

The effect of time from injury to fasciotomy in patients with acute upper extremity compartment syndrome

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ABSTRACT

BACKGROUND: Acute compartment syndrome of the upper extremity is a surgical emergency, and timely diagnosis with immediate fasciotomies is essential for the preservation of function. This retrospective study aimed to compare the complication rates of patients who underwent fasciotomy before and after 6 hours following the initial trauma.

METHODS: The medical records of the patients who underwent fasciotomy for surgical treatment of ACS of the upper extremity between 2016 and 2022 were retrospectively analyzed for age, gender, dominant hand, mechanism of injury, injury level, affected compartments, associated injuries, time elapsed till fasciotomy, and complications. The patients were divided into two groups according to the timing of fasciotomy.

RESULTS: A total of 32 patients underwent fasciotomies for upper extremity ACS. The mean age of patients who underwent fasciotomy ≤ 6 hours (group 1; 10 males, 7 females) and patients who underwent fasciotomy > 6 hours (group 2; 13 males, 2 females) was 31.1 and 34.8, respectively. The most common etiology was crushing injury. There was a significant difference in complication rates between group 1 (1/17) and group 2 (10/15) ($p < 0.001$). The length of hospitalization stay in group 2 was statistically higher than in group 1 ($p = 0.005$).

CONCLUSION: Fasciotomies for ACS of the upper extremity should be performed in less than 6 hours following the initial trauma to prevent complications.

Keywords: Acute compartment syndrome; cement injection injury; fasciotomy; fin injury; mercury injection injury; upper extremity; wasp sting injury.

INTRODUCTION

The compartment syndrome of the upper extremity is a devastating condition that may cause irreversible tissue damage. Clinical suspicion and efficient fasciotomies are the mainstays of management to preserve the function of the extremity. Since the upper extremity has compartments that have a relatively fixed volume, anything that acutely increases the volume or critical external pressure decreases the tissue perfusion. This insult initiates a vicious cycle, which eventually

results in catastrophic tissue necrosis. If acute compartment syndrome (ACS) remains undiagnosed, or if the fasciotomy is delayed for some reason, unfortunately, Volkmann's ischemic contracture becomes the inevitable clinical scenario. In such cases, loss of circulation and the subsequent myonecrosis may lead to the loss of the extremity, renal failure, and even death. Therefore, clinicians working in emergency units should be familiar with possible etiologies leading to ACS.

The most common cause of acute upper extremity compartment syndrome is a fracture, which results in intracompartment

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mental hemorrhage.^[1,2] However, it must be stressed that crush injuries, blunt trauma, extravasations, and insect bites may also lead to compartment syndrome. Because of its relative rarity and diverse symptomatology, the physician may not associate these situations with compartment syndrome.^[3] Therefore, signs and symptoms of compartment syndrome should be sought.

Although ACS is a surgical emergency, some rare etiologies can cause a delay in the diagnosis of ACS. The literature is scant for comparative studies investigating the outcomes of early versus late surgical intervention for ACS, and the cut-off point for late surgery is not clearly defined. This study aims to compare patients who underwent fasciotomy from injury before six hours with patients who underwent fasciotomy from injury after six hours to underline the importance of acute upper extremity compartment syndrome, to present our atypical cases leading to it, and to guide physicians working in emergency units to keep compartment syndrome in mind whenever they see a patient with an insult to the upper extremity in Türkiye.

MATERIALS AND METHODS

Patients

The study was conducted according to the Helsinki Declaration of 1975, following ethical approval by the institutional non-interventional clinic research ethics board (GO 21/337). Informed consent was obtained from each patient or parent. From January 2016 to May 2022, 32 patients requiring upper extremity fasciotomy due to acute upper extremity compartment syndrome were involved and retrospectively reviewed. The patients for whom elective fasciotomy was performed following revascularization or replantation of a part of the upper extremity were excluded. All fasciotomies were performed by the same microsurgical team consisting of experienced microsurgeons.^[4]

Demographic and clinical data consisted of patient age, gender, dominant hand, mechanism of injury, injury level, affected compartments, associated injuries, time elapsed till fasciotomy, and complications (Table 1, Table 2). The duration of the compartment syndrome was determined using the time of injury and admission to the emergency department in Türkiye. All the patients diagnosed with ACS underwent fasciotomy immediately (Fig. 1). If the time was longer than 6 hours, the compartment syndrome was considered prolonged.

