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ORIGINAL PAPER

Acute compartment syndrome in children: a case series in 24 patients and review of the literature

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Abstract Trauma-associated acute compartment syndrome (ACS) of the extremities is a well-known complication in adults. There are only a handful of articles that describe the symptoms, the diagnostic procedure and treatment of ACS in children. The aim of this study was to analyse the diagnostic procedures in children compared to adolescents with ACS to obtain evidence for the diagnosis, treatment and outcome of children with ACS. Twenty-four children and adolescents with ACS have been treated at the Department of Trauma Surgery of the Medical University of Vienna, Austria. Two age-related groups were investigated to compare the diagnostic and therapeutic algorithm: group A comprising children aged 2–14 years (n=12) and group B comprising adolescents aged 15–18 years (n=12). Patient characteristics, diagnosis and therapy-associated data, complications and clinical outcome were analysed. In both groups we found fractures in most of our patients (n=19) followed by contusion of the soft tissues (n=3). In group A most of our patients were injured as pedestrians in car accidents (n=5) followed by low-energy blunt trauma (n=3). The most common region of injury and traumatic ACS was the lower leg (n=7) followed by the feet (n=3). For fracture stabilisation most of the patients (n=6) received an external fixator. The mean time from admission to the fasciotomy was 27.9 hours. In four patients a compartment pressure measurement was performed with pressure levels from 30 to 75 mmHg. A histological examination of soft tissue was performed in five patients. From fasciotomy to definitive wound closure 2.4 operations were necessary. The mean hospital stay was 18.9 days. In group B most of our patients had a motorcycle accident (n=5). The most common region for traumatic ACS in this group was also the lower leg (n=9). In most of the patients (n=6) intramedullary nails could be implanted. The mean time from admission to the fasciotomy was 27.1 hours. In six patients a compartment pressure measurement was performed with pressures from 25 to 90 mmHg. In five patients a histological examination was performed. From fasciotomy to definitive wound closure 2.3 operations were necessary. The mean hospital stay was 18.4 days. Secondary fasciotomy closure was performed in all cases. A split-skin graft was only necessary in three patients (13%). We avoided primary closure in the same setting when the fasciotomy was performed. Thus, we found no difference between the two groups in the diagnostic procedures, the indication for fasciotomy, the number of operations needed from fasciotomy to definitive wound closure, time of hospitalisation and clinical outcome. The rate of permanent complications was 4.2% (one patient from group A), which means that nearly all patients experienced full recovery after fasciotomy. ACS represents a surgical emergency and the indication should be determined early even in doubtful cases to avoid complications.

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Introduction

Acute compartment syndrome (ACS) has been recognised since 1881 when Volkmann first described the contracture of the hand caused by compartment syndrome [1]. The first reported treatment of acute limb compartment syndrome was by Petersen in 1888 [2]. The diagnosis and management of ACS in the adult population is well known, but only a few authors have reported on the paediatric population [3].

The changing life situation with other injury mechanisms and the changed anatomical situation of adults and adolescents on the one hand (more high-energy trauma, closed epiphyses) and of children on the other hand allow alternative forms of fracture stabilisation (intramedullary nailing, external fixator) with different risk levels of developing an ACS.

ACS is a diagnostic dilemma in small children, who may not have the cognitive and verbal ability to provide clinical information particularly in an extraordinary situation, resulting in delays in diagnosis and adequate therapy. However, early diagnosis is pivotal for the outcome of ACS and is determined by the duration of ischaemia and the pressure in the osseofascial compartment. Immediate and adequate treatment can lead to healing with good functional and cosmetic results. If operative treatment is delayed or inadequate, excessive tissue necrosis may lead to severe local and systemic complications, such as reversible or irreversible muscle and neurovascular damage with functional loss of the extremity or myoglobinaemia with subsequent acute renal failure.

The aim of the study was to analyse the diagnostic procedure for compartment syndrome in children from arrival at the hospital until discharge to obtain better evidence for the diagnosis, treatment and outcome of children with ACS.

