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Original Research

# Do Open Tibial Shaft Fractures Portend a Worse Outcome in the Pediatric Population? A Pilot Study Utilizing a Matched Cohort

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A R T I C L E I N F O

*Keywords:*
Tibial shaft fracture
Open fracture
Complication

A B S T R A C T

*Background:* Tibia fractures are the third most common pediatric long bone fractures and are associated with numerous complications such as compartment syndrome, angular deformity, and nonunion. This study sought to determine if complication rates were higher in open tibia fractures than in closed tibia fractures in the pediatric population, with the hypothesis that there would be no difference.
*Methods:* A single-center, retrospective cohort study was performed at a quaternary care academic pediatric hospital identifying all open tibia fractures treated from March 1, 2016, to November 30, 2021. These patients were matched by sex, age, and injury pattern, with patients treated for closed tibia fractures during this same time period. Data collected included demographics, clinical and radiographic information, and complications.
*Results:* Both fracture groups included 30 patients (24 males and 6 females). The average age at injury was 11.3 years in the open group, and 11.2 years in the closed group. The median follow-up duration was 7.7 months (1.2-67.8 months) and 9.3 months (1.4-62.9 months) for the open and closed groups, respectively, ($P = .5749$). One hundred percent of open fractures were treated operatively, versus 50% of the closed-group ones ($P < .0001$). There was no significant difference in any type of complications when comparing the open group to the closed tibia fracture group (odds ratio: 1.29, 95% confidence interval: 0.48 to 3.45, $P = .6180$). The most common complication was the development of a clinically significant angular deformity (26.7% in the open group and 10% in the closed group, $P = .1806$). There was a 10% rate of compartment syndrome in both groups and a nonunion rate of 6.7% for the open group and 3.3% for the closed group ($P > .999$).
*Conclusions:* This pilot study utilizing a matched cohort found no significant difference in complication rates between open and closed pediatric tibia fractures, though complications were prevalent in both groups. These findings emphasize the importance of maintaining a high clinical suspicion for compartment syndrome and thoroughly counseling patients on the risks of angular deformity.
*Key Concepts:*

(1) A matched cohort study demonstrates complication rates are similarly high in both open and closed pediatric tibial shaft fractures.
(2) Angular deformity is the most common complication overall.
(3) Treatment algorithms may differ in open versus closed tibial shaft fractures, with open fractures fixated with different constructs and immobilized for longer.

*Level of Evidence:* Level III, case control study

## Introduction

There is limited evidence regarding the optimal management of pediatric open tibia fractures, their complications, and their outcomes relative to pediatric closed tibia fractures. This lack of research has important implications as tibial shaft fractures account for 15% of pediatric long bone fractures and are the third most common fracture behind femur and radius/ulna fractures [1,2]. In polytrauma patients,

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tibia fractures remain the third most common long bone fractures in patients after femur and humerus fractures. To address these injuries, clinicians within pediatric orthopaedic surgery have numerous treatment options available including closed reduction with casting or immobilization, flexible or rigid intramedullary nails, plate and screw constructs, and external fixation [2]. The outcomes and complications comparing these various procedures remain relatively unknown.

In closed fractures, the reported complication rate of nonoperative management is 9% versus 24% in those undergoing operative fixation [3]. In open tibia fractures in the adult population, open tibial shaft fractures have an infection rate reported between 5% and 50% and nonunion rate between 7% and 60% [4]. In one study including both pediatrics and adults, open tibia fractures have a surgical site infection rate of 21.3% in adults versus 13.5% in the pediatric population, with shorter time to soft tissue recovery and time to discharge in children [5]. This suggests that pediatric patients have lower rates of infection and better prognoses than adults, but the outcomes of open versus closed pediatric tibia fractures may vary widely regarding nonunion, loss of reduction (LOR), venous thromboembolism (VTE), neurovascular injuries, compartment syndrome (CS), infection, angular deformity (AD), and leg-length discrepancies (LLDs) [5].

For these pediatric patients, understanding the complications associated with closed and open tibia fractures can inform patients of prognosis, treatment options, and the possible need for additional procedures. Therefore, using a matched cohort based on sex, age at time of injury, and location of the fracture, this study investigated if there was a difference between complications in open tibial shaft and closed tibial shaft fractures, with the hypothesis that there would be no overall difference in complication rates.

