Bywaters and Beall after a 1941 London bombing [1]. It has also been reported in patients with barbiturate overdose and prolonged limb compression [2], and in patients wearing pneumatic antishock garments [3]. These patients presented with massively swollen limbs, shock, myoglobinuria, and renal failure, symptoms termed crush syndrome or traumatic rhabdomyolysis. More recently, numerous patients with crush syndrome were reported after the 1976 earthquake in Tangshan, China

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[4], the 1988 earthquake in Armenia [5], and the 1995 earthquake in Hanshin-Awaji, Japan [6, 7].

We analyzed the medical records of 95 patients with crush syndrome admitted to eight major hospitals within and surrounding the damaged area. We attempted to find prognostic factors for the incidence of acute renal failure. We also evaluated the results of fasciotomy in these patients and assessed the indication for fasciotomy in patients with crush syndrome. Finally, we tried to establish some guidelines for treating these patients.

Materials and Methods

Study design

Patient information was obtained from medical records at eight hospitals within or surrounding the affected area, including three medical centers and five local hospitals, during the first 2 weeks after the earthquake, i.e., between September 21 and October 5, 1999. The investigation was undertaken between November 1999 and March 2000. We gathered data through questionnaires sent to the physicians concerned at the eight hospitals. Questionnaires not returned by the end of March 2000 were considered refusals to participate.

Patients

Questionnaires were designed to include patients with rhabdomyolysis, defined as a serum creatine kinase (CK) elevation to more than 1,000 U/L [8], within 2 weeks following the earthquake. Patients with a peak serum CK concentration of less than 1,000 U/L within 2 weeks following the earthquake were excluded.

Measurements

The following data were collected from the questionnaires: patient census data; trap time, according to the records of the rescue team; time to hospital; anatomical injury sites; associated injuries; disposition including admission, fasciotomy, mortality, morbidity, complication, discharge, transfer, and prognoses; first day urine volume after the earthquake; development of oliguria (urine volume < 400 mL/d) or need for dialysis; total fluid volume given in the first 48 hours after admission; and laboratory data.

Laboratory data including blood urea nitrogen (BUN); serum concentrations of CK, aspartate aminotransferase (AST), potassium (K), creatinine (Cr), lactate dehydrogenase (LDH), phosphate (P), calcium (Ca), and bicarbonate; and blood gas pH were serially measured independently in each hospital after the earthquake. For each patient, peak serum concentrations of Cr, BUN, CK, AST, LDH, K, and P and nadir levels of Ca, blood gas pH, and bicarbonate were recorded. Acute renal failure was defined as a Cr concentration of more than 159 μmol/L (1.8 mg/dL) [7] in a previously healthy person and/or acute oliguria (urine excretion < 400 mL/d) [9].

In our hospital, after triage at the emergency room or while treating fractures or other associated injuries in the operating room, surgeons carried out fasciotomy with proper sterilization in the case of compartment syndrome. Typical clinical manifestations of compartment syndrome are severe muscular pain in the muscular cavity, tense swelling, hypoesthesia or anesthesia of the muscular cavity, and pain on passive mobilization of the limb. The diagnosis is confirmed by the escape of muscle groups at the fasciotomy [10]. Two incisions with four-compartment fasciotomy were made in the lower leg, and one-incision fasciotomy was made in other regions of the body. Intramuscular pressure was not measured in these patients because of the sudden influx of a large number of patients after the earthquake. The wounds were then dressed with sterilized gauze soaked with povidone-iodine solution and dressings changed twice daily. The decision to use fasciotomy in other hospitals was made individually by the physicians there.

Superficial infection was defined as infection confined to the skin and subcutaneous tissues, and deep infection was defined as the presence of infection deep to the fascial layer with muscle involvement.

Data analysis

Clinical and laboratory data are presented as mean ± standard deviation (SD). A p value of less than 0.05 was considered to indicate statistical significance; all tests were two-tailed. Statistical significance was tested using Student's t-test and analysis of variance. Pairwise analysis (Scheffé post hoc multiple comparison test) between groups was used where appropriate. The Spearman rank correlation was used to determine correlation between peak CK concentration and peak Cr, BUN, AST, LDH, K, and P and nadir Ca, blood gas pH, and bicarbonate. All statistical analyses were performed using the statistical package SPSS for Windows (Version 10.0, SPSS, Chicago, IL, USA).

