Original Clinical Article

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# Early morbidity associated with fasciotomies for acute compartment syndrome in children

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**Abstract**

*Purpose* Acute compartment syndrome (ACS) requires urgent fasciotomy to decompress the relevant muscle compartment/s prior to onset of irreversible myonecrosis and nerve injury. A fasciotomy is not a benign procedure. This study aims to describe and quantify early morbidity directly associated with fasciotomies for ACS in children.

*Methods* Clinical charts of 104 children who underwent 112 fasciotomies over a 13-year period at a tertiary children's hospital were reviewed. The following were analyzed: ACS aetiology, fasciotomy site, number of subsequent procedures, method of wound closure, short-term complications and length of hospital stay.

*Results* Short-term complications included wound infections (6.7%) and the need for blood transfusion (7.7%). Median number of additional operations for wound closure was two (0 to 10) and median inpatient stay was 12 days (3 to 63; SD 11.7). After three unsuccessful attempts at primary closure, likelihood of needing skin grafting for coverage exceeded 80%. Analyses showed that fasciotomy-wound infections were associated with higher risk for four or more closure procedures. Number of procedures required for wound closure correlated with longer inpatient stay as did ACS associated with non-orthopaedic causes.

*Conclusion* Fasciotomy is associated with significant early morbidity, the need for multiple closure operations, and prolonged hospital stay. The decision for fasciotomy needs careful consideration to avoid unnecessary fasciotomies, without increasing the risk of permanent injury from missed or delayed diagnosis. Skin grafting should be considered after three unsuccessful closure attempts. Less invasive tests or continuous monitoring (for high-risk patients) for compartment syndrome may help reduce unnecessary fasciotomies.

*Level of Evidence* Level IV, Case series

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## Introduction

Acute compartment syndrome (ACS) occurs when the pressure within an unyielding myofascial compartment exceeds the capillary pressure, thereby restricting muscle perfusion. Muscle ischemia leads to oedema, which further increases the pressure within the compartment. If left untreated, ACS may result in disastrous complications associated with irreversible myonecrosis, such as ischemic contractures, permanent neurological damage and even amputation.[1,2] ACS can arise following a variety of injuries such as fractures, intramuscular hematomas, burns, snake bites, infections and iatrogenically following surgical interventions such as osteotomies.[3-8]

The treatment of ACS is well established and involves an emergent fasciotomy of all the involved compartments. The decision to proceed with fasciotomy is based on the clinical assessment, which relies on the prompt detection of signs and symptoms of an impending compartment syndrome before permanent damage occurs. These include pain out of proportion to the injury, often manifested by increasing analgesic requirement, and pain with passive stretch of the muscles within the involved compartment, in the face of increasing or tense swelling.[9] A sensory deficit or paraesthesia, indicative of ischemia to the nerves, may be a late finding and/or if present due to the injury itself, can mask the cardinal symptoms of pain. The absence of a palpable pulse suggests that compartment pressure exceeds the systolic pressure, which would be a very late finding unless it is associated with a concomitant vascular injury. Recording of compartment pressures can be helpful to corroborate clinical suspicion and is particularly useful in circumstances where subjective clinical signs may be difficult or unreliable, such as in the obtunded patient or in the face of nerve injury which masks the pain. The diagnosis of ACS in children can be challenging, particularly in younger children. The physical examination can be difficult and unreliable in a frightened, irritable or pre-verbal child. Children are unlikely to tolerate invasive compartment pressure measurements.

While there are many reports in the literature on the diagnosis, management and morbidity of ACS in general, reports in children are scarce. Short-term complications in children have reportedly been very rare.[3,9]

As necessary as they are, fasciotomies are not benign procedures. They are associated with significant morbidity and costs, which are not well quantified in the literature. The clinical decision to intervene must, therefore, also take into account the potential morbidity of fasciotomy. The purpose of our study is to describe the early morbidity associated with a fasciotomy for ACS in children and adolescents.