## Materials and methods

A single-center, Institutional Review Board-approved, retrospective cohort study was performed at a quaternary care academic pediatric hospital. All patients from 0 to 18 years of age presenting between March 1, 2016, and November 30, 2021, with an open or closed tibia shaft fracture were identified from the local Trauma and Burn Database. Patients were excluded if their electronic medical record had missing surgical data, radiographic data, or if the patient had less than 5 weeks of clinical follow-up. We identified 30 patients with open tibia shaft fractures who met our inclusion criteria; they were then matched to patients with closed tibia shaft fractures based on sex, age at time of injury, location of the fracture (distal, middle, or proximal tibia), and fracture pattern (transverse, spiral, oblique, or comminuted). Matching was performed by two of the contributing authors (Dylan R. Rakowski and Julia S. Sanders), who were blinded to patient outcome at time of matching.

Retrospective data were extracted from the electronic medical record into the local Research Electronic Data Capture (REDCap®) database. Demographic and clinical data including the mechanism of injury, location and laterality of injury, injury pattern, Gustilo Anderson classification when applicable, and presence or absence of other injuries were all noted. Basic surgical log data were also examined. The usage of antibiotics and blood products was documented; it was also noted if either were administered at an outside facility.

Radiographs and clinical follow-up notes were reviewed for the following outcomes: LLDs, nonunion (defined as less than 3 bridging cortices on orthogonal radiographs after 6 months), LOR (defined as a change in alignment requiring clinical intervention such as repeat reduction, cast wedging or surgery), VTE, neurovascular injury, CS, clinically significant infections defined by return to the operating room, as well as AD (defined as $>5^\circ$ of varus or valgus, and/or $>10^\circ$ of procurvatum or recurvatum or deformity significant enough to require an intervention).

Descriptive statistics were used to characterize the demographics and clinical characteristics in the two groups. Chi-squared tests, Fisher's exact tests, or Student's t-tests were used to compare the two groups. To account for the 1:1 matched design, conditional logistic regression models were used to test for differences in the occurrence of complications between groups as well as differences in the occurrence of unplanned return to the operating room between groups. Based on the available sample size and an anticipated incidence rate of 9% in the closed fracture group, we determined that the proposed study has greater than 80% power to detect an odds ratio (OR) of ≥6.7. Power calculations were based on a Chi-squared test with an α level of 0.05. The anticipated incidence of complications of nonunion, malunion, delayed union, LOR, wound complication, and cast manipulation/wedging in the closed group was based on a recent systematic review of tibia fractures in children that reported an overall complication rate of 9% in fractures that were managed nonoperatively [3].

## Results

### *Population*

The open fracture group included 30 patients (24 males and 6 females), with an average age at the time of injury of 11.3 years ( ± 3.8 years). Utilizing the Gustilo Anderson classification, this included 10 type I fractures, 13 type II fractures, 4 type IIIa fractures, 2 IIIb fractures, and 1 type IIIc fracture. The matched group based on age, sex, and fracture pattern included a total of 30 patients (24 male and 6 females; $P > .999$), with an average age at the time of injury of 11.2 years ( ± 3.8 years; $P = .8919$). Additional group characteristics are detailed in Table 1. The open fracture group had significantly higher transfer rates from an outside hospital ($P = .0013$) and higher rate of additional injuries ($P < .0001$).

### *Treatment*

The median duration of time from injury to treatment was similar in the closed fracture group (median: 0, range: 0-5 days) compared to that in the open fracture group (median: 0, range: 0-1 days; duration of follow-up was similar ($P = .5749$) in the closed treatment group (median:

