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Is the timing of fixation associated with fracture-related infection among tibial plateau fracture patients with compartment syndrome? A multicenter retrospective cohort study of 729 patients

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ABSTRACT

Background: Tibial plateau fractures with an ipsilateral compartment syndrome are a clinical challenge with limited guidance regarding the best time to perform open reduction and internal fixation (ORIF) relative to fasciotomy wound closure. This study aimed to determine if the risk of fracture-related infec-

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tion (FRI) differs based on the timing of tibial plateau ORIF relative to closure of ipsilateral fasciotomy wounds.

Methods: A retrospective cohort study identified patients with tibial plateau fractures and an ipsilateral compartment syndrome treated with 4-compartment fasciotomy at 22 US trauma centers from 2009 to 2019. The primary outcome measure was FRI requiring operative debridement after ORIF. The ORIF timing relative to fasciotomy closure was categorized as ORIF before, at the same time as, or after fasciotomy closure. Bayesian hierarchical regression models with a neutral prior were used to determine the association between timing of ORIF and infection. The posterior probability of treatment benefit for ORIF was also determined for the three timings of ORIF relative to fasciotomy closure.

Results: Of the 729 patients who underwent ORIF of their tibial plateau fracture, 143 (19.6%) subsequently developed a FRI requiring operative treatment. Patients sustaining infections were: 21.0% of those with ORIF before (43 of 205), 15.9% at the same time as (37 of 232), and 21.6% after fasciotomy wound closure (63 of 292). ORIF at the same time as fasciotomy closure demonstrated a 91% probability of being superior to before closure (RR, 0.75; 95% CrI, 0.38 to 1.10). ORIF after fasciotomy closure had a lower likelihood (45%) of a superior outcome than before closure (RR, 1.02; 95% CrI; 0.64 to 1.39).

Conclusion: Data from this multicenter cohort confirms previous reports of a high FRI risk in patients with a tibial plateau fracture and ipsilateral compartment syndrome. Our results suggest that ORIF at the time of fasciotomy closure has the highest probability of treatment benefit, but that infection was common with all three timings of ORIF in this difficult clinical situation.

Introduction

Tibial plateau fracture with an ipsilateral compartment syndrome is an injury often associated with high-energy mechanisms and substantial associated soft tissue damage. Based on previous literature, a compartment syndrome develops in 4.3% to 14.5% of tibial plateau fractures [1–11] and more commonly in those patterns that are more comminuted or involve more soft tissue envelope damage, such as Schatzker VI patterns. Treatment for the compartment syndrome is typically a 4-compartment fasciotomy through either a 1- or 2-incision approach, while treatment of the fracture is typically open reduction and internal fixation (ORIF). Although a few small studies have demonstrated low deep infection rates in those fractures with compartment syndrome [2,12], multiple recent papers have demonstrated surgical site infection (SSI) rates after fasciotomy to be greater than 20% [3,7-9,13,14], indicating an important unsolved problem.

Fracture fixation can occur near the time of injury or in a delayed fashion with temporary initial external fixation to maintain length, alignment, and rotation of the tibial plateau fracture. One potential for improved outcomes is in the timing of fixation relative to closure of fasciotomy wounds. A meta-analysis of the available data regarding timing of ORIF of the tibial plateau fracture relative to fasciotomy closure demonstrated a nonstatistically significant difference in the infection rates based on ORIF performed before, at the same time as, and after fasciotomy wound closure (24% versus 16% versus 17%, respectively) [9]. Although this difference in infection proportion might be viewed to be potentially clinically important, the sample size of 81 plateau fractures lead to an underpowered estimate of infection rates, and is therefore at risk of a type 2 error. Thus the optimal timing of ORIF remains unknown.

The purpose of the present study was to determine whether the timing of tibial plateau fracture ORIF relative to fasciotomy wound closure (delayed primary closure or split thickness skin grafting) is associated with differences in infection rates. Our hypothesis was that ORIF performed before fasciotomy closure would increase the risk of infection compared with ORIF performed at the same time or after fasciotomy wound closure.

Methods

Study design

In this retrospective cohort study, institutional review board (IRB) approval was obtained at each participating site and the coordinating center. A total of 22 trauma centers in the United States participated in this study. Each study site abstracted the required patient data and transferred deidentified data to the coordinating center, in accordance with the study's protocol and data use agreement.