Results

A total of 99 questionnaires for 99 patients from the eight hospitals were returned. Four patients were excluded

because the CK concentration and fasciotomy status were not recorded. A total of 95 patients were included in this study, 35 female and 60 male. The average age was 38 ± 17.7 years (range, 1–75 yr; n = 88). The average trap time was 7.1 ± 5.4 hours (range, 0.1–31 h; median, 6 h; n = 54). The average time for transfer to the emergency room was 19.1 ± 22.6 hours (range, 2–144 h; n = 89). Eight patients died, and the average survival time was 9.3 ± 10.9 days (range, 0–32 d). Fractures (n = 41, 45.1%) and motor/sensory neuropathy (n = 31, 34.1%) were the most common associated injuries, followed by head (10.8%), chest (7.4%), and abdominal injuries (7.4%). Only one patient had heat-related injuries (1.1%). Forty-four patients (46.3%) had acute renal failure and 30 patients (31.6%) required dialysis. Complete renal function returned to these patients after dialysis.

The average peak serum CK concentration was 48,158 ± 66,930 U/L, ranging from 1,040 to 351,540 U/L (median, 20,744 U/L). Twenty-one of the 28 (75%) patients with a peak serum CK concentration of more than 50,000 U/L had acute renal failure, while only 23 (34.3%) patients with a peak serum CK concentration of less than 50,000 U/L had acute renal failure.

To evaluate the severity of crush syndrome, clinical and laboratory data were compared between the four groups of patients with crush syndrome in whom the peak CK concentration was between 1,001 U/L and 10,000 U/L, between 10,001 U/L and 50,000 U/L, between 50,001 U/L and 100,000 U/L, and more than 100,000 U/L (Tables 1–3). There was no significant difference in age, trap time, time to hospital, total amount of intravenous fluid volume administered in the first 48 hours after admission, and duration of oliguria once acute renal failure developed between the four groups (Table 1). Total urine volume in the first day of admission was significantly less if the peak CK concentration was more than 50,000 U/L (Table 1); incidence of acute oliguria, acute renal failure, and the need for hemodialysis were significantly increased if the peak CK concentration was more than 50,000 U/L ($p < 0.01$; Table 2). There was no significant difference among the four groups in the incidence of sensory and/or motor neuropathy, but there was significantly less incidence of fracture in the group with a peak CK concentration between 50,001 U/L and 100,000 U/L. In the group with a peak CK concentration between 1,001 U/L and 10,000 U/L, sig-

Table 1. Clinical features

	CK (U/L)	Mean ± SD	*p* value*
Age, yr (N = 88)	1,001–10,000 (n = 30)	43.2 ± 18.5	0.77
	10,001–50,000 (n = 31)	38.5 ± 17.5	
	50,001–100,000 (n = 16)	33.6 ± 17.9	
	> 100,000 (n = 11)	28.6 ± 11.4	
Trap time, h (N = 54)	1,001–10,000 (n = 18)	8.1 ± 2.5	0.29
	10,001–50,000 (n = 15)	9.4 ± 4.9	
	50,001–100,000 (n = 12)	6.2 ± 4.3	
	> 100,000 (n = 9)	5.9 ± 7.1	
Time to hospital, h (N = 89)	1,001–10,000 (n = 29)	16.0 ± 13.2	0.04†‡
	10,001–50,000 (n = 34)	17.2 ± 18.3	
	50,001–100,000 (n = 15)	34.1 ± 41.8	
	> 100,000 (n = 11)	12.5 ± 7.0	
Urine volume, mL (N = 62)	1,001–10,000 (n = 15)	1912 ± 1638	0.03†
	10,001–50,000 (n = 23)	1534 ± 1477	
	50,001–100,000 (n = 13)	933 ± 888	
	> 100,000 (n = 11)	490 ± 419	
IV fluid, mL (N = 90)	1,001–10,000 (n = 32)	4945 ± 3343	0.23
	10,001–50,000 (n = 32)	6194 ± 2824	
	50,001–100,000 (n = 14)	6663 ± 4129	
	> 100,000 (n = 12)	6526 ± 2432	
Oliguira duration, days (N = 31)	1,001–10,000 (n = 4)	6.3 ± 9.2	0.18
	10,001–50,000 (n = 10)	7.6 ± 6.7	
	50,001–100,000 (n = 9)	15.2 ± 11.7	
	> 100,000 (n = 8)	9.6 ± 5.3	

CK = serum creatine kinase; SD = standard deviation; trap time = duration patient trapped under masonry, reported by rescue team; time to hospital = duration until patients arrived at hospitals; urine volume = total urine volume during first day of admission; IV fluid = total amount of intravenous fluid administered in the first 48 hours after admission. *Statistical significance tested using analysis of variance (ANOVA). Scheffé test used to compare and identify different groups: †statistically significant; ‡ANOVA showed statistically significant, but Scheffé test failed to show any difference between the four groups.

