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OTA Classification is Highly Predictive of Acute Compartment Syndrome Following Tibia Fracture: A Cohort of 2885 Fractures

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Objective: To determine the correlation between the OTA classification of tibia fractures and the development of acute compartment syndrome (ACS).

Design: Retrospective review of prospectively collected database

Setting: Single level 1 academic trauma center

Patients: All patients with a tibia fracture from 2006 to 2016. 3606 fractures were initially identified. Skeletally mature patients with plate or intramedullary fixation managed from initial injury through definitive fixation at our institution were included, leaving 2885 fractures in 2778 patients.

Methods: After database and chart review, univariate analyses were conducted using independent t-tests for continuous data and chi-square tests of independence for categorical data. A simultaneous multivariate binary logistic regression was developed to identify variables significantly associated with ACS.

Results: Average age was 42.9 +/- 18.0 years. 823 (28.5%) fractures were open. 565 (19.6%) fractures underwent initial external fixation. 952 (33.0%) fractures involved the proximal (OTA 41), 1262 (43.7%) involved the middle (OTA 42), and 834 (28.9%) involved the distal segment (OTA 43). 1696 fractures (58.8%) underwent plating, 1118 fractures (38.8%) underwent intramedullary fixation, and 71 (2.4%) underwent a combination.

ACS occurred in 136 limbs (4.7%). The average age was 36.2 years versus 43.3 years in those without ($p<0.001$). Males were 1.7 times more likely to progress to ACS than females ($p=0.012$). Patients who underwent external fixation were 1.9 times more likely to develop ACS ($p=0.003$). OTA 43 injuries were at least 4.0 times less likely to foster ACS versus OTA 41 or 42 injuries

(p=<0.007). OTA 41-C injuries were 5.5 times more likely to advance to ACS compared to OTA 41-A(p=0.03) There was a significantly higher rate of ACS in OTA 42-B (p=0.005) and OTA 42-C (p=0.002) fractures when compared to OTA 42-A fractures. In the distal segment, fracture type did not predict the risk of ACS(p>0.15). Group 1 fractures had a lower rate of ACS compared to group 2 (p=0.03) and group 3 (p=0.003) fractures in the middle segment only. Bilateral tibia fractures had a 2.7 times lower rate of ACS (p=0.04).

Open injury, multiple segment injury, fixation type, and concurrent pelvic or femoral fractures did not predict ACS.

Conclusions: In this large cohort of tibia fractures we found that the age, sex, and OTA classification were highly predictive for the development of ACS.

Key Words: Acute Compartment Syndrome;compartment syndrome;tibia fracture;tibial plateau fracture;tibial shaft fracture;tibial pilon fracture;OTA Classification

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Introduction

Acute compartment syndrome (ACS) occurs when the pressure within one or more of the body's muscular compartments rises above that of capillary inflow pressure resulting in muscular ischemia and, if left untreated, eventually necrosis. Unfortunately, the current gold-standard test, intra-compartmental pressure monitoring with a side port needle, has been proven error prone in technique and unreliable in a clinical setting, despite its precision in controlled testing environments. (1,2) There are collaborations working on alternative testing methods including biomarkers, MRI, pulsed phase-locked loop ultrasound, laser flowmetry, scintigraphy, and near infrared spectrophotometry; (3) however, to date, ACS remains a clinical diagnosis based largely on subjective signs and symptoms in the awake and alert patient. Reported in 2.7 to 33.3% of patients presenting with tibial fractures, delay in diagnosis of ACS can result in not only long term disability to the patient, but has also been identified as one of the cases with a high rate and amount of indemnity when medico-legal action is taken. (4)

Unfortunately, the treatment for ACS, fasciotomies, is not without morbidity. It has been shown to decrease healing rate, increase cost, and prolong hospital stay. (5,6) Thus, it encourages the treating orthopaedic surgeon to obtain a prompt and accurate diagnosis with the tools readily available. Some patient and injury characteristics may assist the clinician in the diagnosis. Age, energy of the injury, location, implant type, and fracture pattern have all been associated with the risk of ACS.(7-10)

The Orthopaedic Trauma Association (OTA) fracture classification, revised in 2006, allows for fracture classification based on both location and severity of the fracture pattern. As it has been shown that both location and fracture pattern play a role in the risk of ACS, it would

stand to reason that the OTA classification system could be used to better predict the development of ACS following tibial fracture. (8,10)

The aim of this study was to assess the correlation between OTA fracture classification in tibial fractures and their subsequent development of ACS, while controlling for known risk factors. We hypothesized that, as the OTA classification is indicative of fracture severity, it would also be predictive of the risk of developing ACS.