## Patients and methods

This is an Institutional Research Ethics Board approved study. The surgical database of a large tertiary children's hospital, the Hospital for Sick Children in Toronto, Canada, was used to identify all patients who underwent fasciotomy for ACS between April 1992 and March 2005 inclusive.

The inclusion criteria for our study were all patients who underwent fasciotomy of the upper or lower limbs for ACS regardless of aetiology. This included trauma-related causes as well as those who underwent elective orthopaedic procedures that are associated with a significant risk of developing ACS. Similarly, patients who developed compartment syndrome from a vascular, cardiovascular or haematological procedure or condition were also included. Trauma-related causes were sub-classified into high- and low-energy trauma. High-energy trauma was defined as either a motor vehicle accident, fall from height or polytrauma. All patients who underwent prophylactic fasciotomy during elective orthopaedic procedures such as a corrective osteotomy or other procedures in which the main purpose of the procedure was not fasciotomy for ACS, were excluded.

The medical records were reviewed to determine the underlying aetiology, location and timing of fasciotomy (at or as the index procedure or as a subsequent procedure), number of subsequent operations after fasciotomy for definitive wound closure or coverage, method of wound closure or coverage, length of hospital stay and the short-term inpatient complications of wound infection and need for blood transfusions. Results are reported in means (SD) or medians (ranges) if the data are skewed. The association between the independent variables (possible risk factors: age, gender, aetiology of ACS, fasciotomy wound infection, baseline compartment pressure, antibiotic usage) and the following outcome variables (number of procedures required for wound closure/coverage, need for skin grafting, and the length of hospital stay, respectively), was evaluated using univariate and multivariable analyses. Risk factors with $p < 0.20$ in univariate analyses were assessed in the multivariable regression analysis for number of procedures for closure and length of stay. We also included in the analysis whether compartment pressure was measured or not, and if the fasciotomy was done at the index procedure (potentially prophylactically even if not documented as such) *versus* those done as a subsequent procedure (more likely to be compartment syndrome) had a differential impact on the number of procedures for closure or length of stay. Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, North Carolina).

## Results

There were 121 cases of fasciotomy recorded during the specified study period, of which 112 fasciotomies (in 104 children) fulfilled the inclusion criteria. The mean age was 10.2 years with a SD of 4.6, and the male-to-female ratio was 7:3. In all, 96 (92.3%) children underwent a single limb segment fasciotomy (e.g. lower leg only) and eight (7.7%) children underwent double segment fasciotomies (e.g. lower leg and foot). Table 1 summarizes the patients' demographic information of this cohort including gender, aetiology, compartmental pressure measurement and location of fasciotomy.

### *Aetiology*

Orthopaedic related causes accounted for 96 (92.3%) cases. The specific aetiology for ACS was trauma in the majority of cases (91 of 104 children; 87.5%); 44 (48.4%) from high-energy and 47 (51.6%) from low-energy trauma. Of the 91 children who underwent a fasciotomy for trauma-related ACS, 72 (69.2%) had a fracture without associated vascular injury, 12 (11.5%) had a fracture with an associated vascular injury, three (2.9%) had an isolated vascular injury without fracture and four (3.9%) had soft-tissue injury alone. Five (4.8%) patients developed ACS following elective osteotomies. Non-orthopaedic causes accounted for eight (7.7%) cases of ACS and were secondary to vascular, hematological or infection-related complications.

### *Site*

Fasciotomies (n = 112) were performed in 54 lower legs (48.2%), 42 forearms (37.5%), 12 feet (10.7%), two thighs