There is no standardized ACS description in the literature.^[5] ACS is adopted as a clinical diagnosis in the literature.^[5] ACS was suspected if the patient had marked swelling, disproportionate pain spontaneously or with passive stretching, and tenseness on palpation with a relevant history.

Operative Procedure

After the diagnosis of ACS, adult patients and the parents of children were informed about the operative procedure. Adult patients who had compartment syndrome only affecting the



Figure 1. (a) Preoperative clinical appearance of the patient with ACS after burn injury. (b) Intrinsic minus position.



Figure 2. (a) Preoperative clinical appearance of the patient with stuck upper extremity in a recycling machine. (b) Intraoperative appearance of fasciotomy and decompressed ulnar, radial, and median nerve in forearm (c) In arm.

digits, hand, or forearm were operated under axillary block. Adult patients with compartment syndrome of the arm and all pediatric patients were operated under general anesthesia in Türkiye.

Upper extremity fasciotomy incisions were as described in the literature.^[6-8] For volar decompression, Henry's approach was used. To release the extensor compartments, a dorsal approach on a straight line from the lateral epicondyle to Lister's tubercle was used for dorsal release as in the Thompson approach. The clinical presentation of every single patient was different because of the diversity of mechanisms of injury. Thus, the incisions were individualized for each patient according to the level of injury. Ulnar, median, and radial nerves were decompressed in the forearm to avoid a neurological deficit (Fig. 2). If indicated, the release of the Cleland ligament was performed by incising the neurovascular bundle (Fig. 3).

All patients were followed with a wet-to-dry dressing after fasciotomy. If there was a defect after fasciotomy, negative

Table 1. Demographics and compartmental parameters of patients (Time elapsed until fasciotomy ≤ 6 hours)

Patient No	Age (year)	Gender	Dominant Hand	Injured Extremity	Etiology of compartment syndrome	Injury Level	Affected Compartments	Amount of fasciotomy incisions	Associated Injuries	Time elapsed until fasciotomy	Hospitalization for compartment syndrome (day)	Follow up period (month)	Complications
1	21	Male	Right	Right	Gunshot injury	Forearm	Hand, forearm	6	Hemothorax	3 hours	7	12	-
2	24	Male	Right	Right	Avulsion-crush injury	Forearm	Hand, forearm	7	-	4 hours	6	13	-
3	41	Male	Right	Right	Gunshot injury	Hand	Hand	5	-	2 hours	10	20	-
4	1	Female	none	Left	Radiopaque extravasation	Metacarpal	Hand, forearm	6	-	1.5 hours	10	15	-
5	25	Male	Right	Right	Gunshot injury	Forearm	Hand, forearm	7	-	6 hours	5	15	-
6	37	Female	Right	Left	Radiopaque extravasation	Metacarpal	Hand, forearm	5	-	2 hours	3	11	-
7	38	Female	Left	Right	Radiopaque extravasation	Metacarpal	Hand, forearm	6	-	6 hours	7	14	-
8	26	Male	Right	Right	Avulsion-crush injury	Forearm	Hand, forearm	6	-	5 hours	5	17	-
9	26	Female	Right	Right	Avulsion-crush injury	Forearm	Hand, forearm	7	-	4 hours	6	13	-
10	21	Male	Right	Right	Penetrating stab injury	Palmar region	Hand	5	-	3.5 hours	8	20	-
11	27	Female	Right	Right	Avulsion-crush injury	Whole upper extremity	Hand, forearm, arm	7	-	6 hours	20	23	-
12	44	Male	Right	Left	Insect bite	Wrist, volar region	Hand, forearm, arm	7	-	5 hours	15	22	-
13	32	Male	Right	Right	Avulsion-crush injury	Forearm	Hand, forearm	6	-	5 hours	15	20	-
14	4	Male	None	Right	Burn	Hand	Hand	5	-	3 hours	20	21	-
15	70	Female	Right	Right	Anticoagulant therapy for cerebrovascular occlusion in intensive care unit	Hand	Hand	5	-	1 hour	7	12	-
16	57	Male	Right	Left	Avulsion-crush injury	Hand	Hand, forearm	6	-	6 hours	7	17	-
17	36	Female	Right	Right	Burn with oil	Hand	Hand	6	-	6 hours	10	6	Amputation of fifth finger distal phalangeal level