Study participants

Billing databases at each trauma center were queried to identify all tibial plateau fractures treated with plate and screw fixation from 2009 through 2019. The diagnosis of compartment syndrome was made clinically by the attending orthopaedic trauma surgeon with or without the use of compartment pressure monitoring, and subsequently treated with emergent 4-compartment fasciotomy. One- or 2-incision fasciotomies were performed based on individual attending preference. Of note, considering the overlap of study periods between this study and the previous paper [9] out of our institution, some of the patients in the previous analysis were also included in this cohort study.

Patients were excluded from the study if the patients were under 18 years of age at the time of injury, the fractures were not treated with ORIF using plates and screws, or if medical record documentation was insufficient to determine timing of either fasciotomy closure or definitive fracture fixation.

A retrospective review of electronic medical records was completed to obtain the dates of injury, ORIF, most recent follow-up, and fasciotomy incisions and closure. Additional patient factors known to affect infections including diabetes, alcohol abuse, smoking, and the presence of a positive methicillin-resistant *staphylococcus aureus (*MRSA) nasal swab, were also collected when available and are outlined in Table 1. Fracture radiographs were classified by both the Schatzker and OTA fracture classifications.

Interventions

The timing of ORIF was categorized into one of three treatment groups: 1) ORIF before fasciotomy closure, 2) ORIF at the same time as fasciotomy closure, and 3) ORIF after fasciotomy closure. The timing of definitive fixation was at the discretion of each local surgeon. Patients were retrospectively assigned into groups based on the timing of final fasciotomy closure, being defined as either delayed primary closure or skin grafting of all fasciotomy wounds.

Table 1
Patient characteristics by treatment group.

	ORIF before closure	ORIF at same time as closure	ORIF after closure	p-value
	(n = 205)	(n = 232)	(n = 292)	
Age, years, mean (SD)	44 (13)	46 (14)	45 (13)	0.15
Sex, female, n (%)	51 (25)	67 (29)	83 (28)	0.59
Smoker, n (%)	87 (42)	91 (39)	105 (36)	0.34
Alcohol abuse, n (%)	52 (25)	91 (39)	92 (32)	<0.01
Diabetic, n (%)	25 (12)	34 (15)	29 (10)	0.26
Open fracture, n (%)	27 (13)	23 (10)	16 (5)	0.01
Initial external fixation, n (%)	146 (71)	189 (81)	283 (97)	<0.001
Limited internal fixation, n (%)	19 (9)	27 (12)	31 (11)	0.72
Schatzker classification, n (%)				0.08
1	3 (1)	4 (2)	3 (1)	
2	18 (9)	19 (8)	12 (4)	
3	3 (1)	7 (3)	9 (3)	
4	12 (6)	20 (9)	13 (4)	
5	16 (8)	14 (6)	36 (12)	
6	152 (75)	167 (72)	219 (75)	
Missing	44 (13)	46 (14)	45 (13)	

ORIF, open reduction and internal fixation.

Primary outcome

The primary outcome measure was occurrence of infection after ORIF requiring a return trip to the operating room for surgical debridement. The original manuscript labelled these as "deep surgical site infections." Upon retrospective review these cases also appear to likely meet at least one of the confirmatory criteria in the more recently proposed fracture-related infection criteria [15]. In reporting our data, we have changed the terminology to the recently proposed term "fracture-related infection (FRI)" at the request of the journal editor over the term "deep surgical site infection" which was how the study was originally performed. This should not imply that we prospectively classified these patients as meeting the FRI confirmatory criteria as this classification did not exist when many of the patients were treated and this study is retrospective.

Statistical analysis

The patient characteristics were described using counts with proportions and means with standard deviations. We compared the patient characteristics between the three treatment groups using t-tests and chi-square tests.

We estimated the association between the timing of ORIF and a FRI using multivariable Bayesian hierarchical regression models. Bayesian models calculate the probability of treatment effect given the evidence observed. This approach contrasts with the more commonly used null hypothesis significance testing where researchers calculate a p-value as the probability that the observed, or more extreme observations of, treatment effect would occur if the null hypothesis is true. In a Bayesian model, the evidence includes data from the current study and can also incorporate previous evidence to inform the results. In this study, we estimate treatment effect with a neutral prior, which assumes no treatment effect (risk ratio [RR] of 1.0), and an informed prior that incorporates the previous evidence with its uncertainty into the model. The informed prior pooled the results of Dubina et al. [9] and Zura et al. [12] and estimated that ORIF at the time of wound closure had a RR of 0.58 (95% confidence interval, 0.19 to 1.48) compared to ORIF before wound closure and that ORIF after wound closure had a RR of 0.84 (95% confidence interval, 0.39 to 1.82) compared to ORIF before wound closure.

