Acute Compartment Syndrome of the Upper Extremity: Clinical Outcomes Following Surgical Treatment. A Retrospective Cohort Study

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ABSTRACT **Background:** Acute extremity compartment syndrome is a surgical emergency for which timely diagnosis is essential.

Objectives: To assess whether the time from the initial insult to the fasciotomy of compartment syndrome of the upper extremity affects outcomes and to examine the differences between compartment syndrome secondary to fractures and that resulting from a non-fracture etiology with regard to the time from insult to fasciotomy and the long-term patient outcomes.

Methods: Patients presented with documented fasciotomy treatment following acute upper extremity compartment syndrome and a minimum of 6 months follow-up. Patient information included demographics, cause of compartment syndrome, method of diagnosis, and outcome on follow-up.

Results: Our study was comprised of 25 patients. Fasciotomies were performed for compartment syndrome caused by fracture in 11 patients (44%), and due to insults other than fractures in 14 patients (56%). The average time to fasciotomy in patients without a fracture was 10.21 hours and 16.55 hours with a fracture. Fasciotomy performed more than 24 hours from the initial insult was not found to significantly affect long-term sequelae compared to fasciotomy performed earlier than 24 hours from the initial insult. The non-fracture group had more long-term sequelae than the fracture group (13/15 patients and 5/11 patients, respectively).

Conclusions: Most injuries treated for fasciotomy of compartment syndrome were non-fracture related, with more complications found in patients with non-fracture related injuries. Time interval from insult to fasciotomy did not affect outcome and was longer in the fracture group, suggesting longer monitoring in this group and supporting fasciotomy even with late presentation.

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Acute extremity compartment syndrome is a surgical emergency for which timely diagnosis is essential. Acute extremity compartment syndrome is defined as an increase in intracompartmental pressure causing a decrease of perfusion pressure, leading to hypoxemia of the tissues. Decreased tissue perfusion can lead to irreversible necrosis that might result in functional impairment, loss of limb, and in rare cases, death. Although described around 130 years ago, this disorder remains challenging to diagnose and treat effectively. Acute extremity compartment syndrome can be diagnosed on the basis of clinical symptoms, instrumental pressure measurement, or both [1]. Given the pathophysiology of compartment syndrome, emergent surgical treatment is required [2] to release the compartment pressure and prevent further tissue damage.

Acute upper extremity compartment syndrome is most frequently seen after a traumatic event. Associated causes in the upper extremity are distal radius fractures, crush injuries, diaphyseal fractures of the radius and ulna and perilunate dislocations [3,4]. In up to 30% of cases, acute extremity compartment syndrome develops from soft-tissue injury without a fracture [5]. Other etiologies that have been reported to cause acute extremity compartment syndrome are thermal injuries, positioning during surgery, constricting casts or wraps, bleeding disorders, snake bites, infections [5-7], and intravenous or extravenous infusion of an agent such as iodine [8,9].

Research results specifically describing compartment syndrome of the upper extremity is scarce and mainly consists of case reports, small series, and reviews. Therefore, the true frequency and epidemiology of acute extremity compartment syndrome is difficult to assess.

In this study, we assessed whether the time from the initial insult to fasciotomy for compartment syndrome of the upper extremity affected outcomes and examined the differences between compartment syndrome secondary to fractures and that resulting from a non-fracture etiology with regard to the time from insult to fasciotomy and the long-term patient outcomes.

