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ORIGINAL PAPER

Acute compartment syndrome in patients undergoing fasciotomy of the forearm and the leg

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Abstract

Purposes The primary objective of this study is to compare the likelihood of acute compartment syndrome in the leg versus the forearm in patients who undergo fasciotomy for a clinical diagnosis of suspected acute compartment syndrome. The secondary objective is to identify factors associated with higher likelihood of acute compartment syndrome or with the use of split-thickness skin graft in these patients.

Methods We identified 449 patients diagnosed with suspected acute compartment syndrome of 468 legs and 119 patients diagnosed with suspected acute compartment syndrome of 119 forearms, treated with fasciotomy, from January 2000 to June 2015. Patients clinically diagnosed with suspected acute compartment syndrome were scored for likelihood of acute compartment syndrome based on muscle appearance, time to closure, neurologic deficit at final follow-up, and contracture at final follow-up.

Results There was no difference in likelihood of acute compartment syndrome between the leg and the forearm, with about 70% having relatively high likelihood. Forearm fasciotomy was associated with documentation of poorer muscle appearance ($p = 0.01$) and contracture ($p < 0.001$) compared with leg fasciotomy. Multivariable logistic regression analyses showed that compartment pressure measurement ($p = 0.01$) was associated with higher likelihood of acute compartment syndrome in legs and that male sex ($p = 0.001$) and non-vascular mechanism of injury ($p = 0.02$) were associated with split-thickness skin graft in legs.

Conclusions The likelihood and severity of acute compartment syndrome are comparable in the leg and the forearm.

Keywords Acute compartment syndrome · Diagnosis · Forearm · Leg · Split-thickness skin graft

Introduction

Acute compartment syndrome is a disorder of increased intracompartmental pressure leading to decreased tissue perfusion [1, 2]. The treatment for acute compartment syndrome is prompt diagnosis and fasciotomy [3, 4]. Delay of treatment can lead to nerve damage and muscle contracture which can severely affect limb function. The resulting muscle death releases myoglobin, which can cause kidney damage and be life-threatening.

Clinical diagnosis of acute compartment syndrome relies on symptoms and signs, often with the aid of compartment pressure measurement. Disproportionate pain and pain with passive stretch are often used as early indicators of acute compartment syndrome, as many of the later signs present after the window for tissue salvage [5–7]. However, there is no reference standard for the clinical diagnosis of acute compartment syndrome, and thresholds for fasciotomy differ among surgeons [8]. There is a low threshold to perform fasciotomy in patients with a clinically suspected acute compartment syndrome due to the potentially severe sequelae of a missed compartment syndrome. Consequently, it is likely that a certain percentage of patients with clinically suspected compartment syndrome do not have acute compartment syndrome resulting in decreased tissue perfusion.

In the present study, we define acute compartment syndrome to be the phenomenon of increased intracompartmental pressure and decreased tissue perfusion, which, if untreated,

Level of Evidence: Level III Prognostic

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results in tissue necrosis [8]. We define clinically suspected compartment syndrome to be the constellation of symptoms and signs, with or without compartment pressure measurement, that suggests the presence of acute compartment syndrome and leads a surgeon to perform a decompressive fasciotomy. In other words, clinically suspected compartment syndrome is what the surgeon is able to observe pre-operatively, but acute compartment syndrome is what the surgeon wishes to treat.

It is unclear whether the thresholds for diagnosing compartment syndrome are the same in the upper and lower extremities. Operative findings, post-operative findings, and coverage methods may give insight into the degree of swelling and tissue damage, and may reflect the presence or absence of acute compartment syndrome.

The primary objective of this study is to compare the likelihood of acute compartment syndrome among people clinically suspected to have acute compartment syndrome and treated with fasciotomy in the forearm or the leg at two level I trauma centres. Secondary objectives of this study are to determine if there are factors associated with higher likelihood of acute compartment syndrome or the use of split-thickness skin graft in patients who undergo forearm or leg fasciotomy.

