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Factors associated with compartment syndrome after a tibial fracture in children

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ABSTRACT

Objectives Compartment syndrome (CS) after a tibial fracture in children is one of the orthopedic emergencies. Identifying high-risk patients in a timely fashion minimizes morbidities. This study aimed to find the risk factors of CS after a tibial fracture.

Methods The study data was retrieved from the Trauma Quality Improvement Program database of the calendar year 2017–2019. All patients aged <18 years old who were admitted to the hospital with tibial fractures were included in the study. Patients' characteristics, including demography, injury, injury severity, and associated crushed and vascular injuries were analyzed between the groups who developed CS versus those who did not develop CS after a tibial fracture. Multiple logistic regression analyses were performed to find the association of CS. All p values are two-sided and a p value<0.05 is considered statistically significant.

Results Of 4492 patients who qualified for the study, 49 (1.1%) patients developed CS. The patients who developed CS sustained more crush injuries and were associated with a higher rate of vascular injury (2% vs 0.1%, p=0.043% & 10.2% vs 2.2%, p=0.005). Multivariable analysis showed that for every increase in 1 year of age, the odds of occurrence of CS increased by 15.7% (adjusted OR (AOR)=1.157, 95% CI: 1.032 to 1.297, p=0.013). Non-African American race was associated with more than double the risk of developing CS when compared with the African American race, AOR was 2.238, (95% CI: (1.08 to 4.638)). The associated crush injury had an approximately 19-fold higher risk of CS when compared with patients presented with no crush injury, AOR was 18.812, (95% CI: (1.513 to 233.931)). Associated vascular injury was found to have significantly higher AOR, 3.509, 95% CI: (1.287 to 9.563) of CS.

Conclusion Increased age, non-African American race, vascular injury, and crushed injury were associated with a risk of developing CS after a tibial fracture.

Level of evidence: IV Study type: Observational cohort study.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Most studies published on risk factors of compartment syndrome (CS) in a tibial fracture in children found variable results.

WHAT THIS STUDY ADDS

⇒ The study was designed to identify risk factors for CS in children by examining the Trauma Quality Improvement Program database.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study showed older children, non-African American race, associated vascular injury, and crushed injury were associated with a risk of developing a compartment syndrome following a tibial fracture: Therefore, identifying the high-risk patients, close monitoring and timely intervention of CS will help reduce morbidities.

INTRODUCTION

Compartment syndrome (CS) of the lower leg after a tibial fracture in a pediatric patient is one of the emergencies that require immediate intervention. Since CS is a clinical diagnosis and traditional teaching of assessment of 5Ps (pain, pallor, paresthesia, pulselessness, and paralysis) is a hallmark for strong suspicion.[1] That 5Ps' assessment may be true in identifying adult patients with CS, however, in children this assessment was found to be challenging and not as reliable as in adults.[2] The proposed 3A's (anxiety, agitation, increasing analgesic requirement) assessment may be more reliable.[3] Additionally, the normal compartment pressure of the lower leg in children was found to be higher than the adult.[4] Higher pressure >35 mm Hg to 40 mm Hg or a difference in diastolic pressure minus compartment pressure above 30 may need immediate fasciotomy to restore the neurovascular status in the leg.[5]

Identifying high-risk pediatric patients for CS who sustain tibial fractures is of paramount importance for salvaging the leg. One study showed that diagnosing CS after a tibial fracture in children usually took around 24 hours.[6] A delay in the diagnosis of CS may be due to a slow process in the development of CS in children. Regardless, a delay in diagnosis can lead to unfavorable outcomes.[6] The number of risk factors that were identified for CS in the lower leg in children included tibial tubercle fracture, open fracture, vascular injury, etc.[7–9] Most studies published on risk factors of CS in a tibial fracture in children found variable results.[7 8] Therefore, this study was designed to identify risk factors for CS in children by examining the National Trauma database. We hypothesized that certain patient characteristics are associated with CS.