Table 2. Clinical outcomes

	CK (U/L)	n (%)	*p* value*
Oliguria (N = 95)	1,001–10,000 (n = 32)	4 (13)	< 0.01†
	10,001–50,000 (n = 35)	10 (29)	
	50,001–100,000 (n = 16)	9 (56)	
	> 100,000 (n = 12)	8 (83)	
Acute renal failure (N = 95)	1,001–10,000 (n = 32)	7 (22)	< 0.01†
	10,001–50,000 (n = 35)	16 (46)	
	50,001–100,000 (n = 16)	11 (69)	
	> 100,000 (n = 12)	10 (83)	
Dialysis (N = 95)	1,001–10,000 (n = 32)	3 (9)	< 0.01†
	10,001–50,000 (n = 35)	9 (26)	
	50,001–100,000 (n = 16)	10 (63)	
	> 100,000 (n = 12)	8 (67)	
Sensory/motor neuropathy (N = 91)	1,001–10,000 (n = 32)	6 (19)	0.04†‡
	10,001–50,000 (n = 32)	11 (34)	
	50,001–100,000 (n = 16)	7 (44)	
	> 100,000 (n = 11)	7 (64)	
Fractures (N = 91)	1,001–10,000 (n = 32)	18 (56)	< 0.01†
	10,001–50,000 (n = 32)	13 (41)	
	50,001–100,000 (n = 16)	2 (13)	
	> 100,000 (n = 11)	8 (73)	
Fasciotomy (N = 95)	1,001–10,000 (n = 32)	4 (13)	< 0.01†
	10,001–50,000 (n = 35)	16 (46)	
	50,001–100,000 (n = 16)	9 (56)	
	> 100,000 (n = 12)	6 (50)	

CK = serum creatine kinase; Sensory/motor neuropathy = patients who developed sensory and/or motor neuropathies. *Statistical significance tested using analysis of variance (ANOVA). Scheffé test was used to compare and identify different groups: †statistically significant; ‡ANOVA showed statistically significant, but Scheffé test failed to show any difference between the four groups.

nificantly fewer fasciotomies were performed (Table 2); among the patients who underwent fasciotomies, 88.6% (31/35) had a peak CK concentration of more than 10,001 U/L.

The peak CK concentration had a significant relationship with peak serum Cr concentration in 94 patients ($r = 0.55$), with peak serum BUN concentration in 92 patients ($r = 0.50$), with peak serum AST concentration in 92 patients ($r = 0.77$), with peak serum K concentration in 89 patients ($r = 0.64$), with peak serum LDH concentration in 70 patients ($r = 0.70$), and with peak serum P concentration in 44 patients ($r = 0.65$) (all $p < 0.01$). There were also significant relationships between the peak CK concentration and those of total serum Ca, arterial blood pH, and arterial blood bicarbonate in 76, 73, and 72 patients, respectively ($r = -0.57$, -0.39, and -0.49; all $p < 0.01$). Patients with a peak CK concentration of more than 50,001 U/L had significantly more azotemia, hyperkalemia, and metabolic acidosis (Table 3).

Serum CK concentrations correlated well with the incidence of acute renal failure and the need for dialysis ($r = 0.48$, 0.49, $p < 0.01$). Serum CK concentration also corresponded to the occurrence of compartment syndrome and the need for fasciotomy ($r = 0.39$, $p < 0.01$). A correlation was observed between the trap time and peak CK concentration (severity of crush syndrome) in 54 patients ($r = 0.50$, $p < 0.01$).

To evaluate the factors associated with fasciotomy, trap time, time to hospital, peak CK and Cr concentrations, incidence of acute renal failure, and incidence of hemodialysis were compared between the two groups of patients with crush syndrome in whom fasciotomies were performed or not (Table 4). Thirty-five patients underwent fasciotomies to treat compartment syndrome. The mean CK concentration in patients who did not undergo a fasciotomy was 35,135 ± 55,802 U/L (median, 10,896 U/L; range, 1,040–275,594 U/L), while that in patients who underwent a fasciotomy was 70,483 ± 78,543 U/L (median, 46,440 U/L; range, 1,755–351,540 U/L), and that in patients who required amputation was 131,276 U/L (range, 46,805–304,958 U/L). Patients in the fasciotomy group were trapped significantly longer than those in the non-fasciotomy group ($p < 0.01$), but no difference was found in the time required to get the patients to the hospital between the fasciotomy and non-fasciotomy groups ($p = 0.99$). The peak CK concentration was significantly