Materials and methods

Study design

After institutional review board approval, a retrospective study was conducted of all fasciotomies performed for suspected acute compartment syndrome of the leg or the forearm at our institutions over a 15-year time period from January 1, 2000, to June 30, 2015. By searching International Classification of Disease, 9th Revision (ICD-9) codes 729.71 (nontraumatic compartment syndrome of upper extremity), 958.91 (traumatic compartment syndrome of upper extremity), 729.72 (nontraumatic compartment syndrome of lower extremity), and 958.92 (traumatic compartment syndrome of lower extremity) through a query of our institutions' Research Patient Data Registry (RPDR) database covering all surgeries at two level I trauma centres, we identified 1028 patients with codes consistent with leg compartment syndrome and 438 patients with codes consistent with forearm compartment syndrome. These represented 655 patients with codes consistent with leg compartment syndrome and 260 patients with codes consistent with forearm compartment syndrome at one level I trauma centre and 373 patients with codes consistent with leg compartment syndrome and 178 patients with codes consistent with forearm compartment syndrome at the other. Medical record data, date of surgery, and demographic information were retrieved through the institutional RPDR.

Of the initial cohort of 1028 patients with codes consistent with leg compartment syndrome, we excluded (1) 432 patients with miscoded diagnosis, no suspected leg compartment syndrome, and no fasciotomy; (2) 52 patients treated with subsequent amputation prior to wound closure; (3) 36 patients who died prior to wound closure; (4) 34 patients initially treated with fasciotomies at outside hospitals; (5) 15 patients who underwent prophylactic fasciotomies with no clinical signs of compartment syndrome; (6) 9 patients with follow-up less than one week; and (7) one patient treated outside of the study period. Of the initial cohort of 438 patients with codes consistent with forearm compartment syndrome, we excluded (1) 289 patients with miscoded diagnosis, no suspected forearm compartment syndrome, and no fasciotomy; (2) 15 patients who underwent prophylactic fasciotomies with no clinical signs of compartment syndrome; (3) six patients who died prior to wound closure; (4) four patients initially treated with fasciotomies at outside hospitals; (5) four patients treated with subsequent amputation prior to wound closure; and (6) one patient with follow-up less than one week. The final cohort included 449 patients with suspected acute compartment syndrome of 468 legs treated with fasciotomy and 119 patients with suspected acute compartment syndrome of 119 forearms treated with fasciotomy (Fig. 1). The patients who underwent prophylactic fasciotomies with no suspicion of ongoing acute compartment syndrome were excluded for the purposes of our study. These excluded cases were often patients with injury mechanism concerning to the treating surgeon for future development of clinical compartment syndrome, but with no present signs or symptoms. All operative techniques used were chosen at the discretion of the treating surgeon. All patients were followed for a minimum of one week and on average 15 months post-operatively (median 8 months, interquartile range two to 18 months).

Outcome measures and explanatory variables

We reviewed the electronic medical records of all patients for our response variable: likelihood of acute compartment syndrome. We identified operative and post-operative findings and introduced a scoring system for the likelihood of acute compartment syndrome based on the appearance of the muscle, the time from fasciotomy to closure, neurologic deficit at final follow-up, and contracture at final follow-up (Table 1). Muscle appearance was scored as documented in the operative note dictated by the treating surgeon. Time from fasciotomy to closure was scored from nursing documentation of operative times. Neurologic deficit and contracture were scored from follow-up clinic notes. Absence of documentation of a neurologic deficit or contracture was scored as absence of neurologic deficit or contracture. A total score less than or equal to 2 was classified as lower likelihood of acute compartment syndrome, whereas a total score greater than 2 was classified as