PATIENTS AND METHODS

The study was approved by our institutional review board. We searched our hospital's computerized patient records for any record containing the terms: compartment syndrome and fasciotomy of the upper limb, within a period of 10 years. Data were collected from admission and discharge reports, surgical reports, imaging, and follow-up visits. Patients included in the study showed documented fasciotomy treatment following a diagnosis of acute compartment syndrome and a minimum of 6 months of documented follow-up after initial fasciotomy procedure. Retrieved patient information included patient demographics, cause of compartment syndrome, course of the injury beginning from the initial insult, method of diagnosis of compartment syndrome (clinical or instrumental). and outcome on follow-up including complications and further operations needed beside skin closure. Patients excluded from this study included those with fasciotomy in areas other than the upper extremity, those who underwent a preventive fasciotomy, those with documented follow-up shorter than 6 months at our facility, and those who were not followed at our facility. Instrumental diagnosis was made by inserting an 18 gauge needle connected to a pressure transducer (Philips Healthcare, USA, IntelliVue MX800 into the suspected compartment. Cutoff parameters for compartment syndrome were an absolute pressure of 30 mmHg or a delta of less than 30 mmHg from the patient's pre-anesthesia diastolic blood pressure measurement.

The primary outcomes were the time from insult to fasciotomy, complications after the surgery, and further operations needed beside skin closure. After dividing the patients into two groups based on the insult type (fracture or non-fracture), we used Mann–Whitney test to calculate the statistical significance of differences regarding the average time from insult to fasciotomy and the difference in the number of further surgeries needed beside skin closure among these groups. Fisher's exact test was used to compare the complications between the fracture or non-fracture groups. Age and sex were compared as potential confounders using Mann–Whitney and chi-square tests, respectively.

Using 24 hours as a cutoff regarding the time from insult to fasciotomy, we divided the patients into two groups and used Fisher's exact test to calculate the statistical significance of differences regarding the complications between the groups. Mann–Whitney test was used to compare the number of further operations needed beside skin closure between these groups. Chi-square tests were used to determine if the method of diagnosis (clinical or instrumental) affected the time from insult to fasciotomy.

RESULTS

Between the years 2008 and 2016 a total of 98 patients underwent a documented fasciotomy for acute extremity compartment syndrome at our facility. In this group, 32 treatments (32.6%) involved the upper extremity. Five patients were excluded because of inadequate follow-up. Two patients were excluded due to their fasciotomy being a preventive operation following revascularization surgery. The research study included 25 patients (22 men and 3 women). The average age was 25 years (range 1–70) [Table 1].

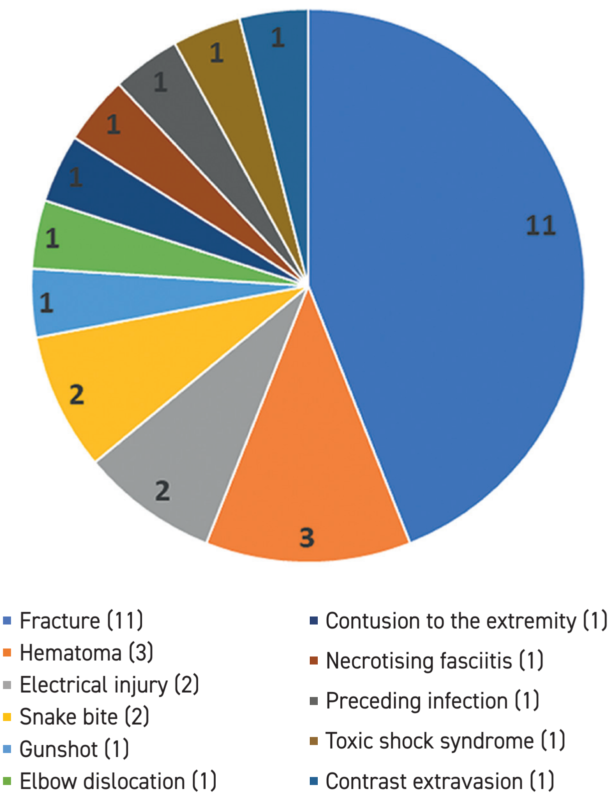
The mean age in the fracture injury group was less than that in the non-fracture group (27.05 years and 28.75 years, respectively). The initial insult leading to fasciotomy for acute compartment syndrome varied among patients [Figure 1].