**Table 1 Demographics, aetiology and features of acute compartment syndrome (ACS)**

| | 112 fasciotomies in 104 patients |
|---|---|
| **Variable** | **Result / distribution** |
| Gender, n (%) | Male: 73 (*70.2*)<br>Female: 31 (*29.8*) |
| Mean age (SD) (yrs) | 10.2 (4.6) |
| Aetiology, n (%) | Trauma: 91 (*87.5*)<br>High energy: 44 (*42.3*)<br>Low energy: 47 (*45.2*)<br>Elective osteotomy: 5 (*4.8*)<br>Non-Orthopaedic causes: 8 (*7.7*) |
| Mean compartment pressure measurement (SD) | Recorded in 51 patients (*49.0*)<br>Mean absolute compartment pressure:*<br>Lower limb: 42.14 mm Hg (17.5) (n = 82)†<br>Upper limb: 43.43 mm Hg (12.7) (n = 15) |
| Site of ACS/fasciotomy (n = 112) (%) | Forearm: 42 (*37.5*)<br>Arm: 0 (*0*)<br>Hand: 2 (*1.9*)<br>Thigh: 2 (*1.9*)<br>Lower leg: 54 (*48.2*)<br>Foot: 12 (*10.7*) |

*number of compartments measure > number of patients who had compartment pressures recorded (51)

†lower limb measurements reported are an average of the four compartments: anterior, peroneal, superficial posterior and deep posterior, since these values were all very similar

(1.8%) and two hands (1.8%). Eight children (7.7%) had fasciotomies at two different sites; seven children at the lower leg and foot and one at the forearm and hand. Fasciotomy was performed at the first operation for that inpatient admission in 63 (60.6%) cases, while 41 (39.4%) underwent fasciotomy at the second operation that admission.

### *Compartment pressures*

Compartment pressures were recorded in 51 (49.0%) cases. This was done intraoperatively after the child was anaesthetized and immediately prior to the fasciotomy. These data are also summarized in Table 1. In the recorded cases, at least one compartment pressure of the involved limb segment was within 30 mmHg of the diastolic blood pressure. In the remainder of cases, the decision for fasciotomy was made solely on clinical judgement and measurement for documentation of intracompartment pressures.

### *Complications following fasciotomy*

Seven (6.7%) patients developed fasciotomy wound infections. Eight (7.7%) patients required blood transfusion following fasciotomies. None of the patients in this series lost their limbs, or any part of their limbs. There were no instances of ischaemic contractures in this cohort.

### *Additional operations for wound closure or coverage*

The median number of additional operations for wound closure was two (0 to 10), with 16 (15.4%) patients requiring four or more procedures (Fig. 1). Five patients did not undergo a secondary operation for wound closure. Eight patients had double segment fasciotomies (i.e. at two regions); if they were closed in the same operation it was considered as a single procedure. Of these, two patients had primary closure after haematoma evacuation and haemostasis was achieved. One patient had a crushed hand and had a partial primary closure of wounds after fasciotomies and fixation of fractures. One patient had a gradual wound closure on the ward using a subcuticular steel wire technique. One patient died in the intensive care unit following complications of underlying cardiac problems. In 34 (32.7%) patients, a split skin graft was used for coverage, while fasciocutaneous rotational flaps for soft-tissue coverage were required in four (3.8%) children (Table 2).

The probability of requiring delayed coverage by skin graft was directly related to the number of attempts to close primarily. If the fasciotomy wound failed to close at the first return to the operating room, the probability of receiving a skin graft was 33/73 or 45.2%; 24/44 (55%) if fasciotomy wound failed to close at the second attempt. After three attempts the probability rose to 13/16 or 81.3% and 100% if more than four procedures were required (Table 2).

In the multivariable analyses, the only risk factors that were significantly associated with increased number of procedures required for primary or delayed secondary closure were fasciotomies done as a second or subsequent procedure (and not at the index operation) ($p = 0.012$) and the development of an infection in the fasciotomy wound ($p = 0.039$) (Table 3). Of the seven patients who had a wound infection, four patients required four or more operations for wound closure. Five of these patients also required skin grafts. All patients who developed wound infection were treated with parenteral antibiotics at a therapeutic dose, for at least one week.