Patients and Methods

After IRB approval, our institution's prospectively-collected database was retrospectively reviewed for all tibial fractures from January 1, 2006 to January 1, 2016. 3606 tibial fractures were initially identified. All patients were treated by a trauma-fellowship trained orthopaedic surgeon at one of two trauma centers within our institution. Inclusion criteria were skeletally mature patients, patients undergoing plate or intramedullary fixation, and fractures managed from initial injury through definitive fixation at our institution. Patients transferred to our facility, skeletally immature patients, those patients with previous implants of the tibia, pathologic fractures, acute amputations, formal prophylactic fascial release, and those treated with a frame, cast, or percutaneous pinning were excluded. After review, 2885 fractures in 2778 patients remained for analysis.

Demographics were recorded prospectively including date of injury, age, and sex. Injury details were likewise prospectively logged, including OTA fracture classification, skin compromise (open vs. closed and Gustilo classification)(11), concurrent injuries, initial external fixation, fixation construct, ACS diagnosis, nerve or vessel injury, and subsequent procedures. ACS was initially diagnosed by physical exam in all awake and alert patients. In those patients

either obtunded or sedated, compartment monitoring was performed using a digital monitor with side-port needle (Stryker Surgical; Kalamazoo, MI). The diagnosis of ACS was confirmed by surgeon discretion at the time of fasciotomy as evidenced by muscle herniation, muscle cyanosis, or muscle necrosis. Those patients who showed none of the aforementioned signs were considered to be without ACS.

A retrospective radiographic review was performed to confirm fracture classification as was a patient chart review to confirm patient demographics and details of compartment release, when performed.

Statistical Methods

Descriptive statistics are reported as means and standard deviations for continuous variables and as percentages for categorical variables. Univariate analyses were conducted using Independent t-Tests for continuous data and Chi-square Tests of Independence for categorical data. A bilateral variable was used. A multi-segment variable was used and fractures involving multiple segments were added to parallel groups during analysis. A simultaneous multivariate binary logistic regression was developed to identify variables significantly associated with ACS. The significance level was set at $p = 0.05$. All analyses were conducted using SPSS version 22.0 (Armonk, NY: IBM Corp).

Results

The average age for all patients was 42.9 +/- 18.0 years, 62.7% were male, and 823 (28.5%) fractures were open. 100 patients (3.6%) had bilateral fractures, while 7 (0.3%) had two discrete injuries at distinct time points. 565 (19.6%) fractures received initial external fixation. 952 (33.0%) fractures involved the proximal segment (OTA 41), 1262 (43.7%) involved the middle segment (OTA 42), and 834 (28.9%) involved the distal segment (OTA 43). 163 fractures (5.7%) were combined, multi-segment fractures of the same tibia. 1696 fractures (58.8%) underwent plate fixation alone, 1118 fractures (38.8%) underwent intramedullary fixation alone, and 71 (2.5%) underwent a combination of nail and plate fixation for combined injuries. 153 fractures (5.3%) occurred concurrently with ipsilateral femoral fractures, while 78 (2.7%) occurred in conjunction with a pelvic or acetabular injury.

Four patients were prophylactically released at the operating surgeon's discretion due to intraoperative subjective signs, but were not found to have muscle cyanosis, necrosis, or significant herniation and were primarily closed within 48 hours. These patients did not have preoperative symptoms, nor objective intraoperative testing or muscle findings and thus were excluded. This left 136 patients (4.7%) with ACS and no patient developing a bilateral ACS. The average age of those developing ACS was 36.2 years versus 43.3 years in those without ($p<0.001$, OR 0.972, 95% CI 0.960-0.984). 77.9% of fractures developing ACS occurred in male patients compared to 61.9% of fractures without ACS ($p=0.016$; OR 1.72; 95% CI 1.125-2.628). External fixation was initially performed in 32.4% of fractures with ACS compared to 19.0% of those without ($p=0.003$; OR 1.94; 95% CI 1.26-2.99).