Table 2. Demographics and compartmental parameters of patients (Time elapsed until fasciotomy <6 hours)

Gender	Dominant Hand	Injured Extremity	Etiology of compartment syndrome	Injury Level	Affected Compartments	Amount of fasciotomy incisions	Associated Injuries	Time elapsed until fasciotomy	Hospitalization for compartment syndrome (day)	Follow up period (month)	Complications
Male	Right	Right	Gunshot injury	Forearm	Hand, forearm, arm	7	-	9 hours	9	23	-
Male	Right	Right	High pressure cement injection	Hand	Hand	5	-	7.5 hours	11	21	Amputation of fourth and fifth fingers proximal phalangeal level
Male	Right	Left	Gunshot injury	Forearm, arm	Hand, forearm, arm	9	Hemothorax	10 hours	14	20	Stiff hand
Male	Right	Right	Gunshot injury	Forearm	Hand, forearm, arm	7	Hepatic damage	6.5 hours	13	23	Stiff hand
Male	Right	Left	Cellulite after pricking fish fin	Palmar region	Hand	5	-	35 hours	15	21	Stiff hand
Male	Right	Right	High pressure dye injection	Pulpa of index finger	Hand	2	-	7 hours	10	21	Amputation of index finger proximal phalangeal level
Male	Right	Left	Blunt trauma (kick) to axillary artery	Axilla	Hand, forearm, arm	7	-	19 hours	10	16	Total brachial plexus paralysis
Male	Right	Left	Necrotizing fasciitis from IV drug abuse	Antecubital fossa	Hand, forearm, arm	7	Multi-organ failure	7 hours	20	0	Exitus
Male	Right	Right	Avulsion-crush injury	Whole upper extremity	Hand, forearm, arm	7	Shoulder dislocation	26 hours	30	23	Crush syndrome, Ulnar nerve palsy
Male	Right	Right	Penetrating stab injury	Forearm	Hand, forearm	6	-	12 hours	10	18	-
Male	Right	Left	Fall down stairs / Anticoagulant therapy	Hand, forearm	Hand, forearm	6	Subarachnoid hemorrhage	8 hours	24	19	Dorsal hand skin necrosis
Male	Right	Right	Penetrating stab injury	Forearm	Hand, forearm	6	-	12 hours	10	15	-
Female	Right	Right	Burn with hot vegetable water	Hand, forearm, arm	Hand, forearm, arm	7	-	10 hours	30	11	Flexion contracture of humeroradial joint
Female	Right	Left	Burn with oil	Hand	Hand	5	-	7 hours	10	6	-
Male	Right	Right	Cellulite	Hand	Hand	5	-	20 hours	14	7	Necrosis of dorsal skin of thumb



Figure 3. (a) Preoperative volar aspect and (b) Dorsal aspect of the 3rd 4th and 5th fingers with ACS after burn injury. (c) Volar aspect and (d) Dorsal aspect of the fingers after releasing Cleland ligament and neurovascular bundle.

pressure wound therapy was preferred to decrease edema. The fasciotomy incision was closed on postoperative day 5 if the wound could be primarily closed. If not, the defect was reconstructed with a skin graft.

