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Original Research

# Outcomes of Suprapatellar Intramedullary Nail Fixation of Tibial Shaft Fractures in Skeletally Immature Patients☆

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A R T I C L E I N F O

*Keywords:*
Tibia shaft fractures
Open physis
Intramedullary rigid nail
Suprapatellar approach
Malunion

A B S T R A C T

*Background:* Tibial shaft fractures in children require individualized treatment approaches, including elastic nails, plates and screws, intramedullary rigid nails (IMN), and external fixators, with selection based on fracture characteristics and patient factors. IMN risks damaging the physis, but can provide enhanced stability and immediate weight bearing. While both infrapatellar and suprapatellar approaches exist for IMN placement, studies in adults have demonstrated that the suprapatellar approach offers higher patient satisfaction, less anterior knee pain, and lower radiation exposure. However, there is a lack of data on IMN for pediatric tibial fractures.

*Methods:* This single-center, retrospective cohort study analyzed patients aged 11–16 with open proximal tibia physis and tibial shaft fractures treated with IMN via the suprapatellar approach from January 2016 to October 2023. Demographic, fracture, and operative data were collected, and proximal tibial angles were measured. Follow-up radiographs were evaluated for tibial growth and alignment, with malunion defined as over 5 degrees of angular deformity.

*Results:* Thirty-five patients aged 11 to 16 (mean 14.7 years, SD 1.1) met the inclusion criteria. Males comprised 60%; the average follow-up was 12.4 months. Most fractures (74%, 26/35) were closed. The most common (57%) fracture pattern was OA42A1-3. Fracture union occurred by 9 weeks in 79% of cases. The mechanical Medial Proximal Tibial Angle (mMPTA, range 85–90 degrees) and Posterior Proximal Tibial Angle (PPTA, range 77–84 degrees) were normal in all pre-operative patients; there were no statistically significant changes in mMPTA and PPTA over the follow-up period. The reported Visual Analog Scale pain scale averaged 1.87 at the final follow-up. Most patients reported return to full activities (87%), with the operative leg comparable to the contralateral leg in 78% of cases.

*Conclusions:* Our findings demonstrated that suprapatellar IMN insertion leads to low pain scores and good function in short-term follow-up for adolescent patients treated for tibial shaft fractures. No proximal tibia growth disturbance was detected. Further prospective studies are warranted.

*Key Concepts:*
(1) The suprapatellar approach appears to be safe for adolescent tibial nailing.
(2) Growth disturbance was not encountered in this carefully selected patient group.
(3) Radiographic tibial fracture union was achieved in call patients in this cohort.

*Level of Evidence:* Level IV

☆ This study was performed at the University of Tennessee Health Science Center–Campbell Clinic, Department of Orthopaedic Surgery and Biomedical Engineering.

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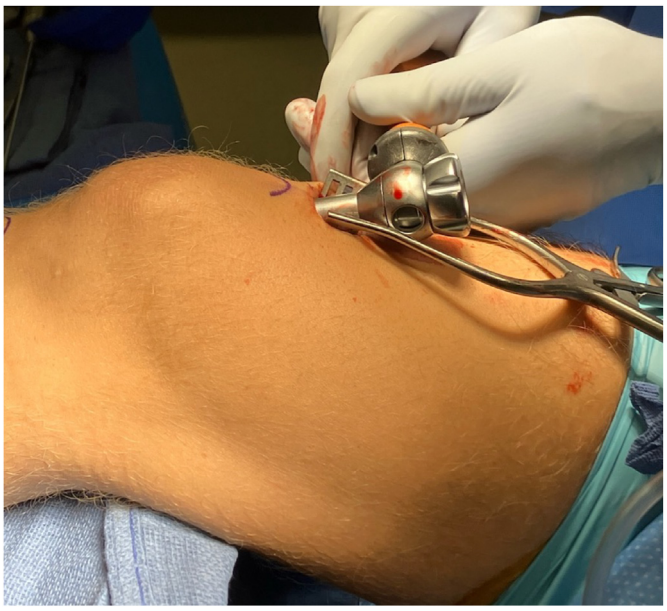