Distal segment injuries (OTA 43) had a significantly lower percentage developing ACS when compared to both middle (OTA 42) ($p=0.001$; OR 4.03; 95% CI 1.72-9.43) and proximal

(OTA 41) (p<0.001; OR 4.75; 95% CI 4.11-5.47) segment injuries after controlling for patient and treatment variables (Table 1). There was no difference in the rate of ACS between proximal and middle segment injuries (p=0.65).

After controlling for patient and treatment variables, OTA 41-C fractures had a significantly higher rate of ACS when compared to type OTA 41-A(p=0.03). There was no difference between OTA 41-A and 41-B (p=0.40). There was a trend toward a higher rate of ACS in OTA 41-C fractures compared to 41-B, but this did not reach significance (p=0.07). There was a significantly higher rate of ACS in OTA 42-B (p=0.005; OR 2.57; 95% CI 1.32-5.00) and OTA 42-C (p=0.002; OR 3.00; 95% CI 1.49-6.04) fractures when compared to OTA 42-A fractures. There was no difference between OTA 42-B and 42-C fractures (p=0.4). In the distal segment, fracture type did not predict the risk of ACS(p>0.15).

After controlling for patient and treatment variables as well as for segment, in middle segment fractures (OTA 42), group 1 fractures had a significantly lower rate of ACS when compared to both groups 2 (p=0.03; OR 2.63; 95% CI 1.08-6.45) and 3 (p=0.003; OR 3.91; 95% CI 1.57-9.73). There was no significant difference between groups 2 and 3 in middle segment fractures (p=0.09). There was no association between group and the development of ACS in the proximal segment (OTA 41) (p>0.11) or distal segment (OTA 43) (p>0.39). The incidence of ACS by group is reported in table 2.

Patients who suffered concurrent bilateral tibial fractures had an overall 2.7 times lower incidence of developing ACS (p=0.037, OR 0.37; 95% CI 0.15-0.94). Open injury (p=0.572), injuries involving two bone segments (p=0.429), fixation type (p>0.575), concurrent pelvic injury (p=0.531), and ipsilateral femoral fracture (p=0.612) were not predictive of the development of ACS.

Discussion

After controlling for age, sex, implant, and concurrent injuries, we found that the OTA classification is an independent risk factor for development of ACS. The design of the OTA fracture classification is that, after identification of bone and segment, the fracture classification proceeds from least to most severe in type, group, and subgroup, thus it only logical that with more severe fractures the risk of ACS is increased.(12) Our data also showed that the risk of ACS significantly decreased in fractures of the distal segment (OTA 43) when compared to fracture of the shaft (OTA 42) or proximal segment (OTA 42). Further, we exhibited that both fracture type and group are predictive in certain segments. However, it should be noted, that ACS occurred in nearly every tibia fracture possible in the OTA classification, and a high degree of suspicion for ACS should be maintained for all patients with tibia fractures (Table 2).

Our findings also confirmed what several have shown before, that age and sex are both highly predictive of the development of ACS.(7,9,13) Young patients and males are significantly more likely to develop ACS. This has been speculated to be due to increased muscular mass and fascial stiffness in these patients, but may also have to do with the injury mechanism involved in patients of a certain sex or age. (7)

We found that patients that underwent external fixation had a higher likelihood of ACS (p=0.003) even after controlling for fracture pattern. It is possible that the use of external fixation is a surrogate for the energy involved in the injury, with patients involved in higher energy accidents and more severe grade of soft tissue injury being more likely to receive both external fixation and develop ACS. However, it is also probable that the inverse is true and patients who were diagnosed with ACS were more likely to receive initial external fixation as temporization.

Unfortunately, due to the retrospective nature of the study, it is difficult to confirm this suspicion.