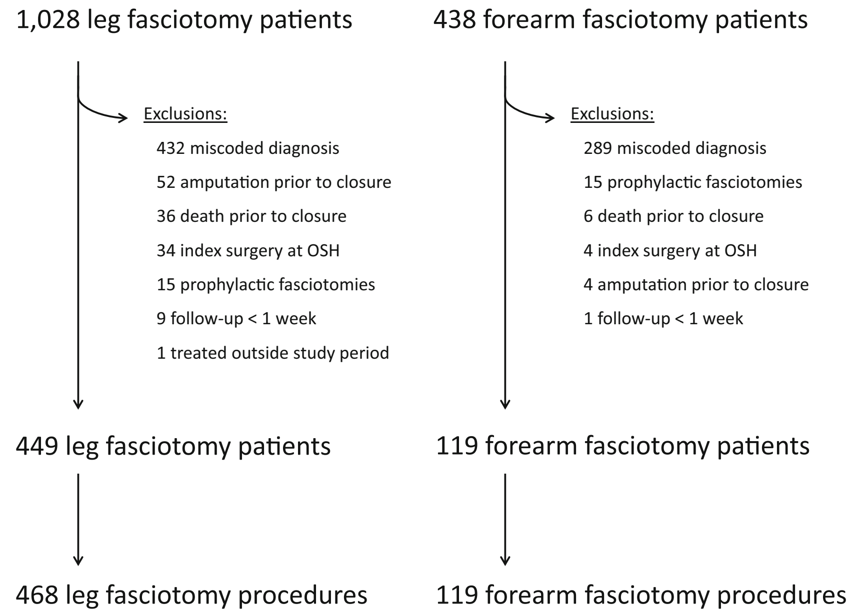

Fig. 1 Study population inclusion flow diagram

higher likelihood. The following patient-related factors were studied: age, sex, race, body mass index (BMI), modified Charlson Comorbidity Index, diabetes mellitus, smoking status, presence of fracture, open fracture, presence of another fracture in the same limb, presence of another fracture in general, chest or abdomen injury, closed head injury, and mechanism of injury. The following treatment-related factors were studied: origin of consult, use of compartment pressure measurement, time from injury to fasciotomy, and number of debridements prior to definitive closure.

Statistical analyses

Categorical variables were presented using frequencies and percentages, and continuous variables using median and interquartile range as most continuous variables were not normally

Table 1 Classification of acute compartment syndrome

	Score	Leg (n = 468)	Forearm (n = 119)	
Appearance of muscle		n (%)	n (%)	p value
Normal	0	208 (44)	53 (45)	0.012
Bulging	1	150 (32)	25 (21)	
Dusky	2	53 (11)	14 (12)	
Necrosis	3	57 (12)	27 (23)	
Time until closure				
Immediate	0	62 (13)	13 (11)	0.625
Closed < 72 h	1	51 (11)	16 (13)	
Closed > 72 h	2	153 (33)	34 (29)	
Skin graft	3	202 (43)	56 (47)	
Neurologic deficit				
Absent	0	375 (80)	99 (83)	0.516
Present	2	93 (20)	20 (17)	
Contracture				
Absent	0	452 (97)	92 (77)	< 0.001
Present	2	16 (3.4)	27 (23)	
Diagnosis of acute compartment syndrome		n (%)	n (%)	
Lower likelihood (total score ≤ 2)		146 (31)	34 (29)	0.656
Higher likelihood (total score > 2)		322 (69)	85 (71)	
		Median (IQR)	Median (IQR)	
Total score		3 (2–5)	4 (2–6)	0.070

IQR = interquartile range

distributed. We used the Fisher exact test to assess if there was a difference in lower versus higher likelihood of acute compartment syndrome between forearm and leg fasciotomies. The Mann-Whitney *U* test was used to assess difference in the continuous likelihood of acute compartment syndrome score between forearm and leg fasciotomies. In bivariate analyses, we assessed if explanatory variables were associated with our secondary outcome measures (higher likelihood of acute compartment syndrome and having split-thickness skin graft) using the Fisher exact test for categorical variables and the Mann-Whitney *U* test for continuous variables. In multivariable logistic regression analyses, we included all explanatory variables with a p value below 0.10 on bivariate analyses to assess what factors were associated with our secondary outcome measures (a higher likelihood of acute compartment syndrome and having split-thickness skin graft) while accounting for potential confounders. We used multiple imputations (40 times) to account for missing values in multivariable analyses (tobacco use was missing for 14 patients, body mass index for 114 patients, modified Charlson Comorbidity Index for eight patients, and time to fasciotomy for 191 patients). In addition, we used the Poisson regression analysis to assess if the number of debridements differed between groups.