Our Bayesian models were constructed with Markov Chain Monte Carlo simulations (4 chains, each with 2000 iterations). We use these simulations to calculate the posterior probability of treatment effect given the available data. We report the risk ratios of a FRI with ORIF at the same time as or after fasciotomy closure, in comparison with ORIF before fasciotomy closure using 95% credible intervals (CrI) (akin to the 95% confidence interval). We also estimate the probability of a FRI with each treatment option, and the posterior probability of treatment benefit (RR <1.0). We observed considerable differences in the risk of a FRI by site, and therefore, include the site as a random intercept in the model. All models also adjusted for open fractures, as a confounder. Analyses were performed using R Version 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria) by a trained biostatistician.

Results

The study included 729 patients (mean age, 45 [SD, 13] years; 528 [72%] male). The average duration of follow-up was 18 months post-injury, with 86% of the patients having at least 90 days from the date of injury. Two hundred five patients underwent definitive fixation of the tibial plateau fracture before fasciotomy closure, 232 patients were treated with ORIF at the same time as closure, and 292 patients received ORIF treatment after fasciotomy closure. The treatment groups differed in the proportion of patients that initially received external fixation, the proportion of open fractures, and reported alcohol abuse (Table 1).

FRIs occurred in 143 patients (19.6%). The risk of a FRI in this study population varied considerably by treating hospital (Fig. 1). Of the 143 patients who had an infection, the proportion of patients who sustained infections in each group were 21.0% of those with ORIF before fasciotomy closure (43 of 205 patients), 15.9% at the same time as closure (37 of 232 patients), and 21.6% after fasciotomy wound closure (63 of 292 patients), as shown in Table 2. Of those tibial plateau fractures that had a surgical site infection, 22% were within the first 3 weeks, 41% between 3 weeks and 3 months, and 37% after 3 months. Those patients with open fractures had an overall FRI risk of 33% (n = 19/58 patients), with particularly high risk of infection in Gustilo-Anderson type 3A (n = 8/21, 38%) and 3B (n = 3/6, 50%) tibial plateau fractures.

Under a neutral prior, ORIF at the same time as fasciotomy closure reduced the relative risk of a FRI by 25% (RR, 0.75; 95% CrI, 0.38 to 1.10) compared to ORIF before fasciotomy closure (Fig. 2, Table 2). The analysis indicates a 91% posterior probability that ORIF concurrent with fasciotomy closure is superior to ORIF before fasciotomy closure, and an 88% probability that ORIF at the time of fasciotomy closure is the best of the three treatment options. The relative risk of a FRI was 2% higher for patients treated with ORIF after fasciotomy closure (RR, 1.02; 95% CrI: 0.64 to 1.39) com-

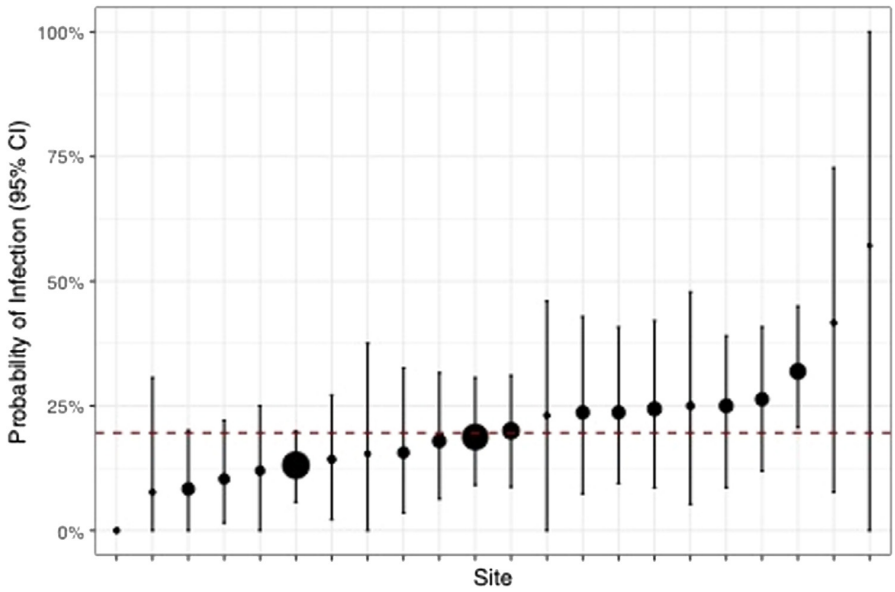

Fig. 1. Probability of infection by study site with 95% confidence interval error bars. Dotted line denotes overall average of 19.6%. Points are scaled relative to the number of patients contributed by each site.