METHODS

Data source and inclusion of patients

The Trauma Quality Improvement Program (TQIP) of participant use files database was accessed from the year 2017 through 2019. All

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patients aged <18 years old who sustained tibial fractures were included in the study. Other variables included in the study were sex, race, injury severity score (ISS), Glasgow Coma Scale (GCS) score, type of injury, mechanism of injury, crush injury, associated vascular injury, type of tibial fracture, and some comorbidities including the history of attention deficit disorder, congenital abnormality, prematurity, mental personality disorder, substance abuse and history of coagulopathy disorder. Included in the study are all associated severe injuries from different body regions. Severe injury of a region was defined as an Abbreviated Injury Scale (AIS) score ≥3.

Table 1 Univariate analysis between the groups who developed compartment syndrome and who did not develop compartment syndrome

Variable	All (N=4492)	No compartment syndrome (n=4443)	Compartment syndrome (n=49)	P value
Age (years), median (Q1–Q3)	14 (12–15)	14 (12–15)	15 (13–16)	0.032
Race, n (%)				
American Indian	59 (1.3)	59 (1.3)	0 (0)	>0.99
Asian	68 (1.5)	67 (1.5)	1 (2)	0.528
African American	1,490 (33.2)	1,481 (33.3)	9 (18.4)	0.039
Pacific Islander	24 (0.5)	24 (0.5)	0 (0)	>0.99
Other race	466 (10.4)	459 (10.3)	7 (14.3)	0.505
White	2,305 (51.3)	2,274 (51.2)	31 (63.3)	0.124
Sex, n (%)				0.485
Female	962 (21.4)	954 (21.5)	8 (16.3)	
Male	3530 (78.6)	3489 (78.5)	41 (83.7)	
ISS, median (Q1–Q3)	4 (4–9)	4 (4–9)	4 (4–9)	0.953
GCS, median (Q1–Q3)	15 (15–15)	15 (15–15)	15 (15–15)	0.636
Trauma type, n (%)				
Blunt	4,261 (94.9)	4,214 (94.8)	47 (95.9)	>0.99
Penetrating	211 (4.7)	209 (4.7)	2 (4.1)	
Missing	20 (0.4)	20 (0.5)	0 (0)	
Mechanism, n (%)				0.99
All others	1,480 (32.9)	1,465 (33)	15 (30.6)	
Fall	1,834 (40.8)	1,813 (40.8)	21 (42.9)	
GSW	195 (4.3)	193 (4.3)	2 (4.1)	
MVT	587 (13.1)	581 (13.1)	6 (12.2)	
Pedestrian hit by	396 (8.8)	391 (8.8)	5 (10.2)	
Crush injuries, n (%)	4 (0.1)	3 (0.1)	1 (2)	0.043
Vascular injuries, n (%)	102 (2.3)	97 (2.2)	5 (10.2)	0.005
Tibial fracture, n (%)				0.299
Open tibia fx	352 (7.8)	349 (7.9)	3 (6.1)	
Proximal tibia fx	1,018 (22.7)	1,010 (22.7)	8 (16.3)	
Proximal tibia fx extra-articular	1,409 (31.4)	1,398 (31.5)	11 (22.4)	
Proximal tibia fx_complete articular_bicondylar_open	127 (2.8)	126 (2.8)	1 (2)	
Tibia fracture, proximal, complete articular; plateau; bicondylar; Schatzker 4, 5, 6	1,081 (24.1)	1,061 (23.9)	20 (40.8)	
Tibia fracture, proximal, extra-articular, open	35 (0.8)	35 (0.8)	0 (0)	
Tibia fracture, proximal, partial articular; Schatzker 1, 2, 3	435 (9.7)	429 (9.7)	6 (12.2)	
Tibia fracture, proximal, partial articular; Schatzker 1, 2, 3, open	35 (0.8)	35 (0.8)	0 (0)	
Fasciotomy	40 (0.9)	37 (0.8)	3 (6.1)	0.009
Comorbidities, n (%)				
Congenital abnormalities	67 (1.5)	66 (1.5)	1 (2)	0.523
Prematurity	16 (0.4)	16 (0.4)	0 (0)	>0.99
Mental and personality disorder	88 (2)	88 (2)	0 (0)	>0.99
Substance abuse	54 (1.2)	53 (1.2)	1 (2)	0.449
Bleeding disorder	16 (0.4)	16 (0.4)	0 (0)	>0.99
AIS ≥3, n (%)				
Brain	199 (4.4)	196 (4.4)	3 (6.1)	0.478
Neck	8 (0.2)	8 (0.2)	0 (0)	>0.99
Face	8 (0.2)	8 (0.2)	0 (0)	>0.99
Spine	16 (0.4)	16 (0.4)	0 (0)	>0.99
Chest	197 (4.4)	197 (4.4)	0 (0)	0.276
Abdomen	112 (2.5)	112 (2.5)	0 (0)	0.635