Results

Descriptive results

Of 468 cases of leg fasciotomy, 327 cases (70%) were in patients of male sex. Median age was 49 (IQR 32 to 62). Median BMI was 27 (IQR 24 to 32). Soft tissue injuries only were found in 253 cases (54%), whereas the presence of fracture was found in 215 cases (46%). Compartment pressure measurement was used in 172 cases (37%). The origin of consult was the emergency department in 387 cases (83%). Split-thickness skin graft was used in 202 cases (43%).

Of 119 cases of forearm fasciotomy, 79 cases (66%) were in patients of male sex. Median age was 45 (IQR 31 to 55). Median BMI was 27 (IQR 24 to 32). Soft tissue injuries only were found in 79 cases (66%), whereas the presence of fracture was found in 40 cases (34%). Compartment pressure measurement was used in 40 cases (34%). The origin of consult was the emergency department in 86 cases (72%). Split-thickness skin graft was used in 56 cases (47%). The number of surgical debridements prior to definitive closure was most commonly two in both anatomical groups and did not differ between groups (Fig. 2).

Likelihood of acute compartment syndrome

No difference was detected in the likelihood of acute compartment syndrome in 468 legs and 119 forearms treated with fasciotomy using our scoring algorithm (Table 1). The median likelihood score for acute compartment syndrome was 3 for legs and 4 for forearms ($p = 0.07$). Forearm fasciotomy was associated with poorer muscle appearance ($p = 0.01$) and contracture ($p < 0.001$) compared with leg fasciotomy.

Factors associated with acute compartment syndrome

Bivariate analyses showed that younger age ($p = 0.030$), presence of fracture ($p = 0.028$), mechanism of injury ($p = 0.007$), and compartment pressure measurement ($p = 0.003$) were associated with higher likelihood of acute compartment syndrome in legs. Multivariable logistic regression analyses showed that compartment pressure measurement (odds ratio 1.76, $p = 0.014$) was the only factor associated with higher

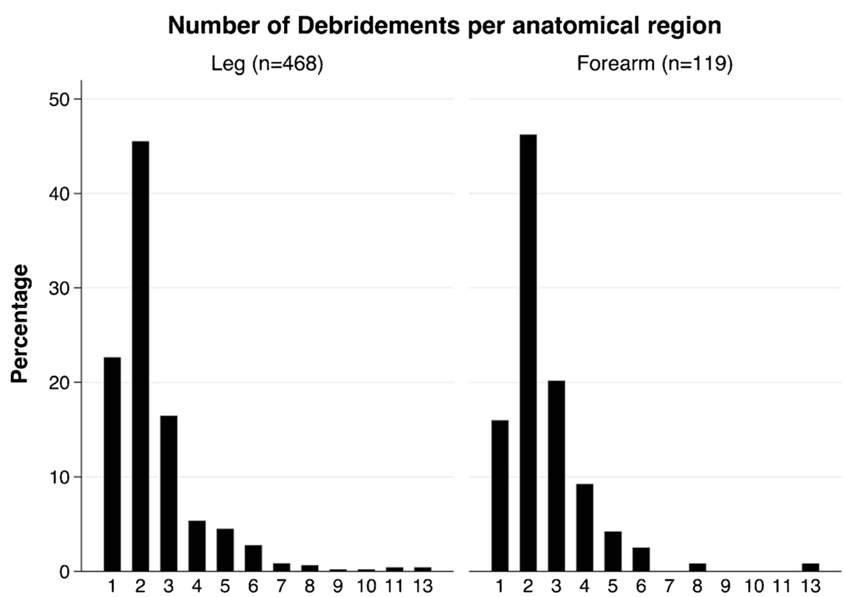

Fig. 2 Number of surgical debridements prior to definitive closure by anatomical region ($p = 0.5$)

Table 2 Multivariable logistic regression analyses of factors associated with a higher likelihood diagnosis of acute compartment syndrome