Patients and methods

Nearly 144,000 children and adolescents between 0 and 18 years of age were treated between January 1992 and January 2010 at our Level I Trauma Centre. Twenty-four patients (0.02%) who developed ACS in any anatomical region were included in this retrospective study (21 male and three female subjects). The mean age was 12.9 years (range: 2–18 years). Patients included were classified into two groups according to their age: group A (age 2–14) and group B (age 15–18). The group cut-off at the age of 14 was chosen because closure of the epiphyses happens in most humans between the ages of 12–16 years.

Patients' records were analysed for the demographic data (sex, age, admission periods and cause of the compartment syndrome), information about diagnostic procedures, interventions and other therapeutic procedures (tissue pressure measurements, time from injury to fasciotomy, wound management, number of operations until definitive closure of fasciotomy), complications and clinical outcome. Intracompartmental pressure (ICP) measurement was performed invasively with the Stryker® S.T.I.C. Pressure Monitor System (Stryker Corporation, Kalamazoo, MI, USA). The average follow-up was 11.1 months (range: 1–43 months).

Results

Overall, 24 patients (male n=21, female n=3) were included in the study and divided into two age-related groups: group A comprising children aged 2–14 years (n=12) and group B comprising adolescents aged 15–18 years (n=12).

Demographics

Group A included (Table 1) 12 children aged 2–14 years (mean age: 9.8 years), three girls with a mean age of 5.3 years (range: 2–11 years) and nine boys with a mean age of 10.2 years (range: 5–14 years). Five patients were injured as pedestrians in car accidents, three patients suffered from blunt trauma (trapped after an earthquake between ruins, jammed between cars at the autodrome and in the baking oven door), two children fell from a height, one patient suffered a sports trauma (sled) and one child had a laceration with severe vascular damage (complete severance of the tibialis posterior artery). The most common region of injury and traumatic ACS was the lower leg (seven patients), followed by the feet (three patients), forearms and hands (two patients each) and the thigh (one patient). One patient developed ACS in four regions at the same time (in both forearms and lower legs).

Group B (Table 2) consisted of 12 boys aged 15–18 years (mean age: 16.8 years). Five patients had a motorcycle accident, two patients were run over by a car, two patients suffered a sports trauma, one patient fell from a height, one patient was injured in a car accident as a passenger and one was injured in an affray. The most common region for traumatic ACS was the lower leg in nine patients, the forearm in one patient and the thigh in another one. One polytrauma patient developed an abdominal compartment syndrome.

The most common cause of ACS in both groups was one or multiple fractures of long bones followed by contusion of the soft tissues.

Diagnostic procedures, treatment and clinical course

In group A the mean time from admission to the fasciotomy was 27.9 hours (range: 2.5–66 hours). For fracture stabilisation six patients received an external fixator and one K-wire fixation; four patients were treated conservatively. The number of operations from fasciotomy to definitive wound closure was 2.9 operations (range: 1–6). The mean hospital stay was 18.9 days (range: 6.5–28.5).

In group B the mean time from admission to the fasciotomy was 27.1 hours (range: 3–99 hours). To stabilise the fracture six patients received intramedullary nails, two patients an external fixator and in two patients plates were

Table 1 Group A (patients aged 2–14 years, n=12): clinical data at presentation after injury, diagnosis, treatment and complications

Patient (age, years/sex)	Mechanism of injury	Diagnostics	Time from admission to the fasciotomy (h)	Type of fasciotomy	Operations to definitive wound closure (n)	Complications
1 (3/F)	Pedestrian in car accident	Clinical	62	SIF	3	0
2 (2/F)	Jammed in baking oven door	Clinical	16.5	SIF	2	0
3 (11/F)	Fall from bike	Clinical	15	SIF	4	0
4 (5/M)	Pedestrian in car accident	ICP 75 mmHg intraoperative	2.5	SIF	1	Delayed bone healing
5 (8/M)	Sports trauma (sled)	ICP 44 mmHg intraoperative	14.5	SIF	2	0
6 (8/M)	Fall from height	Clinical	14	SIF	5	Volkmann's contracture
7 (12/M)	Jammed in autodrome	Clinical	3	SIF	2	0
8 (11/M)	Pedestrian in car accident	Clinical	65	SIF	2	0
9 (10/M)	Pedestrian in car accident	Clinical	46.5	SIF	2	0
10 (10/M)	Trapped between ruins	ICP 30 mmHg preoperative	25	SIF	6	Peripheral nerve damage
11 (14/M)	Fall through glass door	ICP 50 mmHg intraoperative	66	SIF	4	0
12 (14/M)	Pedestrian in car accident	Clinical	4.5	SIF	2	0