%, percentage; AIS, Abbreviated Injury Scale; Fx, fracture; GCS, Glasgow Coma Scale; GSW, Gun Shot wound; ISS, Injury Severity Score; MVT, Motor vehicle trauma.

Table 2 Multiple logistic regression analysis of factors associated with compartment syndrome

Variables	β coefficient	95% CI for β		OR	95% CI for OR		P value
(Intercept)	- 7.205	- 8.987	- 5.423	0.001	0	0.004	<0.0001
Age in years	0.146	0.031	0.26	1.157	1.032	1.297	0.0126
Non-African American	0.806	0.077	1.534	2.238	1.08	4.638	0.0302
Crush injuries	2.934	0.414	5.455	18.812	1.513	233.931	0.0225
Vascular injuries	1.255	0.253	2.258	3.509	1.287	9.563	0.0141

Statistics

Patient demographic, clinical information, and outcomes were summarized using summary statistics (median with IQR (first quartile to third quartile) for continuous variables, and frequency and percentage for categorical variables). To compare the two groups, who developed the CS versus those who did not develop CS, the Wilcoxon rank-sum test was used for continuous variables and the χ^2 test or Fisher's exact test was used for the categorical variables, based on the sample size. A multiple logistic regression model was used to assess the chance of developing CS with those variables which had p value<0.2 in the univariate analysis or known risk for CS. The backward selection procedure was used to identify the factors which were significantly associated with the chance of developing CS. The parameter estimates from the fitted model were summarized using β coefficient estimates and 95% CIs, and 95% CIs for the OR as measures of precisions. The Hosmer-Lemeshow goodness-of-fit test was used to evaluate the model fitting. The receiver operating characteristic curve was a constructed system based on the estimated probability of developing the chances of CS. The corresponding area under the curve (AUC) with their CIs was calculated by using DeLong's method.[10] The Kaplan-Meier procedure was used to estimate the median hospital length of stay, and the SE was estimated using Greenwood's formula. The log-rank test was used to compare the hospital lengths of stay between groups. The two-sided p value was reported for each test. A p value of <0.05 was considered an indication of statistical significance. Statistical analysis was performed using the R language.[11]

Outcomes

The primary outcome of the study was to identify factors that were associated with CS in the lower leg after a tibial fracture. The secondary outcomes were hospital length of stay and discharge disposition.

RESULTS

Patient

Out of 4492 patients who qualified for the study, 49 (1.1%, 95% CI: 0.8% to 1.4%) patients developed CS. The average age of the patient who developed CS was older than those who did not develop CS (median (first quartile to third quartile) (15 (13 to 16) vs 14 (12 to 15), years p=0.032). African American patients were less frequent among those who developed CS as compared with those who did not develop CS (18.4% vs 33.3%, p=0.039). The patients who developed CS sustained more crush injuries (2.0% vs 0.1%, p=0.043) and were associated with a higher rate of vascular injury (10.2% vs 2.2%, p=0.005). There were no significant differences found between the two groups who developed CS versus did not develop CS regarding the type of trauma, mechanism of injury, type of tibial fracture, GCS, ISS, and AIS of different body regions of injury. Most patients who developed CS sustained proximal tibial fractures. There was no significant difference found between the groups regarding the location of tibial fractures (table 1).