Statistical Analysis

Descriptive statistics were expressed as mean ± standard deviation for continuous numerical variables, and categorical variables were expressed as the number of patients and percentage. The distribution of variables was measured with the Kolmogorov-Smirnov test. Statistical analysis for continuous variables was performed with the Mann-Whitney U test when appropriate. Categorical variables were compared with the Pearson Chi-square test. Analyses of the data were performed using the IBM SPSS Statistics 23.0 (IBM Corporation, Armonk, NY, USA) program. Results were considered statistically significant when the p-value was <0.05.

RESULTS

Of the 32 patients, there were 23 males and 9 females. The mean age of patients with fasciotomy ≤6 hours (10 male, 7 female) was 31.1±16.8, and the mean age of patients with fasciotomy >6 hours (13 males, 2 females) was 34.8±12.1 (p=0.455). Nine patients had ACS involving the entire upper extremity. The dominant hand and injured extremity of most patients were the right hand. The most common cause of ACS was a crush injury followed by a gunshot injury. Although avulsion-crush injuries were more common than other etiologies of compartment syndrome, there were unusual etiologies such as high-pressure cement injection (Fig. 4), high-pressure dye injection, and cellulitis after pricking a fish fin (Fig. 5). The mean number of fasciotomy incisions for patients with fasciotomy ≤6 hours was 6.0±0.7, and the mean number for patients with fasciotomy >6 hours was 6.0±1.5 (p=0.655). The mean length of hospital stay for patients with fasciotomy ≤6 hours was 9.4±5.1 days, and for patients with



Figure 4. (a) Intraoperative volar aspect of the patient with cement injection injury after fasciotomy and debridement in hand. (b) Cement injection area between 3rd and 4th fingers.

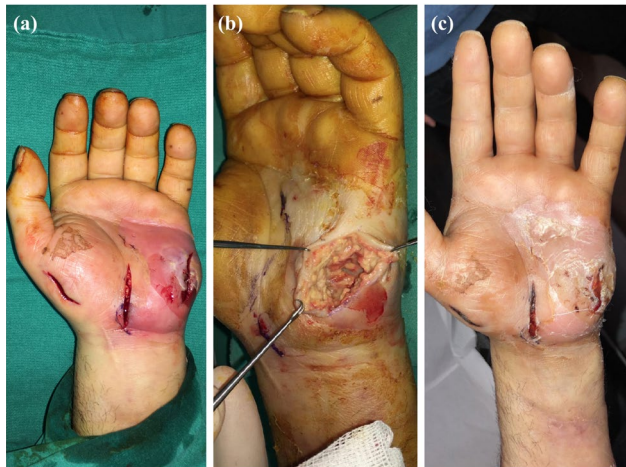


Figure 5. (a) Intraoperative volar aspect of the patient with cellulite due to prick fish fin after fasciotomy and debridement in hand. (b) Necrotic tissue in the hypothenar area. (c) Postoperative clinical appearance after antibiotic therapy.

fasciotomy >6 hours was 15.3±7.2 days (p=0.005). The mean follow-up period for patients with fasciotomy ≤6 hours was 15.9±4.6 months, and for patients with fasciotomy >6 hours was 16.2±7.1 months (p=0.455). The clinical data of patients who underwent fasciotomy ≤ and >6 hours, including accom-

panying disease, dominant hand, injured extremity, etiology of compartment syndrome, injury level, affected compartments, number of fasciotomy, and associated injuries are in Tables 1 and 2, respectively.

Complications

The complication rate in the group with >6 hours to fasciotomy (10/15) was statistically higher than in the group with ≤6 hours to fasciotomy (1/17) (p<0.001) (Table 3). Individual complications are presented in Tables 1 and 2. When necrosis occurred, early and serial surgical debridement was performed, and if indicated, amputation was carried out.