**Table 1.**
Demographics and clinical characteristics.

| | Open fracture | | Closed fracture | | *P* value |
|---|---|---|---|---|---|
| | Freq \| Mean | % \| Stdev | Freq \| Mean | % \| Stdev | |
| **Race, n (%)** | | | | | 0.5795 |
| American Indian or Alaska native | 0 | 0.0% | 1 | 3.3% | |
| Asian | 1 | 3.3% | 0 | 0.0% | |
| Black or African-American | 2 | 6.7% | 4 | 13.3% | |
| White | 18 | 60.0% | 13 | 43.3% | |
| More than one race | 6 | 20.0% | 9 | 30.0% | |
| Unknown or not reported | 3 | 10.0% | 3 | 10.0% | |
| **Ethnicity, n (%)** | | | | | 0.8933 |
| Hispanic or Latino | 11 | 36.7% | 13 | 43.3% | |
| Not Hispanic or Latino | 18 | 60.0% | 16 | 53.3% | |
| Unknown or not reported | 1 | 3.3% | 1 | 3.3% | |
| **Female, n (%)** | 6 | 20.0% | 6 | 20.0% | >0.999 |
| **Fracture location, n (%)** | | | | | >0.999 |
| Distal tibia shaft | 9 | 30.0% | 9 | 30.0% | |
| Proximal/middle tibia shaft | 21 | 70.0% | 21 | 70.0% | |
| **Transfer from outside hospital, n (%)** | 25 | 83.3% | 13 | 43.3% | 0.0013 |
| **Other injury, n (%)** | 24 | 80.0% | 6 | 20.0% | <.0001 |
| **Age at injury, mean (stdev)** | 3.8 | 11.3 | 11.2 | 3.8 | 0.8919 |

9.3 mos, range: 1.4-62.9) compared to that in the open treatment group (median: 7.7 months, range: 1.2-67.8). There were multiple differences in the clinical management of open versus closed tibia fractures (Tables 2 and 3). Among the two groups, patients with open tibia fractures had a significantly higher rate of blood product administration (23% vs 0%; $P = .0105$) and longer duration of immobilization, with 73.3% of the open fractures immobilized for longer than 6 weeks ($P = .0040$). Admission to the pediatric intensive care unit was twice as high in the open fractures (20% vs 10%; $P = .4716$), but this did not reach significance in this cohort of patients. The percentage of patients that were treated operatively was higher in the open fracture group (30 out of 30, 100%; including patients who underwent irrigation and debridement and casting/splinting in the operating room) than in the closed fracture group (15 out of 30, 50%; $P < .0001$. When comparing the groups, patients with open fractures were more likely to be treated initially with external fixators ($P = .0237$) or plate/screw constructs ($P = .0122$) when compared to closed fractures. All patients in the open fracture group received one or more antibiotics following admission. Cefazolin was the most common antibiotic given.

### *Complications*

Complications are detailed in Table 4. There was no significant difference in overall complications when comparing the open group to the closed tibia fracture group (OR: 1.29, 95% confidence interval [CI]: 0.48 to 3.45, $P = .6180$). The most common complication in both groups was the development of a clinically significant AD (open: 26.7% vs closed: 10.0%). Of the 8 patients in the open group who developed AD, 3 patients were initially treated with external fixation, and the remaining 5 were treated with rigid intramedullary nailing, plate and screw fixation, percutaneous screw fixation, percutaneous pin fixation, and casting, respectively (Fig. 1). Of the 3 patients in the closed group who developed AD, all were treated with closed reduction and immobilization.

Complications resulted in an unplanned return to the operating room in 20% (6 out of 30) of patients in the open fracture group compared to 17% (5 out of 30) of patients in the closed fracture group. Of the patients in the open group, there were various reasons for unplanned return to the OR. This included fasciotomy, hemiepiphysiodesis for AD, failure of fixation, hardware removal for symptomatic implants, osteotomy, and one patient that required irrigation and debridement, hardware removal and revision, and treatment of nonunion including osteotomy. In the closed group, 5 patients had an unplanned trip to the OR. One patient had a nonunion, two patients had LOR at 4 weeks and 8 weeks, and one patient had a valgus malunion, all of which required surgical intervention. The other patient required hardware removal for symptomatic implants. There was no significant difference in the odds of unplanned return to the operating room in the open fracture group compared to that in the closed fracture group (OR: 1.20, 95% CI: 0.37 to 3.93, $P = .7633$).