The majority of patients (~88%) who developed CS sustained the injury at 2 on the AIS score and only 12% of patients sustained the injury at 3 on the AIS score. No significant difference was found between the groups regarding the severity of the tibial injury, p=0.517.

Multivariable analysis

Multivariable analysis showed that for every increase in 1 year of age, the odds of occurrence of CS increased by 15.7% (adjusted OR (AOR)=1.157, 95% CI: 1.032 to 1.297, p=0.013). Non-African American race was found to have more than double the risk of developing CS when compared with the African American race, ((AOR) was 2.238, 95% CI: (1.08 to 4.638), p=0.030). The associated crush injury had an approximately 19-fold higher risk of CS when compared with patients presented with no crush injury, AOR=18.812, 95% CI: (1.513 to 233.931), p=0.023). Associated vascular injury was found to have a significantly higher chance of having CS (AOR=3.509, 95% CI:(1.287 to 9.563)) (table 2).

The Hosmer-Lemeshow goodness-of-fit test showed that the predicted probabilities of the multiple logistic regression model were in agreement with the observed proportions of CS (p=0.216). The AUC was 0.659 (95% CI: 0.593 to 0.725) (figure 1).

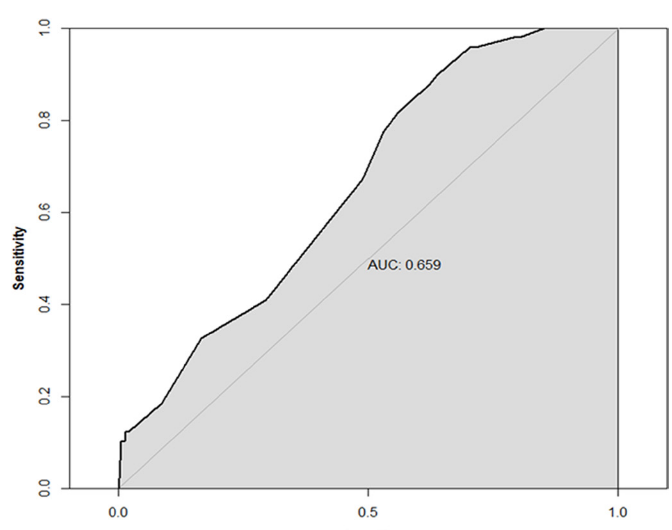

Figure 1 Receiving operating characteristics curve of risk factors of compartment syndrome associated with tibial fractures in children. AUC, area under the curve.

Table 3 Hospital disposition of patients who developed compartment syndrome and who did not develop compartment syndrome

	All (n=4,472)	No compartment syndrome (n=4,424)	Compartment syndrome (n=48)	P value
Hospital disposition				0.062
Home with care	176 (3.9)	172 (3.9)	4 (8.3)	
Home without care	3,988 (89.2)	3,950 (89.3)	38 (79.2)	
Hospice care	1 (0)	1 (0)	0 (0)	
Others	25 (0.6)	25 (0.6)	0 (0)	
Rehab	208 (4.7)	205 (4.6)	3 (6.2)	
Short-term through long-term care facility	62 (1.4)	59 (1.3)	3 (6.2)	
Skilled nursing facility	12 (0.3)	12 (0.3)	0 (0)	

Outcomes

Increased age, non-African American race, associated crush injury, and vascular injuries were associated with a higher risk of developing CS. The patient who developed CS stayed longer in the hospital when compared with those patients who did not develop CS (8 (5–10) vs 3 (3–3), $p<0.001$). There was no significant difference identified between the two groups regarding patients going home without any services (79.2% vs 89.3%, $p=0.062$) (table 3).