Fracture was the insult in 11 patients (44%). Of these, two (15%) had isolated midshaft radius/ulna fractures and the rest had fractures involving the wrist and hand. Two of the 11 fractures were open and 9 closed. All patients with fractures underwent initial fracture alignment and splinting in the emergency room. Following the fasciotomy procedure, 8 patients with forearm and distal forearm fractures underwent open reduction and internal fixation, 2 patients with isolated fractures of the hand underwent closed reduction and Kirshner wire fixation, and one patient with a forearm fracture underwent external fixation of their fracture. Fourteen fasciotomies (56%) were performed for compartment syndrome caused by insults other than fractures: 3 patients (11%) treated with fasciotomy developed compartment syndrome secondary to hematoma, 2 patients (7%) were treated following electrical injury, and 2 patients (7%) were treated following snake bite. An elbow dislocation, contusion to the extremity, necrotizing fasciitis, a preceding infection, a gunshot wound, toxic shock syndrome, and contrast extravasation preceded fasciotomy in single patients. We found no cases regarded as missed compartment syndrome in our cohort.

Table 1. Summary of demographics, diagnosis, and treatment data in 25 patients

Characteristic	Number of patients
Age in years	
Mean (minimum–maximum)	25 patients (1–70)
Sex	
Male Female	22 patients (88%) 3 patients (12%)
Method of diagnosis	
Clinical Instrumental	15 patients (60%) 10 patients (40%)
Time from injury to fasciotomy	
0–12 hours 12–24 hours < 24 hours	8 patients 8 patients 9 patients

Figure 1. The initial insult leading to compartment syndrome



The time from insult to fasciotomy varied greatly (2–600 hours) with a median of 24 hours. Eight patients (32%) underwent fasciotomy within 12 hours of their insult. Another 8 patients (29%) underwent the procedure between 12 and 24 hours. The remaining 9 patients (36%) had a fasciotomy performed more than 24 hours after the initial insult. When comparing the fracture to the non-fracture group, the average time to fasciotomy in patients without a fracture was 10.21 hours and to those with a fracture was 16.55 hours from their insult. The difference between the groups was found to be statistically significant using Mann–Whitney ($P = 0.031$).

The diagnosis was made clinically in 15 patients (60%) and instrumentally in 10 patients (40%). Performing an instrumental diagnosis was not found to delay the time to surgery (Pearson's chi-square, $P = 0.234$). There was no correlation between method of diagnosis and the chance of a fasciotomy being performed more than 24 hours after the insult.

Fourteen patients (60%) underwent further surgeries. Of these, a median of 1 (1–6) operation was performed on each patient following fasciotomy with a total of 32 in our series. Operations included debridement (12 operations), wound closure (8 operations), extension of fasciotomy (1 operations), amputation (4 operations), fracture fixation (4 operations), nerve/vascular suture twice ,and one neurolysis operation.

Nine of the 14 patients (64.2%) with non-fracture injuries underwent additional surgeries in contrast to 5 of the 11 patients (45.5%) with fracture injuries. Patients with a non-fracture injury underwent more additional surgeries (mean 1.64 and 0.81, respectively), but this difference was not statistically significant ($P = 0.299$, Mann–Whitney). A fasciotomy performed more than 24 hours from the insult was not significantly found to affect the number of additional surgeries ($P = 0.952$, Mann–Whitney).

On follow-up, sequelae was found in 19/25 patients (76%) who completed follow-up. We defined sequelae as a long-term consequential morbidity of the insult. Of the 19 patients having sequelae, functional limitation including an active or passive deficit in joint range of motion was found in 8 patients, nerve damage in 7 patients, and an amputation was performed in 4 patients. Unremarkable results were found in 6 patients.

Fasciotomy performed more than 24 hours from the initial insult was not found to significantly affect long-term sequelae compared to fasciotomy performed earlier than 24 hours from the initial insult ($P = 0.637$; Fisher's exact test). There were 12 patients who underwent fasciotomy less than 24 hours after their insult with long-term sequelae in contrast to 7 who underwent fasciotomy later than 24 hours following initial insult. Four patients who underwent a fasciotomy in the first group had no sequelae compared to two in the latter. The non-fracture group was found to have more long-term sequelae (13/15 patients and 5/11 patients, respectively). This difference was not statistically significant ($P = 0.056$ Fisher's exact test).