**Table 2.**
Treatment characteristics.

| | Open fracture | | Closed fracture | | *P* value* |
|---|---|---|---|---|---|
| | Freq | % | Freq | % | |
| **Blood product administration, n (%)** | 7 | 23.3% | 0 | 0.0% | 0.0105 |
| **Admission to the PICU, n (%)** | 6 | 20.0% | 3 | 10.0% | 0.4716 |
| **Initial weight-bearing status, n (%)** | | | | | 0.1627 |
| Non–weight bearing | 24 | 80.0% | 23 | 76.7% | |
| Touch-down weight bearing | 4 | 13.3% | 1 | 3.3% | |
| Weight bearing as tolerated | 2 | 6.7% | 6 | 20.0% | |
| **Immobilization duration, n (%)** | | | | | 0.0040 |
| ≤6 weeks | 8 | 26.7% | 20 | 66.7% | |
| >6 weeks | 22 | 73.3% | 10 | 33.3% | |

PICU, pediatric intensive care unit.
* Based on Fisher's exact test.

**Table 3.**
Initial operative procedures.

| Procedure | Open fracture | | Closed fracture | | *P* value* |
|---|---|---|---|---|---|
| | Freq | % | Freq | % | |
| Closed reduction, casting/splinting | 5 | 16.7% | 15 | 50.0% | 0.0127 |
| Elastic intramedullary nail | 3 | 10.0% | 3 | 10.0% | >0.999 |
| External fixator† | 6 | 20% | 0 | 0.0% | 0.0237 |
| Percutaneous pin fixation | 3 | 10.0% | 1 | 3.3% | 0.6120 |
| Plate and screw | 9 | 30.0% | 1 | 3.3% | 0.0122 |
| Rigid nail | 4 | 13.3% | 10 | 33.3% | 0.1253 |

* Based on Fisher's exact test.
† External fixator includes, external fixator, only (n = 1), external fixator, then elastic nail (n = 1), and external fixator, then rigid nail (n = 4).

**Table 4.**
Summary of complications.

| | Open fracture | | Closed fracture | | *P* value |
|---|---|---|---|---|---|
| | Freq | % | Freq | % | |
| **Any complication, n (%)** | 12 | 40.0% | 10 | 33.3% | 0.5925 |
| **Complication type, n (%)*** | | | | | |
| Leg-length discrepancy | 2 | 6.7% | 1 | 3.3% | >0.999 |
| Nonunion | 2 | 6.7% | 1 | 3.3% | >0.999 |
| Loss of reduction | 1 | 3.3% | 2 | 6.7% | >0.999 |
| Neurovascular injury | 1 | 3.3% | 2 | 6.7% | >0.999 |
| Venous thromboembolism | 0 | 0.0% | 0 | 0.0% | >0.999 |
| Infection | 3 | 10.0% | 0 | 0.0% | 0.2373 |
| Compartment syndrome | 3 | 10.0% | 3 | 10.0% | >0.999 |
| Angular deformity | 8 | 26.7% | 3 | 10.0% | 0.1806 |

* *P* values are based on Fisher's exact test.

## Discussion

Our results suggest that in both open and closed tibia fractures, complications are a common occurrence among the pediatric population. The most important finding of this study is a complication rate in the open tibia fracture group of 40% and 33% in the closed group, with the majority of these complications being secondary to AD. Overall, there was no significant difference in complication rate between the two groups, although it should be understood that this is a small pilot study and that additional patients are needed before making definitive conclusions on outcomes.

Both groups showed a 10% rate of CS, consistent with prior studies. Shore et al. reported an 11.6% rate in 212 children with tibial shaft fractures, identifying an age ≥14 years and motor vehicle accidents as independent predictors of CS [6]. Similarly, Grottkau et al. in a study of 133 cases, linked CS development to age and motor vehicle accidents [7]. Their study noted lower leg CS rates of 3.3% in closed fractures than those of 6.2% in open fractures. In our cohort, 4 of the 6 patients with CS were over 14 years of age, and half were involved in motor vehicle collisions. This was representative of our study as half of the patients who developed CS were in motor vehicle collisions. Clinicians should recognize CS as a serious complication requiring evaluation at presentation and throughout hospitalization. Prompt diagnosis and treatment lead to favorable outcomes, as shown by Flynn et al. where 95% of patients reported no lasting pain, sensory loss, or dysfunction after fasciotomies,