DISCUSSION

The critical time to fasciotomy after injury is controversial. Irreversible tissue damage can emerge in less than 3 hours. [9] Reversible muscle damage in the hand was detected after 4 hours; the damage becomes irreversible after 8 hours. Patients who underwent fasciotomy after 6 hours required secondary procedures. [10] Fasciotomy is recommended within the first four hours of ischemia. [11] In twenty-three pediatric patients with ACS, no statistical difference was detected between the ≤24 hours from injury to fasciotomy group and the >24 hours from injury to fasciotomy group according to functional outcome. [12] Nerve conduction velocity could not return to normal after 12 hours. [7] In the current study, the cut-off time until fasciotomy was accepted at 6 hours and patients with >6 hours until fasciotomy had significantly higher complication rates.

In the upper extremity, the upper arm includes two compartments (anterior and posterior), the forearm includes two compartments (volar and dorsal), and the hand includes ten compartments (dorsal interossei, palmar interossei, adductor pollicis, thenar, and hypothenar). In all compartments, if interstitial pressure is higher than capillary perfusion pressure, capillaries occlude and ischemia starts. [9] The pressure in the compartment should be decreased to prevent muscle necrosis and nerve damage by fasciotomy. Although some authors recommend empiric decompression of all compartments in the forearm, involving both extensor and flexor compartments, [7] we believe that clinical decision-making plays a cru-

Table 3. Patient characteristics expressed as mean

	Time elapsed until fasciotomy ≤6 hours	Time elapsed until fasciotomy >6 hours	p value
Age (years)	31.1±16.8	34.8±12.1	0.455
Amount of fasciotomy incisions	6.0±0.7	6.0±1.5	0.655
Time elapsed until fasciotomy	4.0±1.7	13.0±8.3	<0.001
Length of hospitalization (days)	9.4±5.1	15.3±7.2	0.005
Follow up period (month)	15.9±4.6	16.2±7.1	0.455
Complication	1/17	10/15	<0.001

cial role in performing fasciotomy on the dorsal aspect. Unlike the hand, if the extensor compartment in the forearm or the posterior compartment in the arm is not tense upon palpation, the surgeon may choose not to proceed with fasciotomy on the dorsal aspect of the forearm or arm, provided that the extensor compartments are closely monitored.^[7]

In the literature, the most common etiology of ACS is high-energy injuries, especially fractures.^[13] In this study, a crush injury was observed as the most common etiology in ACS patients, although there were no fractures, except for one patient with shoulder dislocation. While the pathophysiology of ACS is consistent regardless of the initial cause, if the etiology of ACS is a high-pressure injection, material that has been injected must be debrided in addition to fasciotomy.^[14] This study included two patients with ACS due to high-pressure cement and dye injection. Debridement was performed synchronously with fasciotomy in each patient. Cultures for microorganisms should be obtained in patients with ACS resulting from cellulitis. In this study, one patient with diabetes mellitus presented with an unusual history of cellulitis after pricking a fish fin.

To enhance diagnostic accuracy, intracompartmental pressure (ICP) measurement techniques are frequently utilized as a supportive tool.^[15] The normal range of ICP in the literature is between 0 and 4 mmHg. If ICP rises above 20 mmHg for any reason, the upper extremity should be closely monitored. Nevertheless, the use of absolute ICP values for the diagnosis of ACS and the establishment of a critical cut-off pressure remains a subject of ongoing debate. Classical understanding sets an absolute ICP value of 30 mmHg as the threshold to perform fasciotomy.^[16,17] Despite the possibility of measuring ICP using a monitor, we assert that the diagnosis of ACS should be based on clinical signs because the first and most sensitive indicators of ACS are disproportionate pain and pain upon passive stretching of the fingers in conscious patients.^[7] Hand ACS is also identified by the intrinsic minus position with the loss of palmar concavity.^[8] Furthermore, ICP monitoring can be particularly beneficial in unconscious patients.

Extremity function and complications in ACS patients are influenced by injury severity, ischemia time, and accompanying disease.^[7] The most crucial factor is time to protect extremity function. Complications that can occur after 6 hours include neurologic deficit, contractures, gangrene, Volkmann's ischemic contracture, crush syndrome, and complex regional pain syndrome.^[7] However, no clinical study has compared complication rates according to the cut-off time until fasciotomy. In this study, complications in the group with >6 hours to fasciotomy are statistically higher than in the group with ≤6 hours to fasciotomy. One patient with an upper extremity stuck in a recycling machine during his night shift at work for 8 hours experienced an acute complication and ulnar nerve palsy. The acute complication was crush syndrome, which necessitated a two-day stay in the intensive care unit.