SIF single-incision fasciotomy, *DIF* double-incision fasciotomy

implanted, while conservative fracture treatment could be implemented in only two patients. The number of operations from fasciotomy to definitive wound closure was 2.4 operations (range: 1–8). The hospital stay was 18.4 days (mean) in group B (range: 10.9–35 days).

There was no significant difference between the groups regarding the diagnostic procedures, the indication for fasciotomy, the number of operation needed from fasciotomy to definitive wound closure, time of hospitalisation and clinical outcome.

To diagnose ACS, ICP measurement was performed preoperatively or intraoperatively in ten patients (four in group A and six in group B). In six patients (three patients in each group) the mean ICP was 60 mmHg (range: 40–90 mmHg) and in the other patients 30 mmHg (range: 25–37 mmHg) (Tables 1 and 2). Antibiotic prophylaxis was used in all patients. Histological examination of tissue from the injured anatomical region and the most suspicious location was performed in ten patients. In three patients necrotic tissue and in another three patients partially necrotic tissue could be confirmed. In four patients the tissue specimen was vital.

Surgical treatment, i.e. fasciotomy, needed to be performed in all of the patients. Fasciotomies were all performed under sterile conditions in the operating theatre under general anaesthesia (Fig. 1). Only in one patient was it necessary to perform a double-incision fasciotomy (lateral and medial incision) because of clinical evidence of residual tightness of the compartments after the lateral incision. In the other patients a single-incision fasciotomy (lateral incision) was adequate. Overall, 64 surgical interventions (median: 2.7, range: 1–8) were performed in all patients. Three patients (two boys, eight and ten years old, and an adolescent, 16 years old) had more than five surgical interventions (five to eight interventions, median: six). Secondary fasciotomy closure was performed in all cases. Skin wound management in 21 cases (group A: 11 patients, group B: 10 patients) involved temporary closure with Epigard® Synthetic Skin Substitute (The Clinipad Corporation, Norwich, CT, USA) (Fig. 1h, i) combined with Berman's shoelace technique, requiring definitive closure at a later stage. A split-skin graft was only necessary in three of 24 patients (12.5%). Primary closure in the same setting with fasciotomy was avoided.

Overall, the complication rate was 4.2%. Delayed bone healing was observed in two patients (one in each group) and two patients had a peripheral neurological deficit in the lower extremity (one patient in each group). All but one patient experienced full remission. An eight-year-old boy developed permanent contractures of the upper extremity after conservative treatment of epiphysiolysis of the distal radius. In this patient ACS was only diagnosed 12 hours

Table 2 Group B (patients aged 15–18 years, n=12): clinical data at presentation after injury, diagnosis, treatment and complications

Patient (age, years/sex)	Mechanism of injury	Diagnostics	Time from admission to the fasciotomy (h)	Type of fasciotomy	Operations to definitive wound closure (n)	Complications
1 (17/M)	Pedestrian in car accident	ICP 60 mmHg intraoperative	10.5	SIF	2	Delayed bone healing
2 (16/M)	Sports trauma (handball)	Clinical	3	SIF	2	0
3 (16/M)	Affray	ICP 40 mmHg preoperative	19	SIF	1	0
4 (16/M)	Motorcycle	ICP 37 mmHg preoperative	4	SIF	8	0
5 (15/M)	Fall from height	ICP 30 mmHg intraoperative	9	SIF	1	0
6 (18/M)	Pedestrian in car accident	Clinical	11	SIF	4	0
7 (17/M)	Motorcycle	Clinical	64	SIF	3	0
8 (18/M)	Motorcycle	Clinical	7	SIF	2	0
9 (16/M)	Car accident	ICP 90 mmHg preoperative	11	SIF	1	0
10 (17/M)	Motorcycle	ICP 25 mmHg intraoperative	99	SIF	2	0
11 (17/M)	Motorcycle	Clinical	66	SIF	3	0
12 (18/M)	Sports trauma (soccer)	Clinical	22	DIF	1	Peripheral neurological deficits