Interestingly, we did not find an association between implant type and the risk of ACS as previously noted by McQueen et al.(9) We would speculate that this may be due to the external validity of either study, with certain institutions, or surgeons, preferring one implant over another in specific situations.

The result that bilateral tibial fractures was protective from ACS (p=0.037) is more difficult to theorize causality, as this is counterintuitive to our expectation. Open injury (p=0.111), concurrent pelvic injury (p=0.531), and ipsilateral femoral fracture (p=0.612) did not predict the development of ACS in our group. Park et al. found that the risk of ACS was not linked with “associated fractures” (p=0.83); however, they did not define that which constituted an “associated fracture” and thus it is difficult to parse out the relationship between our findings and theirs other than they are seemingly supportive. (7)

Fracture Segment (OTA 41-43)

Our data shows that patients with fractures of the middle (OTA 42) and proximal segment (OTA 41) are more likely to develop a subsequent ACS when compared to those with fractures of the tibial plafond (OTA 43). However, we found that there was no significant difference when comparing proximal to middle segment fractures.

Our findings contradict those of Park et al. who found that ACS was significantly more common in patients with fractures of the diaphyseal segment when compared to both the proximal and distal segments.(7) They showed a rate of 8.1% for OTA 42 fractures, 1.6% for OTA 41 fractures, and 1.4% for OTA 43 fractures. They also noted that the only distal fracture

developing a ACS was an injury involving both the diaphysis and distal metaphysis. Their feeling, although not substantiated by definitive evidence, is that because much of the muscle mass in the leg surrounds the diaphyseal region, the diaphyseal segment is more prone to bleeding into the compartments and subsequent pressure induced ischemia.

Recently published findings by Allmon et al. found that ACS was more common in fractures of the proximal segment than those of the middle segment ($p<0.001$) or distal segment($p<0.001$).(8) Our findings showed that ACS is most commonly found in patients OTA 41 fractures; however, unlike the results of Allmon's group, our findings did not show a statistically significant difference between the rate of ACS in patients with fractures of the proximal or middle segments ($p=0.65$). Conversely, like their findings, we found that patients with fractures of the tibial plafond had a significantly lower rate of ACS than did those with fractures of the middle segment ($p=0.001$) or proximal segment ($p<0.001$).

While the current study does not confirm the hypothesis by Park et al., we agree that it would be sensible for fractures in the distal segment of the tibia to have a lower rate of ACS as the majority of the muscle bodies have tapered off leaving only tendinous structures with fewer muscular compartments for acute hemorrhage and ACS to develop.(7)

Fracture Type (OTA 4X-A – 4X-C)

Fracture type is the first variable to describe the pattern of the fracture rather than the location. As with any good classification system, the type of fracture is very generalizable. For periarticular fractures (proximal and distal segment), type A, B, and C indicate a fracture that is extra-articular, partial articular, and complete articular, respectively. For diaphyseal fractures, type A indicates a simple pattern, type B indicates a wedge pattern, and type C indicates a

complex pattern without any intact cortical contact between the proximal and distal fracture fragments.

Several authors have previously looked at tibial fractures and whether there is correlation between the type of fracture and the risk of ACS. Park et al. determined that in a cohort of patients with a total of 414 fractures, there was no association between OTA fracture type and subsequent development of ACS in any segment, although significance factors were only published for the diaphyseal segment (p=0.53).(7) Similarly, McQueen et al. evaluated a group of 1388 patients with diaphyseal tibia fractures and established that the OTA type played no role in the risk of development of ACS.(9) Ziran and Becher performed an analogous study in the proximal tibia, evaluating 162 tibial plateau fractures, and found that OTA fracture type was highly predictive of the development of ACS (p<0.001). (10)

Our study evaluated tibial fractures and found that OTA type was significantly associated with the development of ACS in both the proximal (OTA 41) and middle (OTA 42) segments, but not in the distal segment. In the proximal segment, there was a significantly higher rate of ACS in type C fractures when compared to type A (p=0.03), but no difference between types A and B (p=0.4) and only a trend toward a higher rate in type C fractures when compared to type B (p=0.07). In the middle segment, we found a statistically significant difference between the rate of ACS in fractures of both types B (p=0.005) and C (p=0.002) when compared to type A fractures. There was no difference between types B and C (p=0.4) in the middle segment.