DISCUSSION

We summarized our experience with 25 patients who underwent fasciotomy for acute compartment syndrome of the upper extremity. The literature regarding the epidemiology and outcome of this specific entity is scarce. Data can be found in studies focusing on compartment syndrome not specific to the upper extremity. McQueen et al. [3] studied a series of 164 cases of traumatic acute extremity compartment syndrome. Of these, 16 (10%) were associated with distal radius fractures, 13 (8%) with diaphyseal forearm fractures, and 4 (2.5%) with hand fractures. Of the entire cohort, 54 (31%) had a non-fracture related injury [3]. In other research studying this cohort but focusing on non-fracture related injuries, McQueen found a mean delay to fasciotomy from presentation of 12.4 hours compared to patients with a fracture. Patients in the non-fracture group were described as older and presenting with more co-morbidities.

Bae et al. [10] studied acute compartment syndrome in children. In a series of 33 patients they found that 51% were upper extremity injuries and 76% of all injuries were associated with fractures. In their study, the mean time from injury to surgical decompression was 30.5 hours (3-144) with 16 (48%) of these undergoing surgery in a period longer than 12 hours after their insult. Kalyani and co-authors [11] performed a systematic review of acute compartment syndrome in the forearm in 12 published studies describing a total of 84 cases. Their results showed that 70% of patients were treated by fasciotomy; 36% of all cases were linked to fractures, 10% were linked to drug abuse, 8% to intravenous infiltrations, and 3% to snake bites. An overall complication rate of 42% was reported [11]. In their study of compartment syndrome of the hand, Ouellette and colleagues [12] described 19 patients who underwent fasciotomy for compartment syndrome of the hand. Compartment syndrome developed after intravenous injections in 11 patients (58%), after a gunshot wound, and crush injury as well as an arterial line use in 2 patients each (10%) and post-arthrodesis and prolonged pressure in a single patient each (5%). Eight of the patients also had compartment syndrome of the forearm; 15 of the patients reported had obtunded sensorium. A reported complication rate of 21% was observed in this series. Patients are at particular risk of developing acute extremity compartment syndrome when they sustain a distal radius fracture and simultaneous ipsilateral elbow injury or a distal radius fracture with translation [13] or associated brachial artery injury [14].

Our results further shine light on the epidemiology and outcome of patients with compartment syndrome of the upper extremity. We found that at our institution 32.6% of all patients presenting with compartment syndrome that were treated with fasciotomy had compartment syndrome of the upper extremity, a distinctly larger number than that published by McQueen [3]. Another notable finding was that 44% of our cohort had a fracture as their initial insult. This number is lower than the results presented by McQueen (69%) [3] and Bae (76%) [10] regarding compartment syndrome in general but relatively similar to that presented by Kalyani (36%) [11] regarding the upper extremity. Our results showed that non-fracture associated compartment syndrome can result from a wide array of insults in all age groups with a slight tendency toward older individuals advising a high index of suspicion in upper extremity injuries in all age groups.

The time from onset of compartment syndrome to fasciotomy is an important predictor of outcome with a critical delay time that has been reported between 6 and 24 hours [5,7,9,12,15,16]. Matava et al. [17] studied compartment syndrome in a canine model and showed that irreversible damage occurred after 8 hours. Unfortunately, assessing the precise time of onset of compartment syndrome is a difficult task, especially given the many different mechanisms of injury leading to it. The time from diagnosis to surgical treatment could not be withdrawn from our computerized records. We examined the time from initial insult to fasciotomy and found this period varied greatly. Roughly one-third of the patients underwent fasciotomy within 12 hours, two-thirds within 24 hours, and the remaining more than 24 hours following insult. We found that fasciotomy performed earlier than 24 hours from insult had no effect on outcome compared to fasciotomy performed later than 24 hours from insult, suggesting timely surgical treatment following diagnosis. We found that this time was longer in the fracture group than in the non-fracture group (16.55 hours vs. 10.21, respectively, $P = 0.031$). We advise a longer and closer follow-up in this patient group. Clinically, as long as fasciotomy is preformed immediately following diagnosis, time from insult should not be taken into consideration.