	Odds ratio	Standard error	p value	95% CI
Leg (n = 468)				
Age	0.99	0.01	0.683	0.99–1.01
Soft tissue only	0.81	0.30	0.559	0.39–1.66
Mechanism of injury				
High-energy blunt trauma	Reference	Reference	Reference	Reference
Low-energy blunt trauma	0.64	0.22	0.200	0.32–1.27
Penetrating trauma	2.42	1.54	0.163	0.70–8.41
Crush injury	1.17	0.70	0.796	0.36–3.81
Vascular injury	0.64	0.27	0.299	0.28–1.48
Other**	0.97	0.44	0.947	0.40–2.38
Compartment pressure measurement	1.76	0.41	0.014	1.12–2.78
Forearm* (n = 119)				
Mechanism of injury				
High-energy blunt trauma	Reference	Reference	Reference	Reference
Low-energy blunt trauma	1.96	2.42	0.584	0.18–22.0
Penetrating trauma	0.60	0.42	0.470	0.15–2.40
Crush injury	4.64	3.65	0.051	0.99–21.7
Vascular injury	0.54	0.46	0.472	0.10–2.92
Other**	1.11	0.67	0.863	0.34–3.61
Time to fasciotomy***				
< 6 h	Reference	Reference	Reference	Reference
6–12 h	0.41	0.34	0.282	0.08–2.10
12–24 h	2.86	2.24	0.179	0.62–13.3
> 24 h	1.38	0.80	0.576	0.45–4.28

95% CI 95% confidence interval

*Missing values were imputed using multiple linear imputations including all variables (the number of imputations was set to 40)

**Other mechanisms of injury include intravenous infiltration (12), infection (11), burn (13), electrocution (2), spontaneous bleed (30), postoperative bleed (10), blast injury (1), and unclear etiology (9)

***Time to fasciotomy was available for 29 with lower likelihood of ACS of the forearm and 72 patients with higher likelihood of ACS of the forearm

likelihood of acute compartment syndrome in legs (Table 2). No factors were associated with higher likelihood of acute compartment syndrome in forearms.

Factors associated with use of split-thickness skin graft

Bivariate analyses showed that younger age ($p = 0.030$), male sex ($p < 0.001$), diabetes mellitus ($p = 0.039$), smoking status ($p = 0.012$), presence of fracture ($p < 0.001$), open fracture ($p = 0.001$), presence of another fracture in the same limb ($p = 0.014$), mechanism of injury (p < 0.001), time from injury to fasciotomy ($p = 0.017$), and origin of consult ($p < 0.001$) were associated with split-thickness skin graft in legs. Bivariate analyses showed that presence of fracture ($p < 0.001$), open fracture ($p = 0.001$), presence of another fracture in the same limb ($p = 0.007$), time from injury to fasciotomy ($p = 0.049$), and origin of consult ($p = 0.008$) were associated with split-thickness skin graft in forearms. Multivariable logistic regression analyses showed that male sex (odds ratio 2.17, $p = 0.001$) and non-vascular mechanism of injury (odds ratio 0.29, $p = 0.005$) were associated with split-thickness skin graft in legs. Multivariable logistic regression analyses showed no factors associated with split-thickness skin graft in forearms (Table 3).

Discussion

Acute compartment syndrome of the extremity is a limb- and life-threatening disorder whose treatment is prompt surgical fasciotomy [1, 2, 4]. Limbs are most at risk for the development of acute compartment syndrome within 48 hours from injury [9]. The lack of a reference standard for the diagnosis of acute compartment syndrome leads to reliance on symptoms and signs with or without the aid of compartment pressure

Table 3 Multivariable logistic regression analyses of factors associated with split-thickness skin graft (STSG)