Our findings agree with those of Ziran et al. in regards to the proximal segment; however, refute those of both Park and McQueen in regards to the diaphyseal segment.(9,10) In the study by Park et al., their findings may be explained by the study simply being underpowered. However, the study by McQueen included a similar number of diaphyseal fractures as our study

(1388 vs. 1262) and their results are opposite after only controlling for age, while our analysis controlled for several other factors and significance was still confirmed. This is likely due to the large number of patients in their study missing OTA classification data. Out of 1388 fractures, 672 (48%) were missing classification data. Less likely, but also a possibility would be by either study providing internal validity without widespread application, thus a multicenter study would be required to provide further evidence as to the external validity of the current study.

Fracture Group (OTA 4X-X1 – 4X-X3)

Wennergren et al. recently showed that the OTA classification system had moderate interobserver and intraobserver reliability for tibia fractures.(14) However, it has garnered little attention in regards to ACS. Most recently, Allmon et al. commented on the risk of ACS based on fracture group, but only briefly in terms of OTA 42-C2, or segmental diaphyseal fractures, which did not show a significantly higher rate of ACS in comparison to other fracture types or groups.(8) However, no other authors, to our knowledge, have evaluated the risk of ACS based on fracture group.

After controlling for patient and treatment variables as well as for segment, in middle segment fractures (OTA 42), when compared to group 1 fractures, group 2 fractures had a 2.6 times higher rate of ACS and group 3 fractures had a 3.9 times higher rate of ACS. There was no association between group and the development of ACS in the proximal segment (OTA 41) ($p>0.11$) or distal segment (OTA 43) ($p>0.39$).

The fracture group generally describes the complexity of the fracture and thus may, in the case of ACS risk, be a surrogate for the energy involved in creating the fracture. However, it may also be an indicator of bone quality or a host of other factors. Due to the retrospective nature of

the study and insufficient documentation in many charts, we were not able to document high vs. low energy injuries or bone quality with reliability and thus chose not to include these as a variable. Further study may be warranted to determine if there is an association between energy and fracture group.

Limitations

As with any retrospective analysis, several inherent biases are present. These biases include standardization of radiographs used for analysis and treatment as well as diagnosis bias based on surgeon subjectivity in the identification of ACS. We attempted to limit bias in radiographic classification of fracture pattern through use of a prospectively collected database, which logged OTA classification of fractures by the treating surgeon at the time of fixation. Retrospective review was used only for confirmation of classification. We further attempted to limit bias in diagnosis of ACS by excluding those that did not show signs of ACS at the time of surgical release and by excluding any patient that had prophylactic fascial release.

Another limitation is that due to the inadequacy in documentation of many patients at the time of injury, we excluded use of mechanism of injury as a potential factor in the multivariate analysis. This was purposely excluded as we found many patients lacked sufficient details (i.e. fall height) in their injury documentation to make this a clinically accurate variable. Finally, as with any single center study, our findings may lack external reliability as certain centers tend to receive a disproportional number of fractures from certain mechanisms that may not hold true at other centers.

Conclusion

In this large cohort of tibia fractures, we found that the age, sex, and OTA classification are highly predictive for the development of ACS. Fractures of the distal segment (OTA 43) are at lower risk of ACS. Type C fractures of the proximal segment (OTA 41) along with type B or C fractures of the middle segment (OTA 42) are at the highest risk. While these findings should help to guide clinical practice and patient counseling, treating physicians must recognize that even simple fracture patterns are not immune to the development of ACS and surgeons must remain diligent in examination and monitoring of any patient with a tibial fracture.