Table 3. Peak or nadir levels of pertinent laboratory data

	CK (U/L)	Mean ± SD	*p* value
BUN, mmol/L (N = 92)	1,001–10,000 (n = 31)	11.0 ± 13.2	< 0.01†
	10,001–50,000 (n = 33)	15.5 ± 12.3	
	50,001–100,000 (n = 16)	29.8 ± 24.3	
	> 100,000 (n = 12)	26.4 ± 12.0	
Cr, μmol/L (N = 94)	1,001–10,000 (n = 31)	176 ± 239	< 0.01†
	10,001–50,000 (n = 35)	301 ± 286	
	50,001–100,000 (n = 16)	568 ± 38	
	> 100,000 (n = 12)	530 ± 258	
AST, U/L (N = 92)	1,001–10,000 (n = 30)	145 ± 182	< 0.01†
	10,001–50,000 (n = 34)	688 ± 924	
	50,001–100,000 (n = 16)	686 ± 311	
	> 100,000 (n = 12)	1401 ± 868	
LDH, U/L (N = 70)	1,001–10,000 (n = 21)	685 ± 791	< 0.01†
	10,001–50,000 (n = 28)	2007 ± 2724	
	50,001–100,000 (n = 12)	2500 ± 1670	
	> 100,000 (n = 9)	10109 ± 8114	
K, mmol/L (N = 89)	1,001–10,000 (n = 28)	4.2 ± 0.8	< 0.01†
	10,001–50,000 (n = 33)	4.7 ± 1.1	
	50,001–100,000 (n = 16)	5.5 ± 0.9	
	> 100,000 (n = 12)	7.0 ± 1.7	
P, mmol/L (N = 44)	1,001–10,000 (n = 14)	0.97 ± 0.44	< 0.01†
	10,001–50,000 (n = 14)	1.81 ± 0.93	
	50,001–100,000 (n = 7)	2.25 ± 0.47	
	> 100,000 (n = 9)	2.13 ± 0.75	
Ca, mmol/L (N = 76)	1,001–10,000 (n = 26)	1.96 ± 0.22	< 0.01†
	10,001–50,000 (n = 26)	1.77 ± 0.26	
	50,001–100,000 (n = 13)	1.68 ± 0.29	
	> 100,000 (n = 11)	1.50 ± 0.27	
pH (N = 73)	1,001–10,000 (n = 23)	7.39 ± 0.10	0.02†
	10,001–50,000 (n = 25)	7.35 ± 0.15	
	50,001–100,000 (n = 14)	7.31 ± 0.15	
	> 100,000 (n = 11)	7.24 ± 0.15	
Bicarbonate, mmol/L (N = 72)	1,001–10,000 (n = 23)	20 ± 4	< 0.01†
	10,001–50,000 (n = 25)	18 ± 5	
	50,001–100,000 (n = 14)	16 ± 5	
	> 100,000 (n = 10)	12 ± 3	

CK = serum creatine kinase; BUN = serum blood urea nitrogen; Cr = serum creatinine; AST = serum aspartate aminotransferase; LDH = serum lactate dehydrogenase; K = serum potassium; P = serum phosphate; Ca = total serum calcium; pH = arterial blood pH; bicarbonate = arterial blood bicarbonate. *Statistical significance tested using analysis of variance. Scheffé test was used to compare and identify different groups: †statistically significant.

higher in patients who underwent fasciotomies ($p = 0.01$). The incidence of acute renal failure (66 *vs* 35%, $p < 0.01$) and the need for hemodialysis (51 *vs* 20%, $p < 0.01$) were also higher in the fasciotomy group than in the non-fasciotomy group. Among the fasciotomy group, 23 patients had acute renal failure and 18 patients needed dialysis (Table 4).

After fasciotomy, eight cases (23%) with superficial infection and 16 cases (46%) with deep infection were noted. The fasciotomy wound required debridement an average of 2.5 times (range, 1–12 times). Delayed primary closure was performed in 11 patients, and split-thickness skin graft was performed in 17 patients to aid wound closure. Six patients had amputations (five above-knee amputations, one hip disarticulation) due to uncontrolled infection. One patient died of sepsis stemming from wound infection, which was not amenable to repeated debridement and amputation. High infection rates (68.6%) were noted in patients who underwent fasciotomy.