SIF single-incision fasciotomy, *DIF* double-incision fasciotomy

after cast fixation, when the patient returned for the first follow up visit.

Discussion

The most common cause of ACS is trauma, usually after fractures [4]. Following trauma, bleeding or oedema in a closed osseofascial compartment causes an increased ICP with ischaemia [5]. Ischaemia results in tissue membrane damage and leakage of fluid through capillary and muscle membranes. With arterial reperfusion the damaged membranes continue to leak, and the rise in the hydrostatic force results in further increase of ICP thus developing a vicious cycle [6]. The capillary perfusion decreases below a level necessary for tissue viability [7] compromising the circulation and function of the tissues leading to muscle and nerve ischaemia with muscle infarction and nerve damage.

In the early stage of ACS Hoffmeyer et al. [8] found marked perifascicular and intrafascicular oedema with dissociation of the muscle fibres and necrosis in the tissue sections. In the late stages atrophy and hypertrophy of muscle fibres with lipid globules appear in the tissue examined. In our study only six of ten patients, in whom tissue sections were performed, showed necrotic or partially necrotic tissue in the histological examination.

Thus, early treatment by fasciotomy is pivotal. The mean time from admission to fasciotomy was 27.9 hours (range: 2.5–66 hours) in group A and 27.1 hours (range: 3–99 hours) in group B. This means a difference of 0.8 hours (2.9%) between groups A and B. The exact time of appearance of the first symptoms of the ACS could not be evaluated retrospectively.

Diagnosis on clinical grounds is not easy. Pain (severe and out of proportion to the apparent injury) [9], pallor, paraesthesia, paralysis and pulselessness (five Ps) [10] are the relatively unreliable cardinal symptoms of ACS. In small children pain is hard to evaluate. Pulselessness is noted only at a late stage [11]. Ulmer [12] examined the clinical signs and symptoms of compartment syndrome and reported that the false-positive rate was high in relation to the true-positive rate. Thus, clinical findings of ACS were more likely to be present in patients who do not have ACS than in those who do. This implies that other diagnostic devices should be used when in doubt to establish the diagnosis of ACS, although the clinical presentation is the most important indication for fasciotomy. The combination of a relevant trauma, tight extremities, excessive pain sensations, pain on passive stretching of the muscle, sensory loss and an increasing analgesia requirement should give rise to a high suspicion. A high level of serum creatine phosphokinase (CPK) may be another supportive indicator for diagnosing ACS.

Using the ICP for the diagnosis of ACS and a presumptive critical cut-off pressure are still controversial. The discussion regarding a critical pressure to diagnose compartment syndrome is ongoing. Mubarak et al. [13]