### *Hospital length of stay*

The mean length of stay was 15.8 days; the median length of stay was 12 days (SD 11.7; 3 to 63). In the univariate analyses, ACS associated with non-orthopaedic causes were associated with a significantly longer hospital stay. In the multivariable analyses, the aetiologic category was the most significant determinant of length of stay ($p = 0.006$) (Table 4). ACS associated with soft-tissue injury without fracture and those secondary to osteotomies had significantly shorter hospital stays compared with those due to non-orthopaedic causes ($p = 0.008$ and 0.01, respectively). For the seven patients who developed fasciotomy wound infections, the mean hospital length of stay was 25.6 days (SD 4.4; 18 to 32). In the multivariable analysis infection was not significantly associated with length of

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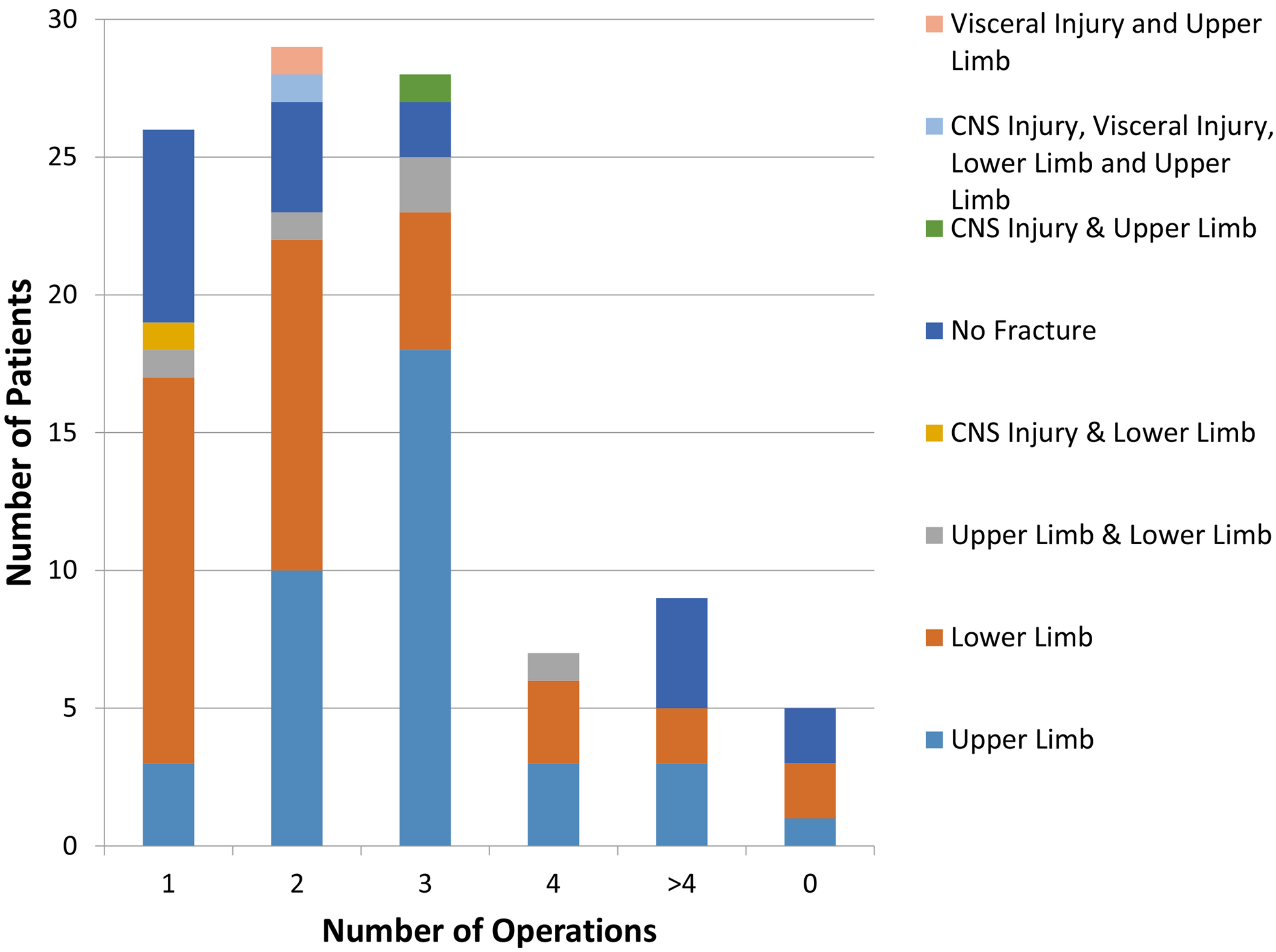


**Fig. 1** Shows the number of patients for each number of operations required. Each column is then subdivided based on the type of injuries (CNS, central nervous system).