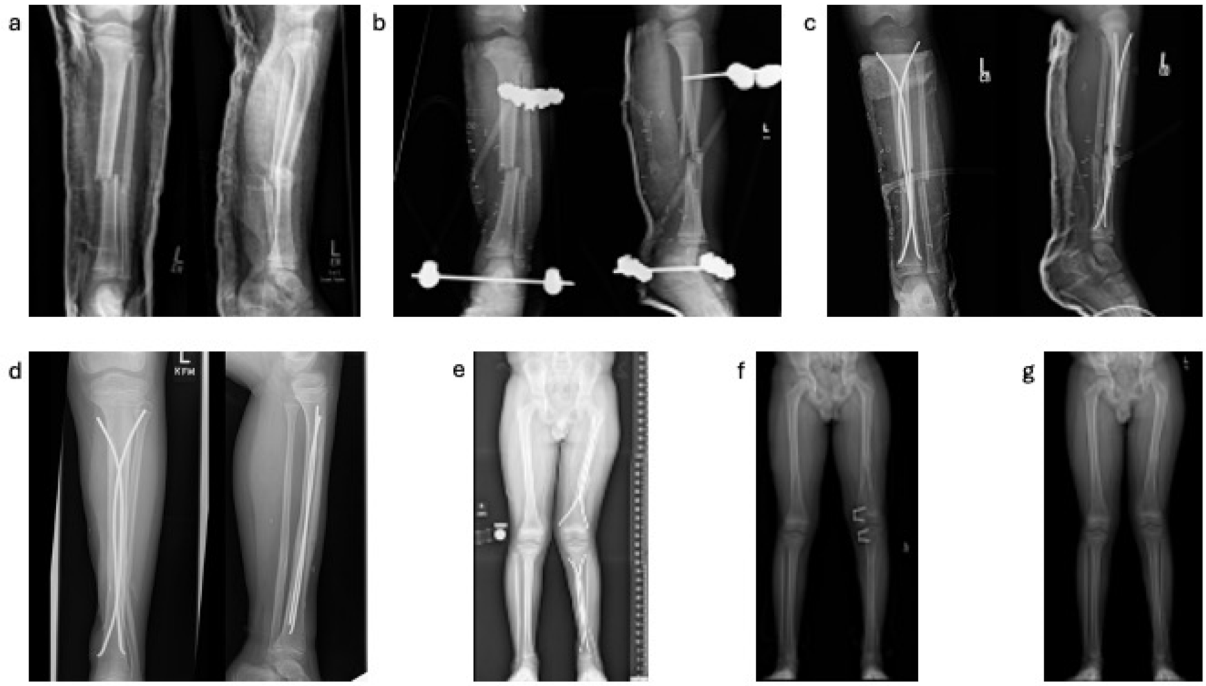


**Figure 1.** Six-year-old male with 3B open tibia fracture (a) treated initially with external fixation (b), followed by conversion to flexible intramedullary nails (c). He healed completely (d) but developed an angular deformity (e) treated with guided growth after hardware removal (f). Most recent films demonstrate mild leg length discrepancy and genu valgum (g).

compared to poorer outcomes when surgery was delayed beyond 48 h [8]. Bae et al. highlighted that while 75% of children exhibited pain and one additional CS symptom, fewer than 40% showed pain plus two symptoms [9]. These studies point to the importance of early recognition and intervention before the progressive sequalae of CS results in permanent harm.

Another important consideration for children with tibia fractures is bony healing. While less common than in the adult population, the nonunion rate (defined as <3 bridging cortices on orthogonal radiographs after 6 months) was 6.7% and 3.3% in the open and closed tibia fracture groups, respectively. These results are similar to that observed in the study by Hope et al. who reviewed the cases of 92 open tibia fractures in children and reported a nonunion rate of 7.5%, with more severe injuries (Gustilo type III) being associated with outcomes of delayed union and nonunion [10]. Thabet et al. investigated the outcomes of tibia shaft fracture in 52 adolescents with a nonunion rate of 3.8% and a delayed union rate of 5.8% [11]. These findings underscore the importance of monitoring fracture healing in pediatric patients as the risk of nonunion remains significant, particularly in severe injuries.