A postoperative one-year follow-up revealed that the patient regained most of his upper extremity functions without renal failure. A slight ulnar nerve palsy with hyperextension at the metacarpophalangeal joints and flexion at the proximal and distal interphalangeal joints of the 4th and 5th fingers was observed. The length of hospitalization and mean follow-up period in the group with >6 hours to fasciotomy were higher than in the group with ≤6 hours to fasciotomy due to complications and related surgeries.

Our study has several limitations. The sample size is small, and the study has a retrospective design. Patients may not recall the exact time of injury; therefore, the cut-off time might be affected. Moreover, the etiology of ACS was not standardized. Nevertheless, we were able to report unusual etiologies of ACS in this study, which can increase the awareness of clinicians and maintain a low suspicion threshold for ACS diagnosis.

CONCLUSION

In conclusion, patients with >6 hours to fasciotomy have higher complication rates and an increased length of hospitalization due to the management of complications. ACS can develop after some unusual etiologies other than fractures. Clinicians should maintain a low diagnostic threshold for ACS when faced with unusual etiologies.

Ethics Committee Approval: This study was approved by the Hacettepe University Ethics Committee (Date: 16.03.2021, Decision No: 2021/06-59).

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ORIJİNAL ÇALIŞMA - ÖZ

Akut üst ekstremitte kompartman sendromunda yaralanma ile fasiyotomi arasındaki sürenin etkisi

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AMAÇ: Üst ekstremitte akut kompartman sendromu, cerrahi acil bir durumdur ve ekstremitte fonksiyonlarının korunması için hızlı tanı konulması ve fasiyotomilerin derhal gerçekleştirilmesi hayati öneme sahiptir. Bu retrospektif çalışmanın amacı, travmayı takiben 6 saat içinde fasiyotomi yapılan ve daha geç zamanda yapılan hastaların komplikasyon oranlarını karşılaştırmaktır.

GEREÇ VE YÖNTEM: 2016-2022 yılları arasında üst ekstremitte AKS'nin cerrahi tedavisi için fasiyotomi yapılan hastaların tıbbi kayıtları, yaş, cinsiyet, dominant el, yaralanma mekanizması, yaralanma seviyesi, etkilenen kompartmanlar, ilişkili yaralanmalar, fasiyotomiye kadar geçen süre ve komplikasyonlar açısından retrospektif olarak analiz edildi. Hastalar, fasiyotomi zamanlamasına göre iki gruba ayrıldı.

BULGULAR: Üst ekstremitte AKS için toplam 32 hastaya fasiyotomi yapıldı. Fasiyotomi yapılan hastaların yaş ortalaması 6 saatten daha kısa sürede fasiyotomi yapılan grupta (grup 1; 10 erkek, 7 kadın) 31.1 ve 6 saatten daha fazla süre sonra fasiyotomi yapılan hastalarda (grup 2; 13 erkek, 2 kadın) 34.8 idi. En yaygın etiyoloji ezilme yaralanmasıydı. Grup 1 (1/17) ve grup 2 (10/15) arasında komplikasyon oranları açısından anlamlı fark vardı ($p<0.001$). Grup 2'de hastanede kalış süresi, grup 1'e göre istatistiksel olarak anlamlı şekilde daha yüksek bulundu ($p=0.005$).

SONUÇ: Üst ekstremitte AKS için fasiyotomilerin, ilk travmadan sonraki 6 saat içinde yapılması gerekmektedir. Bu şekilde komplikasyon oranları azaltılabilir.

Anahtar sözcükler: Akut kompartman sendromu; üst ekstremitte; fasiyotomi; ezilme; yüksek basınçlı enjeksiyon yaralanmaları.

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