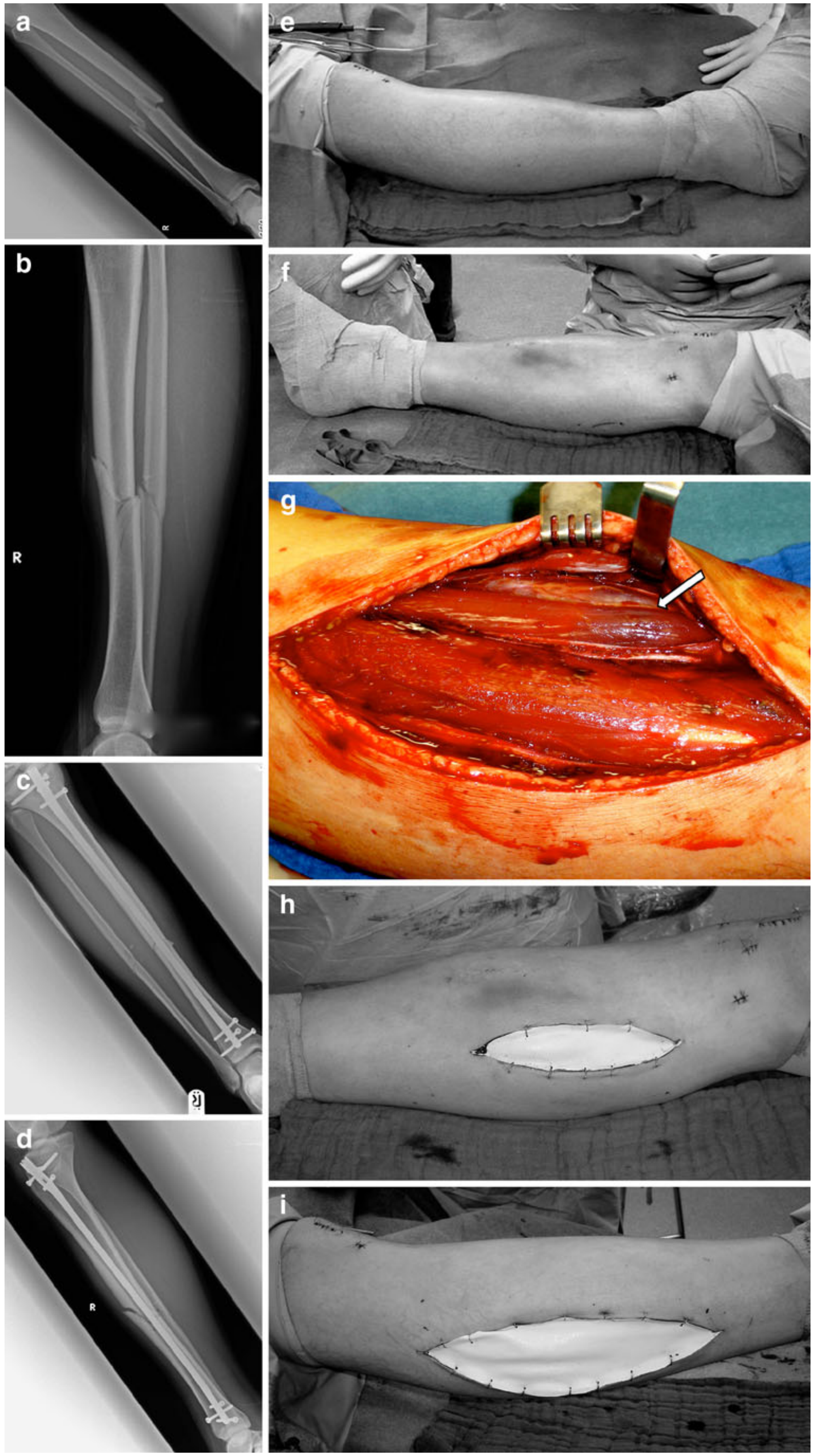

Fig. 1 Case study: 18-year-old boy injured by playing soccer. ACS 16 h after intramedullary nailing. **a**, **b** Preoperative X-rays. **c**, **d** Postoperative X-rays. **e**, **f** Clinical picture before fasciotomy (16 h after fracture stabilisation). **g** Vital and partially non-vital muscle (*arrow*) in the fasciotomy wound. **h**, **i** Medial and lateral fasciotomy temporarily closed with Epigard®