Eight species of bacteria were cultured from the infected fasciotomy wounds: *Pseudomonas aeruginosa* (9 wounds); *Acinetobacter baumanii* (9); *Escherichia coli* (4); *Klebsiella pneumoniae* (2); *Staphylococcus aureus* (2); *Proteus mirabilis* (1); and *Enterobacter cloacae* (1). Some patients had mixed flora.

Table 4. Trap time, time to hospital, peak serum creatine kinase (CK) and creatinine (Cr) concentration, incidence of acute renal failure (ARF), and the need for hemodialysis were compared between patients underwent fasciotomy and those who did not

	Fasciotomy			Non-fasciotomy			
	Mean ± SD	Median	Valid No.	Mean ± SD	Median	Valid No.	*p* value*
Time trapped, h	9.9 ± 6.0	9.5	22	5.2 ± 4.0	4.3	32	< 0.01†
Time to hospital, h	19.0 ± 20.9	12.0	34	19.1 ± 23.8	11.0	55	0.99
CK, U/L	70,483 ± 78,543	46,440	35	35,135 ± 55,802	10,896	60	0.01†
Cr, μmol/L	475 ± 330	530	35	252 ± 286	106	59	< 0.01†
	Case No./total No./%			Case No./total No./%			
ARF	23/35/66			21/60/35			< 0.01†
Hemodialysis	18/35/51			12/60/20			< 0.01†

*Statistical significance tested using Student's *t*-test; †statistically significant.

Discussion

Crush syndrome is caused by continuous prolonged pressure on muscle tissues, and presents with systemic and local manifestations. It is found primarily in patients who have been extricated after being trapped for at least 4 hours [11]. Patients were trapped for a median of 6 hours (0.1–31 h) in our series. The pathogenesis of the crush syndrome is unclear, although both ischemia-reperfusion injury [12] and/or stretch myopathy [13, 14] have been postulated. Systemic manifestations are caused by the disintegration of muscle tissue and the influx of myoglobulin, potassium, and phosphorus into the circulation, which cause hyperkalemia and hyperphosphatemia. Crush syndrome is characterized by hypovolemic shock, hyperkalemia, and acute renal failure.

Early vigorous fluid resuscitation is very important in the prevention of acute renal failure. Once urine flow is established, many authors suggest that mannitol-alkaline diuresis successfully prevents acute renal failure [15–18]. In our series, 46.3% of patients had acute renal failure and 31.6% of patients required dialysis. Most of these patients received 2,000 to 3,000 mL/day of infused fluids during the first 2 days (mean, 5,867 ± 3,224 mL/48 h; median, 5,395 mL/48 h; range, 500–17,922 mL/48 h). The high incidence of acute renal failure in this study was partly attributed to the lack of fluid resuscitation. Indeed, some patients who received more then 12,000 mL of fluids in the first 48 hours did not develop acute renal failure, even in cases where their peak serum CK concentration was more than 100,000 U/L. Furthermore, some patients who received less fluid or delayed initial treatment developed acute renal failure despite having reasonable CK concentrations. Once acute renal failure is noted, hemodialysis does not ensure return of renal function [19, 20], but no chronic renal failure was noted in our series.

High serum CK concentration is a good indicator of muscle damage and correlates well with the incidence of acute renal failure as well as the need for dialysis. Oda et al found that the risk of acute renal failure was highest in patients with a serum CK concentration greater than 75,000U/L [6]. In our series, 75% (21/28) of patients with a CK concentration greater than 50,000 U/L had acute renal failure, while only 34% (23/67) of patients with a CK concentration less than 50,000 U/L had acute renal failure (Table 2).

The local manifestation of crushed limbs included wooden swollen limbs with no voluntary contraction [21–23]. Rigor distal to the joint may be seen in some cases [24]. Motor or sensory deficits should be seen in most cases and may mimic the symptoms of a spinal cord injury. About 30% of the patients in our series had motor or sensory deficits. Capillary filling and distal pulse were prominent in our patients. Fractures were noted in 45.1% of our patients.

Few criteria exist to serve as guidelines for making the diagnosis of compartment syndrome. Subjective criteria include the five P's (pulselessness, pallor, paralysis, paresthesia, and pain) [25], but the sole objective criterion is the measurement of intracompartmental pressure. Nor is there a reliable objective method to determine when a fasciotomy is required. An optimal threshold pressure with both good sensitivity and specificity has not been identified [26]. Despite the development of various techniques for the measurement of intracompartmental pressure, it is not appropriate to rely on this measurement alone [27]. If the clinical signs point to the possibility of compartment syndrome, then a fasciotomy is required regardless of whether the pressures are measured [25, 28]. Fasciotomy to treat documented compartment syn-

drome complicating a crush syndrome is a valid surgical indication [29], though no evidence shows that fasciotomy improves outcome [30].