Other than the immediate danger of upper extremity compartment syndrome there is further morbidity to the patients caused by the insult, the high-pressure state, or the surgical treatment. We found that a large percentage of patients underwent further surgeries (60%), which resulted in long-term sequelae (76%). In their review focusing on forearm compartment syndrome, Kalyani and colleagues [11] showed that of the 61 extremities that underwent fasciotomy, 34 (56%) underwent additional surgeries. Of the studies included in our review, 7 [18-24] described long-term complications in 18 of 43 extremities (42%) including functional and neurological deficits. In their study of compartment syndrome of the hand, Ouellette and co-authors [12] described 19 patients who underwent fasciotomy for compartment syndrome of the hand. Of the 17 followed, 13 (79%) had normal function of the hand. Of the remaining 4 (21%), two underwent amputations, one had a contracture leading to a functional limitation, and one was spastic secondary to brain damage. Our study shows a more problematic situation with additional surgeries performed in 60% of patients and complications seen in 76% of patients with long-term follow-up.

Specific deduction made regarding the difference in fracture related and non-fracture related compartment syndrome is difficult to make due to different non-fracture etiologies and their distinct mechanisms. An interesting finding is the difference between the fracture group and the non-fracture with the latter having more long-term sequelae ($P = 0.056$ Fisher's exact test). Although not statistically significant, this finding points to a trend suggesting either a higher amount of initial tissue damage or ongoing tissue damage not necessarily influenced by the surgical treatment. Further studies of the distinct etiologies should be conducted to describe the natural history of these injuries.

LIMITATIONS

This study is limited by its retrospective design. Patient age, level of injury, and mechanisms are varied. Also, clinical decisions and treatment were provided by various personnel. Only documented fasciotomy procedures were included. Furthermore, our finding of no missed compartment syndrome or Volkmann's contractures on follow-up may be due to lack of documentation. Specifically regarding Volkmann's contracture, we did not explicitly search for these sequelae in our patient records. Our cohort, although being large relative to other studies, lacked the volume for statistical analysis that could have been made with a larger group. Furthermore, five of our patients were lost to follow-up, weakening our conclusions regarding long-term results

CONCLUSIONS

Surgical fasciotomy for compartment syndrome of the upper extremity is a rare but hazardous entity with high morbidity. As opposed to the lower extremity, most injuries were non-fracture related. Time interval from insult to fasciotomy did not affect outcome. The proportion of fracture-related injuries among patients treated later than 24 hours after insult was higher, which suggests longer monitoring in this group. More complications may be expected in patients with non-fracture related injuries. Maintaining a high index of suspicion is crucial to timely diagnosis and successful treatment.

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Capsule

Astrocytic interleukin-3 programs microglia and limits Alzheimer's disease

Communication within the glial cell ecosystem is essential for neuronal and brain health. The influence of glial cells on the accumulation and clearance of β-amyloid (Aβ) and neurofibrillary tau in the brains of individuals with Alzheimer's disease (AD) is poorly understood, despite growing awareness that these are therapeutically important interactions. **McAlpine** and co-authors showed, in humans and mice, that astrocyte-sourced interleukin-3 (IL-3) programs microglia to ameliorate the pathology of AD. On recognition of Aβ deposits, microglia increase their expression of IL-3Rα–the specific receptor for IL-3 (also known as CD123)–making them responsive to IL-3. Astrocytes constitutively produce IL-3, which elicits transcriptional, morphological, and functional programming of microglia to endow them with an acute immune response program, enhanced motility, and the capacity to cluster and clear aggregates of Aβ and tau. These changes restrict AD pathology and cognitive decline. These findings identify IL-3 as a key mediator of astrocyte-microglia cross-talk and a node for therapeutic intervention in AD.

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