	Odds ratio	Standard error	*p* value	95% CI
Leg* (*n* = 468)				
Male sex	2.17	0.54	0.001	1.38–3.59
Diabetes mellitus	1.20	0.40	0.594	0.62–2.32
Tobacco use**				
Never smoker	Reference	Reference	Reference	Reference
Past smoker	0.9	0.67	0.728	0.50–1.61
Current smoker	1.07	0.27	0.788	0.65–1.76
Age	1.00	0.01	0.989	0.99–1.01
Soft tissue only	0.66	0.23	0.248	0.33–1.33
Open fracture	1.53	0.58	0.261	0.73–3.22
Ipsilateral limb fracture	1.32	0.49	0.454	0.64–2.72
Mechanism of injury				
High-energy blunt trauma	Reference	Reference	Reference	Reference
Low-energy blunt trauma	0.71	0.25	0.326	0.36–1.41
Penetrating trauma	0.35	0.19	0.050	0.13–1.00
Crush injury	0.49	0.28	0.214	0.16–1.50
Vascular injury	0.29	0.13	0.005	0.12–0.69
Other***	0.94	0.42	0.885	0.39–2.56
Compartment pressure measurement	1.08	0.25	0.728	0.69–1.71
Time to fasciotomy****				
< 6 h	Reference	Reference	Reference	Reference
6–12 h	0.82	0.33	0.620	0.37–1.80
12–24 h	0.56	0.21	0.124	0.27–1.17
> 24 h	0.61	0.21	0.143	0.31–1.19
Origin of consult				
Emergency department	Reference	Reference	Reference	Reference
Other*****	0.57	0.21	0.121	0.28–1.16
Forearm* (*n* = 119)				
Soft tissue only	0.36	0.27	0.182	0.07–1.64
Open fracture	8.57	9.95	0.064	0.88–83.4
Ipsilateral limb fracture	1.01	0.87	0.993	0.19–5.45
Time to fasciotomy****				
< 6 h	Reference	Reference	Reference	Reference
6–12 h	0.36	0.37	0.325	0.05–2.80
12–24 h	2.94	1.96	0.106	0.80–10.9
> 24 h	1.49	0.82	0.470	0.51–4.38
Origin of consult				
Emergency department	Reference	Reference	Reference	Reference
Other*****	0.40	0.21	0.075	0.15–1.10

95% CI 95% confidence interval

*Missing values were imputed using multiple linear imputations including all variables (the number of imputations was set to 40)

**Tobacco use was available for 262 patients who underwent no STSG after leg ACS, 195 who underwent STSG after leg ACS, 62 who underwent no STSG after forearm ACS, and 54 who underwent STSG after forearm ACS

***Other mechanisms of injury include intravenous infiltration (12), infection (11), burn (13), electrocution (2), spontaneous bleed (30), postoperative bleed (10), blast injury (1), and unclear etiology (9)

****Time to fasciotomy was available for 180 patients who underwent no STSG after leg ACS, 115 who underwent STSG after leg ACS, 54 who underwent no STSG after forearm ACS, and 47 who underwent STSG after forearm ACS

*****Other origins of consult include medical floor (20), surgical floor (37), MICU (14), SICU (32), operation room (7), and clinic (4) measurement [5–7, 10]. Since missed diagnosis or delayed treatment is harmful [11–14], surgeons rightfully err on the side of overdiagnosis and overtreatment. One measure of this overtreatment is the likelihood—quantified based on observations available in the medical record—of acute compartment syndrome among patients diagnosed based on symptoms, signs, and varying on clinical practice, compartment pressure measurements [8]. We studied large cohorts of patients with a clinically suspected acute compartment syndrome of the forearm or the leg to compare the likelihood of a true acute compartment syndrome.

The likelihood of acute compartment syndrome between patients treated with fasciotomy in the forearm and the leg was similar, but we did not have adequate power to show statistical equivalence. Myonecrosis, a predictor for surgical site infection after fasciotomy for acute compartment syndrome, was seen more often in forearms than legs [15]. Acute compartment syndrome is a difficult clinical diagnosis to make, illustrated by the fact that the rate of acute compartment syndrome diagnosed by surgeons varies widely. Moreover, the tools used by surgeons to make this diagnosis vary as well [8]. Surgeons are tasked with walking the line between performing unnecessary surgeries and missing or delaying appropriate treatment.