There is a paucity of reports concerning intracompartmental pressure measurement in crush syndrome patients, especially in mass casualties. Oda et al [6] and Matsuoka et al [30] reported 372 patients with crush syndrome after the 1995 Hanshin-Awaji earthquake, 49 of whom underwent fasciotomy. Among them, 12 patients experienced surgical site infection. Two patients died due to sepsis from surgical site infection, and three patients required amputation to control infection. In most cases, fasciotomy was carried out without pressure measurement, and in some patients, fasciotomy was performed when the intracompartmental pressure was more than 50 mmHg. The exact number of patients who underwent pressure measurement was not provided [6, 30]. Reis and Michaelson [24] and Oda et al [7] reported no intracom-partmental pressure measurement in their series. Nadjafi et al reported 38 cases of fasciotomy after the 1990 Iran earthquake, without mentioning the measurement of intracompartmental pressure [19]. There is a need for prospective studies of the intracompartmental pressure in patients with crush syndrome.

Fasciotomy is the gold standard for treating patients with acute compartment syndrome, but the role of fasciotomy in the treatment of crush syndrome is still a matter of debate. Mubarak and Owen [21], Sheng [4], and Oda et al [6] have suggested fasciotomy for treating patients with crush syndrome. On the contrary, Reis and Michaelson [24], Storgaard et al [31], and Michaelson [11] suggest conservative treatment unless there is an open wound or the distal limb circulation is compromised, despite high or increasing intracompartmental pressure [31]. Matsuoka et al found no evidence of fasciotomy to improve outcome [30]. Better and Stein even contend that, "The urge to explore limbs with traumatic rhabdomyolysis surgically should therefore be resisted unless there is an overriding reason to do so" [15].

Early fasciotomy might prevent further muscle necrosis and damage, but the major disadvantage of fasciotomy is the necessity of converting a closed wound into an open one, which increases the rate of infection. In our series, most microorganisms were hospital acquired. The large surface area of the open wound increases the depth of hypovolemic shock. Most fasciotomy patients in our series needed hemodialysis due to acute renal failure (18/35). The use of heparin in dialysis may increase the tendency for bleeding in the wound. Fasciotomy cannot cure or prevent any muscle damage that has already become necrotic. CK concentration is a good indicator of the degree of muscle damage. Oda et al reported that one limb injury corresponded to a CK concentration of about 50,000 U/L [6]. In our series, the mean CK concentration in patients undergoing fasciotomy was 70,483 U/L and, in patients undergoing amputation, it was 131,276 U/L. The mean trap time in our patients was 7.1 ± 5.4 hours, which indicated that severe muscle necrosis had already occurred; fasciotomy would not offer much improvement. A high infection rate (68.6%) and amputation rate (17.1%) were also noted in our fasciotomy patients. Of 16 patients with a CK concentration of more than 50,000 U/L who underwent fasciotomy, 15 developed acute renal failure. Fasciotomy cannot prevent acute renal failure caused by muscle necrosis.

Therefore, we agree with Reis and Michaelson [24], Stein et al [32], and Michaelson [11] that fasciotomy should be done only in the case of an open crush wound or when the intracompartmental pressure is so high as to obliterate the blood supply at the distal part of the extremity. If the serum CK concentration is more than 50,000U/L in patients with one limb compression, fasciotomy is not indicated because most of the muscle is already necrotic. In these patients, the muscle is already dead, and fasciotomy offers no benefit but increases the rate of infection and amputation. Once fasciotomy is performed, the surgeon should be cautious about the risk of infection. Adequate debridement of the dead muscle is necessary.

We suggest that vigorous fluid supply followed by alkaline diuresis should be initiated at the earliest possible stage to prevent any systemic complications or acute renal failure. Peak serum CK concentration is a good indicator of the likelihood of acute renal failure and the need for dialysis. It can also reflect the degree of muscle damage. Because of the high infection rate, local treatment for compartment syndrome caused by crush syndrome should be more conservative and fasciotomy should be used sparingly. Intracompartmental pressure should be documented if feasible. If fasciotomy is performed, it should be reserved for patients with a clear interruption of arterial circulation and followed by radical debridement.

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