**Table 2** Number of procedures for primary or secondary closure

| Additional procedures (after initial fasciotomy) for wound closure/coverage (n) | Fasciotomies* (n) (n = 112) | Required skin graft/flap for coverage,n (%) (n = 34; 34 skin grafts, of which 4 also required flaps) |
|---|---|---|
| 0 | 5 | 0 (*0*) |
| 1 | 26, 3 | 1 (*3.8*) |
| 2 | 29, 1 | 9 (*31.0*) |
| 3 | 28, 3 | 11 (*39.3*) |
| 4 | 7, 1 | 4 (*57.1*) |
| > 4 | 9 | 9 (*100*) |

*format is (total number of patients, number of patients who had fasciotomies at two sites). For example, '26, 3' means that out of 26 patients who needed one additional procedure for closure, three patients had fasciotomies at two sites

stay (p = 0.095) but this could have been due to small number of infections in this cohort.

Length of stay was associated with the number of procedures required to achieve wound closure or coverage (Pearson Correlation Coefficient, R = 0.41; p < 0.001). This is represented in a box plot in Figure 2. Mean length of stay was 14.1 days (SD 10.4) when wound closure was achieved in two operations, compared with 25 days (SD 13.8) and 33 days (SD 18.1) when four or more operations were required, respectively.

## Discussion

ACS is a condition with high morbidity and severe long-term sequelae if left untreated or if the diagnosis is delayed. Emergency fasciotomies are currently the only effective way to prevent associated complications such as muscle necrosis, irreversible nerve damage and even the need for amputation.[2] Children experience compromise of cell viability at lower intra-compartmental pressures than adults and this makes prompt diagnosis and early fasciotomy even more critical.[10] Since the consequences of a missed compartment syndrome or delayed treatment can be catastrophic,

**Table 3** Factors associated with number of additional procedures required for fasciotomy wound closure/coverage

| Variable name | Univariate analysis | Multivariable analysis* | |
|---|---|---|---|
| | p-value | Estimate | p-value† |
| Fasciotomy timing (index *versus* subsequent procedure) | **0.013** | -0.63 | **0.012** |
| Fasciotomy wound infection (yes/no) | **0.040** | 1.01 | **0.039** |
| Aetiology category | 0.313 | | |
| 1A *versus* 3 | | | |
| 1B *versus* 3 | | | |
| 1C *versus* 3 | | | |
| 1D *versus* 3 | | | |
| 2 *versus* 3 | | | |
| Gender (female/male) | 0.310 | | |
| Fracture (yes/no) | 0.555 | | |
| Compartment pressure (yes/no) | 0.351 | | |
| Age at surgery (yrs) | 0.282 | | |
| Antibiotic usage‡ | 0.455 | | |

*variable selection for multivariable analysis was based on p-value < 0.20 in univariate analysis
†p-value from multivariable regression model

‡ antibiotic usage is a categorical variable which means: 0 = not given, 1 = given preoperation, 2 = at operation without fasciotomy, 3 = at operation with fasciotomy, 4 = started on ward before wound closure

Aetiology labels are as follows: 1 = trauma/injury; 2 = elective Orthopaedic procedure (osteotomy); 3 = non-orthopaedic causes (vascular, cardiovascular, haematological, infection, other); A = fracture alone; B = fracture with vascular injury; C = vascular injury without fracture; D = soft-tissue injury alone (without fracture)