Table 2
Association between timing of ORIF and fracture-related infection with posterior probability of treatment effect.

		Neutral Prior			Informed Prior		
Treatment	Infection, no. (%)	Risk Ratio	95% CrI	P-TB	Risk Ratio	95% CrI	P-TB
ORIF before closure, *n* (%)	43 (21.0)	Ref (1.00)			Ref (1.00)		
ORIF at same time as closure, *n* (%)	37 (15.9)	0.75	0.38 to 1.10	91%	0.69	0.37 to 1.00	98%
ORIF after closure, *n* (%)	63 (21.6)	1.02	0.64 to 1.39	45%	0.95	0.64 to 1.25	62%

RR, risk ratio; CrI, credible interval; P-TB, posterior probability of treatment benefit (risk <1.0).
Note: Adjusted models include open fracture as a fixed effect and the site as a random intercept.

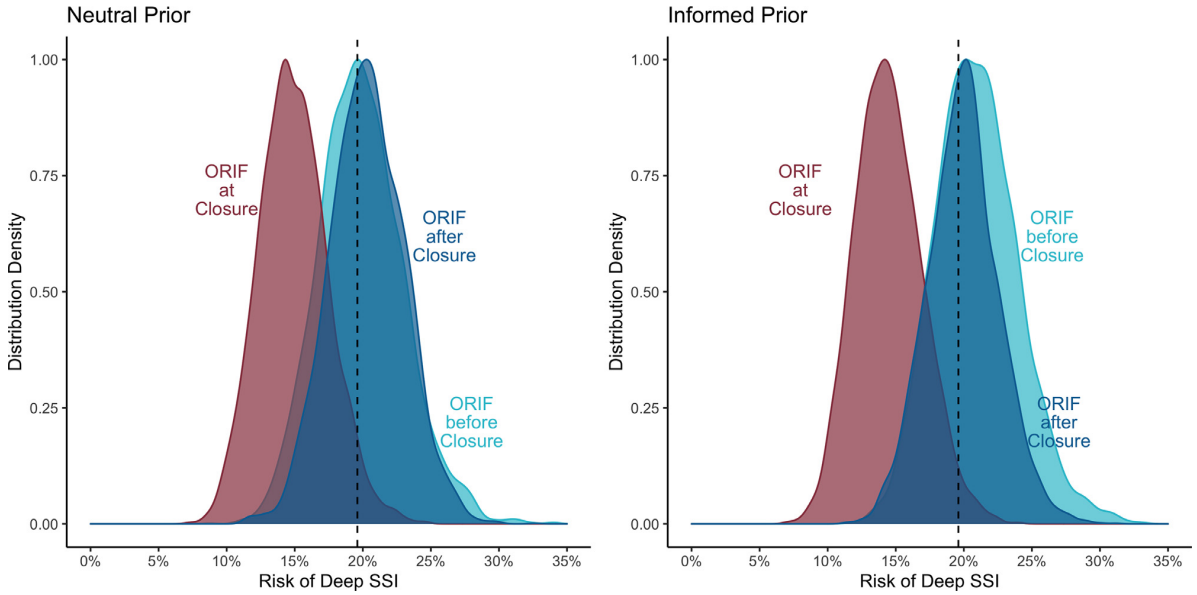

Fig. 2. Posterior probability of a fracture-related infection by ORIF timing. Results are presented using a neutral prior and an informed prior. The dashed line indicates the sample mean risk of a fracture-related infection.

pared to ORIF before fasciotomy closure. The posterior probability of treatment for ORIF after fasciotomy closure was 45%, suggesting the outcomes are similar to ORIF before fasciotomy closure.

In the analysis with an informed prior, the relative risk of a FRI with ORIF at the same time as fasciotomy closure compared with ORIF before fasciotomy closure was 0.69 (95% CrI, 0.37 to 1.00) with a posterior probability of treatment benefit of 98% (Fig. 2, Table 2). The relative risk of a FRI with ORIF after fasciotomy closure compared with ORIF before fasciotomy closure was 0.95 (95% CrI, 0.64 to 1.25) with a posterior probability of treatment benefit of 62%.