Regarding AD, we defined this as any deformity >5° of varus or valgus, and/or >10° of procurvatum or recurvatum, or deformity significant enough to require an intervention. The present study had an AD rate of 26.7% in the open fracture group and 10% in the closed fracture group. While this did not reach statistical significance, there appears to be a trend toward increased incidence of AD within the open fracture group. We believe that as a pilot study, we are underpowered, and additional investigation is warranted regarding this question. Through further analysis of the patients who had AD, this group comprised mainly patients that underwent initial treatment with external fixation (in the open group) or casting (in the closed group). Patients initially treated in multiplanar external fixators in the open groups were either converted to rigid intramedullary nails or flexible intramedullary nails, except for one patient who was definitively treated with the external fixator, given acceptable alignment in the setting of an extensive soft tissue wound being managed by plastic surgery. Thus, there was no single implant that appeared to be associated with AD in the open group. In a study by Pennock et al. on elastic intramedullary nail fixation compared to tibia open reduction and internal fixation, there was residual AD in 41% of the elastic fixation group versus 15% in the open reduction and internal fixation patient groups [12].

Regarding infection, the current study had an infection rate of 10% within the open fracture group and 0% in the closed fracture group (including both nonoperative and operatively treated patients). Overall, this infection rate is similar to the rate reported by Chen et al. who found that 13.5% of patients had a surgical site infection after sustaining an open tibia fracture [5]. In the study by Thabet et al. there was an infection rate of 11.5%, which was made up of 3 pin-site infections, two superficial infections, and one deep infection [11]. In a study by Skaggs et al., 554 open fractures (not just tibiae) in children were reviewed, and an infection rate of 3% was found [13]. Other studies have reported comparable rates of 5% and 8% for surgical site infections [14,15]. Similarly to AD, statistical significance was not achieved, but the study is likely underpowered to detect this difference between groups.

The current study has several limitations. The main limitation is the study size and the heterogeneity of the study groups, with lack of randomized matching. Due to these limitations, we were unable to determine complication rates based on fixation methods between the open and closed groups or confirm that study groups were identical in every way except for the open nature. Secondarily, the true rate of long-term complications such as LLD and nonunion are limited by follow-up, given that this study was performed at a quaternary referral center covering multistate area, thus complete follow-up could not be obtained in all patients. The retrospective nature also restricts our conclusions as patients were treated by multiple pediatric orthopaedic surgeons; thus, treatment methods may have been skewed by injury severity, surgeon preferences, and prior training.

Further research is needed to determine if there are superior outcomes with certain treatment modalities, such as closed reduction and casting, flexible or rigid intramedullary nails, plate and screw constructs, and external fixation. Additionally, further studies should incorporate patient-reported outcomes as this would enable providers to quantitatively track patient progress and further understand prognosis in terms of pain, return to activity, and the psychological impact of injury.

This pilot study utilizing a matched cohort found no significant difference in complication rates between open and closed pediatric tibia fractures, though complications were prevalent in both groups. These findings emphasize the importance of maintaining a high clinical suspicion for CS and thoroughly counseling patients on the risks of AD. While no definitive differences were observed, trends in complications suggest that further investigation is warranted to clarify potential difference between open and closed fractures. Larger, prospective studies are essential to better define patient outcomes and guide clinical management.

## Additional links

- POSNAcademy: Evaluation and Management of Pediatric Tibial Shaft Fractures
- POSNAcademy: Preferred Technique: Flexible Nailing Tibial Shaft Fracture

## Consent for publication

The author(s) declare that no patient consent was necessary as no images or identifying information are included in the article.

## Author contributions

**Dylan R. Rakowski:** Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation. **Brennan Roper:** Writing – original draft, Resources, Data curation, Conceptualization. **Sarah R. Purtell:** Writing – original draft, Resources, Data curation. **Patrick Carry:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation. **Julia S. Sanders:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

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## Declarations of competing interests

Senior author Julia S. Sanders is a consultant and receives royalties from OrthoPediatrics, Corp. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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