Fasciotomy timing refers to whether the fasciotomy was done at the index operation, or at a subsequent operation

p-values < 0.05 are represented in bold

**Table 4** Factors associated with length of hospital stay

| Variable name | Univariate analysis | Multivariable analysis* | |
|---|---|---|---|
| | p-value | Estimate | p-value† |
| Gender (female *versus* male) | 0.063 | 1.97 | 0.410 |
| Wound infection (yes *versus* no) | **0.021** | 7.19 | 0.095 |
| Aetiology category | **< 0.001** | | **0.006** |
| 1A *versus* 3 | | 6.21 | 0.543 |
| 1B *versus* 3 | | 16.39 | 0.124 |
| 1C *versus* 3 | | -3.31 | 0.635 |
| 1D *versus* 3 | | -17.75 | **0.008** |
| 2 *versus* 3 | | -15.89 | **0.011** |
| Antibiotic usage | 0.010 | -2.15 | 0.058 |
| Age at surgery (yrs) | 0.498 | | |
| Operation order (index *versus* subsequent) | 0.548 | | |
| Compartment pressure (yes *versus* no) | 0.242 | | |

*variable selection for multivariable analysis was based on p-value < 0.2 in univariate analysis

†p-value from general linear model

Aetiology labels are as follows: 1 = trauma/injury; 2 = elective Orthopaedic procedure (osteotomy); 3 = non-orthopaedic causes (vascular, cardiovascular, haematological, infection, other); A = fracture alone; B = fracture with vascular injury; C = vascular injury without fracture; D = soft-tissue injury alone (without fracture)

p-values < 0.05 are represented in bold

there is understandably a higher probability of making a false positive diagnosis of an ACS in a child and therefore a higher rate of potentially unnecessary fasciotomies to minimize the risk of missing any compartment syndrome. This potential overtreatment is accepted to avoid the consequences of delay or failure to treat. The time interval between the time of injury or onset of symptoms, and the fasciotomy was not readily available for many patients in this series, and as such we are unable to report on the 'false negatives' and the rate of late fasciotomies.

According to the literature, 75% to 80% of children with ACS are male due to the higher fracture frequency in boys, but gender is not a risk factor for ACS per se in children with fractures.[3,9,11-13] Known risk factors include age over 12 years, weight over 50 kg and a complex fracture pattern.[11,12,14] In our series, which spanned 13 years, we identified 112 fasciotomies (104 children) that fulfilled the study criteria. A total of 73% of our cohort were male, consistent with the literature. The average age of our cohort was 10.2 years. In all, 91/104 (87.5%) children had trauma-related ACS, which is in line with the literature reports that the most common aetiology of ACS in children is due to trauma.[3,9,11] Approximately 50% of trauma-related cases of ACS were due to high-energy trauma, in particular motor vehicle accidents. In a study on 1028 children with lower leg fractures, 3% of children sustained ACS, and the incidence was only 1.3% in children under the age of 12 years.[3]

Reported incidence and complication rates of ACS in children seem lower than in adults.[3,15,16] In our study we did not measure the incidence of ACS relative to the risk factors associated with ACS, as that was not the purpose of the study. Instead, our purpose was to describe and quantify the morbidity following fasciotomy performed for the diagnosis of established or suspected ACS. Prophylactic fasciotomies were not the focus of this study, and hence were not included and analyzed.

The decision to perform a fasciotomy is often based on clinical judgement – symptoms and signs, since compartment pressures are not routinely measured. This is particularly true for children as clinical examination is more difficult and invasive compartment pressure measurement may be less feasible. A study conducted on tibial shaft fractures showed a 35% false-positive rate for compartment syndrome. One limitation of our study was that only about half of our patients had their compartment pressures reported. In all cases, this was done under general anaesthesia in the operating room and did not change the clinical decision for fasciotomy. There are no guidelines with regards intracompartmental pressure monitoring; when it is performed, it is always performed in the operating room under anaesthesia. The reasons for