DISCUSSION

Our study showed that increased age, non-African American race, associated crush injury, and vascular injury were correlated with the development of CS in pediatric patients who sustained tibial fractures. Patient sex, injury severity score, type of trauma or mechanism of injury, and injury severity were not found to be associated with the development of CS. Patients who developed CS stayed almost three times longer than the patient who did not develop CS.

Many challenges are encountered in diagnosing CS in a child including difficulty in eliciting the symptoms, performing a bedside compartment pressure in an awake child, and lower sensitivity of manual palpation of the compartment.[2 12 13] Children usually present with 3A's instead of 5p's. Finding those patients who mount anxiety, agitation, and out-of-proportion pain that require an augmented dose of analgesia are key steps toward diagnosing CS.[14] Although delay in diagnosis is relatively common in a child and most of the diagnosis is confirmed within 24 hours of injury or later.[6] Patients who underwent operative intervention, fasciotomy, in less than 48 hours were found to have good outcomes.[6] Intervention after 48 hours resulted in some degree of motor and sensory deficit.

Since timely diagnosis is key for salvaging the limb, identifying high-risk patients is of paramount importance. A recent study examining children with CS found that older age, male gender, gunshot wound, and lower extremity fractures are the higher risk factors for CS.[15] The study used a data set from the National Trauma Data Bank data between 2009 and 2012 and included patients up to 19 years of age. Pandya *et al* examined 31 children with a tibial fracture who underwent operative intervention and found that preoperative abnormal neuro examination of the fractured leg, weight of over 50 kg, and comminuted fractures are the risk factors for CS.[16] Timing of surgery, total operative time, high energy mechanism of injury, and polytrauma, were not associated with CS.

Our study examined the risk factors using the latest TQIP database and found the CS occurrence after a tibia fracture at 1.1%. The study found that the non-African American race has more than double the odds of developing CS compared with the African American race. The exact reason for the association of race with the development of CS in the tibial fracture is not known. We used the African American race in our multivariable model because of the significant difference identified in the univariate analysis. Therefore, using race in the model to control the possible confounders still yielded a positive association of the non-African American race to the occurrence of CS. The study also found that advancing in 1 year of age increased the risk of CS by 15%. Therefore, older children are at higher risk than younger ones. Associated vascular injury in the leg was associated with a more than 3.5-fold increased risk of CS. The most profound factor that was associated with CS was the presence of crushed injury. Concomitant crush injury was associated with an approximately 19-fold increase in the risk of CS. Our study did not find any association of CS with the type of tibial fractures, polytrauma, or severity of the injury.

Limitation

The study was performed using data from the largest national trauma database. However, due to the retrospective design of the study, the study is categorized as a level IV evidence study. Detailed information on the compartment pressure of individual patients or neuro-vascular assessment information are missing from the TQIP database thus limiting the potential observations. We performed the multivariable regression analysis to control for other variables to analyze the factors associated with CS. The AUC is interpreted as the probability that a patient with the risk factors has a higher chance of developing CS than a patient who does not have the risk factors. The estimated AUC (0.659 (95% CI: 0.593 to 0.725)) can be interpreted as our multiple logistic regression model providing an estimation of the chance of developing CS with the accuracy between poor and fair.[17] Even though we can identify risk factors associated with the development of CS, the estimated AUC indicates that there may be other factors that were not captured in the study due to the lack of information available in the data set.

CONCLUSION

Our study found the incidence of CS in tibial fractures at 1.1%. Older children, non-African American race, concomitant vascular injury, and crush injury were associated with a higher risk for CS. These high-risk patients should be closely monitored for signs and symptoms of CS.

Contributors Nasim Ahmed (NA) conceived and designed the study. NA was responsible for retrieving the study data, and Yen-Hong Kuo (YK) performed the data analysis. NA and YK both contributed to article writing and both contributed to the revision of the article. NA is responsible for the content of the study.

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Patient consent for publication Not applicable.

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