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	Compartment Syndrome n = 136	No Compartment Syndrome n =2,749	p-Value	Odds Ratio	95% CI Lower	95% CI Upper
Age (st. dev)	36.2 (14.9)	43.3 (18.1)	<0.001	0.972	0.960	0.984
Sex (Male)	77.9%	61.9%	0.016	1.720	1.125	2.628
Open Injury	34.6%	28.2%	0.986	0.886	0.581	1.350
Multi Segment Inj.	5.1%	5.7%	0.429	0.656	0.231	1.864
Bilateral Injuries	3.7%	7.1%	0.037	0.371	0.147	0.940
External Fixation	32.4%	19.0%	0.003	1.938	1.261	2.985
Concurrent Fracture						
Femur	8.8%	5.1%	0.612	1.186	0.613	2.296
Pelvis	4.4%	2.6%	0.531	1.327	0.547	3.222
Type of Fixation						
Plate	39.0%	38.7%	N/A (Reference)			
Intramedullary Rod	58.8%	58.8%	0.991	0.996	0.499	1.986
Both	2.2%	2.5%	0.575	1.588	0.316	7.987
OTA Classification						
Bone Segment						
1 [Proximal] (n)	47.1% (64)	32.3% (888)	<0.001	4.754	4.108	5.472
2 [Middle] (n)	47.1% (64)	43.6% (1198)	0.001	4.032	1.715	9.434
3 [Distal] (n)	11.0% (15)	29.8% (819)	N/A (Reference)			
Fracture Type						
A (n)	17.6% (24)	30.5% (839)	N/A (Reference)			
B (n)	29.4% (40)	36.8% (1013)	0.14	1.503	0.875	2.580
C (n)	54.4% (74)	36.1% (993)	<0.001	2.712	1.593	4.615
Group (Comminution/Articular Involvement)						
1 (n)	17.6% (24)	30.9% (849)	N/A (Reference)			
2 (n)	36.8% (50)	32.6% (896)	0.013	1.982	1.157	3.394
3 (n)	47.8% (65)	39.6% (1088)	0.052	1.659	0.977	2.762

Table 1. Predictors of ACS following tibia fracture. Univariate analyses were conducted using independent t-tests for continuous data and chi-square tests of independence for categorical data. A simultaneous multivariate binary logistic regression was developed to identify variables significantly associated with ACS. OTA classification analyses included in this table are composite. Multi segment injuries may be tallied in multiple groups under OTA classification

Proximal

41-A1	Avulsion	0.00%	(0/1)
41-A2	Metaphyseal Simple	5.00%	(2/40)
41-A3	Metaphyseal Multifragmentary	3.70%	(2/54)
41-B1	Pure Split	3.00%	(3/101)
41-B2	Pure Depression	11.80%	(4/34)
41-B3	Split Depression	3.40%	(9/265)
41-C1	Articular Simple, Metaphyseal Simple	8.30%	(10/121)
41-C2	Articular Simple, Metaphyseal Multifragmentary	12.90%	(13/101)
41-C3	Articular Multifragmentary	8.90%	(21/236)

Middle

42-A1	Simple Spiral	0.00%	(0/179)
42-A2	Simple Oblique	2.30%	(6/264)
42-A3	Simple Transverse	6.70%	(11/164)
42-B1	Spiral Wedge	1.90%	(2/108)
42-B2	Bending Wedge	7.80%	(14/180)
42-B3	Fragmented Wedge	9.10%	(7/77)
42-C1	Complex Spiral	8.90%	(5/56)
42-C2	Complex Segmented	7.60%	(8/106)
42-C3	Complex Irregular	8.70%	(11/127)

Distal

43-A1	Metaphyseal Simple	1.50%	(1/65)
43-A2	Metaphyseal Wedge	1.80%	(1/57)
43-A3	Metaphyseal Complex	3.90%	(2/51)
43-B1	Pure Split	0.50%	(1/188)
43-B2	Split Depression	1.20%	(1/83)
43-B3	Multifragmentary Depression	0.00%	(0/48)
43-C1	Articular Simple Metaphyseal Simple	2.80%	(3/106)
43-C2	Articular Simple Metaphyseal Multifragmentary	2.30%	(2/88)
43-C3	Articular Multifragmentary	2.70%	(4/148)

Table 2. Frequency of compartment syndrome based on OTA classification. (Number of fractures with compartment syndromes/Total fractures in group)