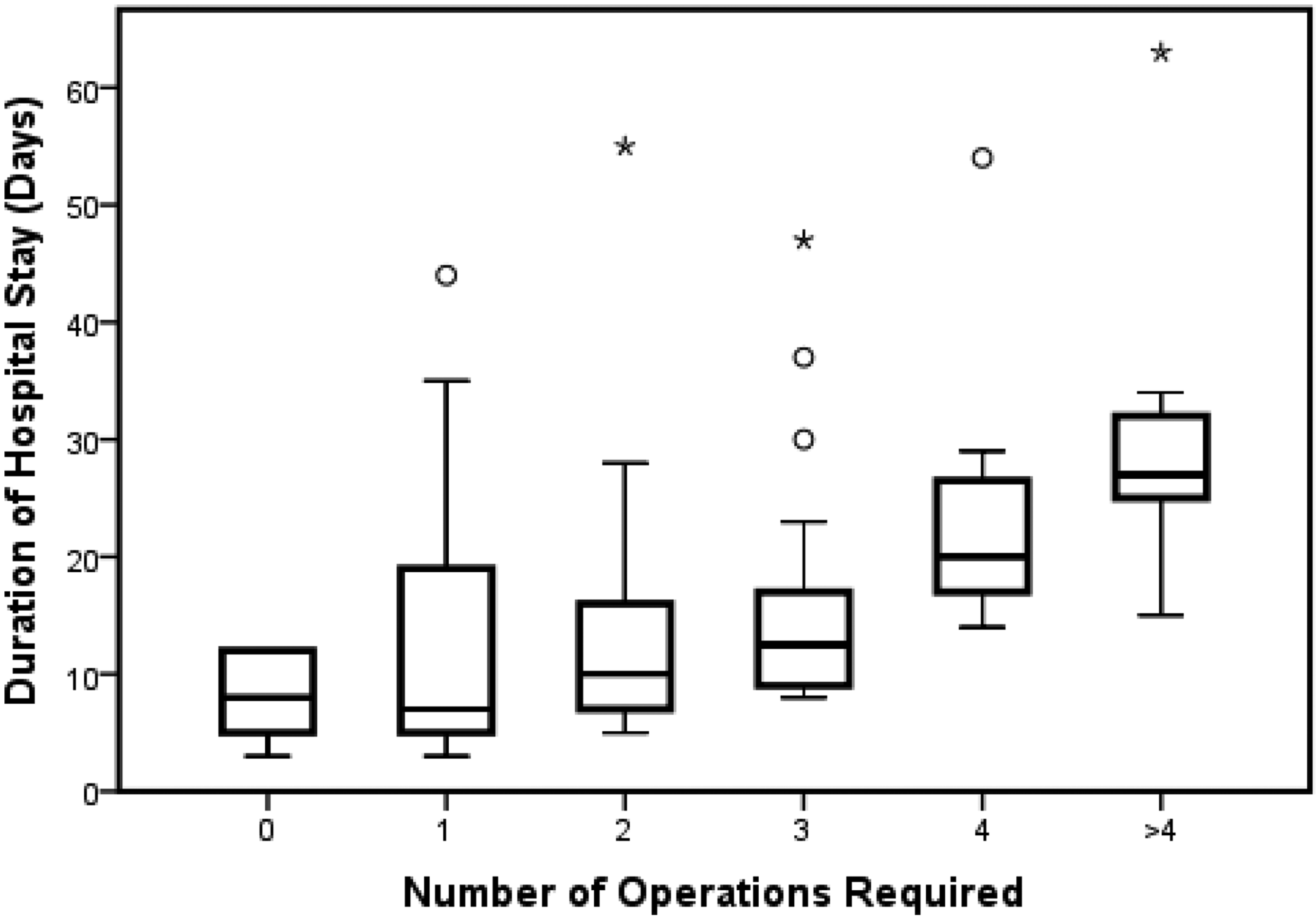


**Fig. 2** Shows a box plot of the hospital stay length for each number of operations required (0 indicates points > 1.5 interquartile range (IQR); * indicates points > 3 IQR).

not measuring the compartment pressure in the operation room were not documented in the other cases. Presumably, the surgical teams were confident of the diagnosis of ACS and had already made the decision to proceed with fasciotomy; or they failed to report their findings. In this cohort, no patient developed a Volkmann's contracture. We did not include cases that developed Volkmann's contracture without a fasciotomy.