used an ICP of more than 30 mmHg as the reference value for performing fasciotomy. Whitesides et al. [14] used the difference between the diastolic pressure and the ICP. Other authors evaluated the difference between the mean arterial pressure (MAP) and the ICP [15] to calculate the critical pressure for indicating fasciotomy. Schmidt [16], like Whitesides et al., describes the perfusion pressure (P= RRdia-ICP) as the safest method for diagnosing compartment syndrome. Using this definition, fasciotomy should be considered whenever P is less than 30 mmHg. The normal compartment pressures in the lower leg of healthy children (13–16 mmHg) were significantly higher than those of adults (0–10 mmHg) [17], because children are in a stage of muscle growth and this increasing volume due to muscle hypertrophy may press against the surrounding fascia [18]. ICP measurement is recommended in young children, unconscious patients, patients with regional nerve blocks and when the clinical signs are equivocal. It may not be necessary if the diagnosis is clinically evident [6]. Some authors [19, 20] warn in their case reports against using epidural anaesthesia or nerve blocks in patients at risk of developing an ACS to avoid delay in the diagnostic procedure of ACS. Johnson and Chalkiadis [21] reviewed cases of paediatric patients with working epidural anaesthesia and found no clear evidence that this kind of regional anaesthesia had delayed the diagnosis of an ACS. Compartment pressure measurement can be made for example with the wick catheter technique modified by Mubarak et al. [22], the simple needle manometry by Whitesides et al. [23], infusion technique by Matsen et al. [24], slit catheter technique modified by Barnes et al. [25], side ported needles [26] etc. A single measurement in one compartment seems to adequately estimate pressures in the compartments at least of the lower leg [18].

Near infrared spectroscopy (NIRS) as a non-invasive continuous method seems to be perfect for monitoring the compartment pressures in children. It measures tissue oxygenation or hypoxia by measuring the muscle oxyhaemoglobin [27]. Muscle oxyhaemoglobin levels strongly reflect compartment pressure, perfusion pressure and loss of myoneural function [28]. The problem is that it is an expensive method that measures only to a limited depth. In ten patients included in our study invasive compartment pressure measurement was performed. Six of ten patients showed a compartment pressure over 40 mmHg. In the other four patients the tissue pressure was at a lower level. Even if ICP measurement is helpful, it is primarily the clinical signs that lead to the decision to perform fasciotomy.

The adequate therapy of ACS, after removing any external sources of compression (circumferential dressings, casts etc.), is the decompression of all involved compartments by an open technique. The skin incision alone reduces the ICP by 5–9 mmHg [29]. The subcutaneous technique, even successfully used in chronic compartment syndrome, appears to be insufficient in ACS [30], especially in younger patients with an intact and firm skin. When in doubt about the viability of soft tissue, tissue that is not obviously necrotic should be left in place at the initial fasciotomy because of the high potential for tissue and muscle function recovery in children (Fig. 1g, arrow). The skin defect in open fasciotomy should not be closed in the same session. To avoid skin grafts, Berman's shoelace technique for secondary closure can be used successfully [31], but healing by secondary intention, secondary skin closure, skin grafting or flap coverage are possible. In our patients in nearly all cases a direct secondary fasciotomy closure could be performed (87.5%); a split-skin graft was only necessary in three patients (12.5%).

Complications occur particularly after late fasciotomies [32]. Local complications are soft tissue and bone infections leading to amputation, nerve damage etc. [33]. We observed delayed bone healing in two patients and a completely reversible neurological deficit in two patients. One patient developed Volkmann's contracture. Thus the total permanent complication rate in our series was 4.2%. We did not observe any systemic complications in our patients, such as renal insufficiency caused by rhabdomyolysis and myoglobulinaemia induced by the high ICP.

Conclusion

The diagnosis of ACS in children can be challenging because of the difficulty with co-operation. The classic symptoms of compartment syndrome (five Ps) may be unobtainable. Adjunctive diagnostic tests such as invasive ICP measurement may help guide treatment. However, the entire clinical picture must be considered especially in infants. Early fasciotomy is pivotal. In our study, patients underwent fasciotomy within a median of 27.5 hours (range: 2.5–99). Persistent contractures as a post-traumatic complication occurred in one of 23 patients (4.2%). Thus, when ACS is present, the indication for open fasciotomy is clear even in infants. It is a surgical emergency where the surgeons must make rapid treatment decisions including when to perform fasciotomy. Thanks to a timely and adequate treatment in nearly all cases complications may be avoided.

Conflict of interest No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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