Discussion

Based on the results of this study, it appears that infection rates are likely lowest when ORIF occurs at the time of fasciotomy closures (16% infection rate) versus before (20.5%) or after (21.8%) fasciotomy wound closure. Our analysis indicated that an 88% chance that the fasciotomy closure at the same time as ORIF was associated with the lowest proportion of infections. This study is by far the largest series in the literature, with nearly 10 times the number of patients than that in the previous largest study [12]. The size of the current study was needed to begin to appreciate the relatively small difference in infection rates between groups. The absolute difference in infection of over 4% with a baseline infection of approximately 20% can be argued to be clinically significant, but infections are still clearly common with all three approaches.

A previous retrospective study established high infection rates in tibial plateau fractures with compartment syndrome (25%) [9], which was similar to other studies by Blair et al. (22%) [7], Ruffalo et al. (23%) [14], Momaya et al. (29%) [8], and Morris et al. (36%) [3]. However, these findings were contrasted by data demonstrating low infection rates from Hak et al. (0%) [2], Thabet et al. (5%) [16], Zura et al. (11%) [12], and Lin et al. (15%) [5]. Our study's overall FRI rate of approximately 20% represents relative average infection risk compared with the available literature for tibial plateau fractures, and similar to a mixed group of traumatic and nontraumatic compartment syndromes (16.7%) [17].

Proponents of each of the three timing scenarios of fixation and wound closure strategy (ORIF before, at the same time as, and after fasciotomy closure) have a rationale for their chosen treatment. Clearly variations in treatment are based on local preferences, training, and surgeon experience. Early fixation in bicondylar tibial plateau fractures without compartment syndrome has been reported to be safe in recent studies [18,19]. Additionally, fixation before early callus formation and loss of cortical keys would make early ORIF a technically easier surgery with less surgical time, though would require access through a fresh fasciotomy site to obtain fixation. ORIF at the same time as fasciotomy closure would mean fewer times through a fresh surgical bed, less trips to the operating room for the patient, while still maintaining many of the advantages of early fixation with respect to fracture visualization. Finally, late fixation would allow for fully healed fasciotomy wounds or skin graft sites and reduction of swelling more proximal where new incisions will be made, though could come at the risk of a more technically demanding and longer surgery with delay.

Considering the number of treating centers ($n = 22$) and surgeons involved (greater than 50) in the present study, great variation in treatment algorithms was apparent based on study center, previous training, and operating room availability, amongst other variables. Despite this being a retrospective study, these large variabilities likely limits the amount of treatment bias from one particular center. Fig. 1 demonstrates no statistically significant difference between study sites despite variability in treatment preferences. Additionally, our multivariate model accounted for study site as a random effect in addition to the fixed effects of open fracture. Although one site included in the study had zero infection in their cohort, they represent a fairly small sample size ($n = 13$ patients) and account for only 6% of the overall patients in our study. That site represents an outlier, and it is difficult to assess the factors leading to such a low infection rate at that institution.

Despite the advantages of our large multicenter sample with a rigorous statistical analysis, there are several limitations to our retrospective study. Potential risk factors for increased FRI have been previously highlighted [20] including smoking status, MRSA status at time of admission, and body mass index, which could not be evaluated in the current study because of the lack of complete data inherent to a retrospective study. Additionally, study patients were not randomized to treatment timing as the data was retrospectively analyzed, and therefore, a selection bias based on injury pattern or treating surgeon's facility might exist. For example, as with any retrospective non-randomized study, there might be unmeasured characteristics that make it more likely for surgeons to treat a fracture with ORIF at the same time as fasciotomy closure that also make it less likely to have an infection. This is a central limitation of all retrospective studies.

The ideal management of tibial plateau fractures that develop an ipsilateral compartment remains a complex problem with respect to both bony reconstruction and soft tissue closure. This injury pattern has a high risk of FRI (approximately 20%) postoperatively. A modest 4% absolute reduction, (90% likelihood that this strategy is lowest) benefit might exist in terms of reduced FRI to performing ORIF at the same time as wound closure. Clinicians should be aware that, regardless of the timing of ORIF and wound closure, infections are very common after tibial plateau fractures with associated compartment syndrome using current techniques. Future efforts should be aimed at trying to reduce the proportion of infections, and the timing of wound closure relative to ORIF appears to have limited effect in this regard.

Declaration of Competing Interests

None.

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