Factors associated with higher likelihood of acute compartment syndrome in legs either imply higher energy transfer to the injured limb or higher suspicion by the clinician. Younger age and male sex have been previously found to be a risk factor for acute leg compartment syndrome after tibial diaphyseal fractures. It is postulated that these patients generally have higher muscle bulk and less compliant fascia, predisposing towards acute compartment syndrome [16, 17]. Presence of fracture and higher energy mechanism of injury all entail higher energy transfer to the injured compartment that may exacerbate the initial cascade towards decreased tissue perfusion [18]. The association of compartment pressure measurement with higher likelihood of acute compartment syndrome is most likely a reflection of our overall institutional practice. This association may also reflect the type of pressure monitoring system used. It may not be seen, for example, at institutions where all high-risk tibial diaphyseal fractures are monitored with continuous compartment pressure monitors [5–7, 19].

Factors associated with skin grafting in legs either reflect inherent tissue properties, higher energy transfer to the injured limb, or institutional practices. Younger patients and male patients generally have higher muscle bulk that may make delayed primary closure more difficult [6, 17]. The presence of a fracture, an open fracture, or another fracture in the same limb, the mechanism of injury, faster time from injury to fasciotomy, and emergency department origin of consult may be surrogates for higher energy injuries with worse soft tissue trauma, which would predispose towards difficult closure and a preference for skin grafting [10]. The association of non-vascular mechanism of injury with the use of split-thickness skin graft likely reflects institutional practice of many vascular surgeons to allow fasciotomy wounds to heal by secondary intention. Diabetes mellitus and smoking status, identified as association in the bivariate analyses but not the multivariable logistic regression analyses, may be correlated with vascular mechanism of injury. Contrary to Duckworth et al., younger age and crush injury were not associated with skin grafting after forearm fasciotomy in our patients [20].

There are limitations and inaccuracies in the scoring system used for the likelihood of acute compartment syndrome. The scoring system is based on appearance of the muscle, the time from fasciotomy to closure, neurologic deficit at final follow-up, and contracture at final follow-up. While bulging musculature or escape of muscles at time of fasciotomy is often cited as a sign of compartment syndrome, this is not validated [10, 13]. Moreover, it is unclear whether lack of muscle bulge reflects expedient treatment of an early compartment syndrome or diagnosis of compartment syndrome in the setting of normal compartment pressures. Time from fasciotomy to closure may be influenced by external logistical factors such as available operative time as well as the use of negative pressure wound therapy and other adjuncts for closure. Absence of documentation of a neurologic deficit or contracture was scored as absence of neurologic deficit or contracture, because it was presumed that significant deficits would be documented, but there is the potential for reporting bias. Some patients may have had contractures due to inadequate exercises rather than sequelae of compartment syndrome. Our scoring system for the likelihood of acute compartment syndrome is not validated, but rather a pragmatic approach to stratify cases using both intra-operative and post-operative documentation. Due to the retrospective nature of this study, we were unable to standardize how monitoring was performed for acute compartment syndrome. Moreover, we were unable to utilize anatomic trauma scoring systems such as the Injury Severity Score or physiologic trauma scoring systems such as the Revised Trauma Score or the Mangled Extremity Severity Score. Lastly, our method of data acquisition may not have identified miscoded patients with forearm or leg acute compartment syndrome.

Our finding that upwards of 70% of fasciotomy patients had high likelihood of acute compartment syndrome reflects the tendency to err towards operative treatment in the management of this limb- and life-threatening problem with imperfect diagnostic criteria. Improved understanding of the population at risk for acute compartment syndrome as well as improved methods of detecting and monitoring the evolution of acute compartment syndrome in suspected cases are paramount to effective treatment of this disorder in the future. The lack of a substantial difference between forearms and legs suggests that the important aspects of diagnosis and treatment are similar in these two most common anatomical sites for compartment syndrome; however, our conclusion can only be considered provisional until the validation of a scoring system for acute compartment syndrome. Nevertheless, our early data on the surgical demographics of acute compartment syndrome are useful to guide future prospective studies of this difficult disorder.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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. For this type of study, formal consent is not required.

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