Fasciotomies, as necessary as they might be, are associated with significant morbidity. Reports on the morbidity of fasciotomies in adults have demonstrated that both short- and long-term complications are common. Short-term complications occur in approximately 30% of adults, and over 80% of adults suffer long-term sequelae of fasciotomy wounds, such as altered sensation or discoloration around the wound margins, dry scaly skin and pruritis, swollen limbs, tethered scars and tendons, recurrent ulceration and muscle herniation.[15,17] Due to the cosmetic appearance of the scars, over 20% of adult patients have been reported to keep the scars covered and changed hobbies; 12% even changed occupation.[17] Our study did not look at the longer term effects, which is another limitation; clearly this would be of interest and add to the knowledge base for this topic. Nevertheless, even the short- term morbidity and length of stay associated with fasciotomies warrants further research to develop clinical and diagnostic tests of high positive predictive value without losing the sensitivity required to avoid a missed compartment syndrome.

The short-term complication rate in our study was higher than in earlier published paediatric studies[16,18]: 6.7% suffered from wound infections and 7.7% needed blood transfusions following the fasciotomies. Length of stay is influenced by many factors, and the fact that non-orthopaedic patients with ACS had the longest hospital stays was most likely related to their underlying medical condition than the development of ACS per se. However, for any given condition, the development of ACS will necessarily be associated with longer stays largely driven by the number of additional procedures required to achieve wound closure or coverage. The mean inpatient stay was 15.8 days (SD 11.7), which is shorter than in earlier paediatric reports, but is still substantially longer than for fracture patients who do not develop ACS.[18]

Our results indicate that fasciotomies in children and adolescents are associated with significant short-term morbidity and complications. These include multiple additional general anaesthetics for the fasciotomy wound-related procedures, wound infections and post-operative anaemia and prolonged hospitalization in many patients. Although little evidence exists to support routine use of antibiotics after fracture management, fasciotomy converts closed fractures to open fractures and will therefore require management of antibiotics. Haemoglobin levels should also be checked regularly postoperatively, since transfusions may be necessary. Since the likelihood of requiring a skin graft or flap increases significantly if more than three procedures are required, it is worth considering skin grafting on the third attempt if primary closure is not possible, but the area to be covered is ready to accept a graft. Although skin grafting does extend hospital stay, the need for additional procedures is reduced, and is especially worth considering when our experience suggests that after three attempts the likelihood of a skin graft rises steeply, and will contribute to even longer hospitalization.

Fasciotomy must be performed urgently in cases of ACS or impending ACS. However, particularly in equivocal cases, the decision to perform a fasciotomy in children should be carefully considered given the potential morbidity that results from what might indeed be very necessary surgery. This is particularly important in children where preoperative, awake compartmental pressure monitoring has limited application. It is unclear whether routine intraoperative testing of compartment pressures (prior to fasciotomy) might reduce a few unnecessary fasciotomies and the associated morbidity involved, while still providing a measure of reassurance that the diagnosis has not been missed. In addition, it may be more suitable to use a lower reference number for compartment pressure monitoring in children; however, this is uncertain at the moment and more research should be done if trauma surgeons feel this is important. Further research into developing less invasive and more accurate tests; or use of continuous monitoring (in high-risk patients) for compartment syndrome might reduce a small number of unnecessary fasciotomies.[19] Longer term follow-up of this cohort will also elaborate on the long-term morbidity associated with fasciotomies.

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## COMPLIANCE WITH ETHICAL STANDARDS

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### OA LICENCE TEXT



### ETHICAL STATEMENT

**Ethical approval**: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

**Informed consent**: This is a retrospective study. Informed consent is waived

### ICMJE CONFLICT OF INTEREST STATEMENT

All the authors declare that they have no conflict of interest.

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