**Figure 1.** Suprapatellar approach in a 14-year-old patient with tibia shaft fracture 42A2.

## Introduction

Tibial shaft fractures represent approximately 15% of all pediatric long-bone injuries, with significant implications for mobility and function during skeletal development [1]. According to Moon et al.'s 2016 study, the annual incidence of these fractures is approximately 137 per 10,000, with adolescent males showing the highest occurrence rates [2]. Treatment strategies range from conservative management to surgical intervention, depending on fracture characteristics and patient factors. Among surgical options, elastic nails and plates traditionally predominate due to their ability to spare the growth plate during insertion, minimizing the risk of physis damage [3]. However, these methods present limitations, including weight-bearing restrictions and stability issues, particularly with comminuted fractures or in adolescent patients [4].

Intramedullary rigid nailing (IMN) has emerged as a promising method for treating displaced or comminuted tibial diaphyseal fractures. It offers immediate weight-bearing capability, enhanced stability, and reduced soft tissue damage due to less surgical dissection when compared with plates [5]. Court-Brown allowed weight bearing as soon as the patient could tolerate it, highlighting the advantages of using IMN over elastic nails and plates [5]. Although IMN has been well-established in adults [6], there has been little research on its application in adolescents whose physes remain open [7].

The primary concern with IMN in skeletally immature patients centers on the risk of physeal damage and subsequent growth

| **Pain** |
|---|
| Has your child complained of knee pain after surgery? (If "yes," go to the next question, if "no" go to function questions)<br><br>On a scale of 0-10, where 0 is no pain and 10 is the worst, what is your child's (your) current pain level in their (your) knee? |
| Has your child (you) had pain in the front part of the knee since having surgery?<br>If "yes":<br>How long after surgery did the pain start? (days, weeks, months, etc.)<br>How long did that pain continue? |
| **Function** |
| Basic<br>*For each of the following questions, please answer with a "yes" or "no."* |
| Is your child (are you) able to walk without assistance? |
| Is your child (are you) able to run? |
| Is your child (are you) able to get down on both knees? |
| Is your child (are you) able to squat? |
| Is your child (are you) still able to do the activities they (you) did prior to the injury? |
| Focused |
| If perfect is 100% and 0 is not working at all, how well does the knee work? |
| Does the knee work as well as the other knee? Y/N |
| **Results of Procedure** |
| Overall, how satisfied is your child (are you) with the surgery?<br><br>1 2 3 4 5 6 7 8 9 10 |
| Has your child (have you) had to visit another provider (such as a pediatrician, general practitioner, nurse practitioner, or chiropractor) for knee pain? Y/N |

**Figure 2.** Patients responded to this questionnaire by telephone.

disturbance [5]. Additionally, anterior knee pain and functional limitations associated with infrapatellar and suprapatellar approaches remain debated [8]. Recent comparisons of the outcomes of suprapatellar and infrapatellar surgical approaches for IMN in tibial fractures have yielded promising results [9]. While the infrapatellar approach was once preferred, recent evidence favors the suprapatellar technique, given higher patient satisfaction [8,10]. Proposed advantages to suprapatellar nailing include easier intraoperative imaging compared to infrapatellar nails since the leg can be held in a semi-extended position rather than a hyperflexed position. Ease of imaging may facilitate fracture reduction as well as nail placement. However, those studies were conducted in adults, and there is little information assessing the results of IMN in pediatric tibial fractures, its impact on proximal tibial alignment, and the role of the suprapatellar approach in adolescent patients with open growth plates.

To address this knowledge gap, we conducted a retrospective analysis to evaluate whether the suprapatellar approach is a reliable surgical procedure in patients with open proximal tibial physis, assess postoperative functionality and pain outcomes in pediatric patients, and determine growth arrest or significant proximal tibia alignment changes after rigid rod insertion through a residual proximal growing physis in skeletally immature patients.

## Materials and methods

This retrospective cohort study was approved by the Institutional Review Board of the University of Tennessee Health Science Center (#23-09734-XP**)**. It was conducted at 1 institution, and included patients ages 11–16 with tibia shaft fractures who underwent IMN through the suprapatellar approach (Fig. 1). Inclusion criteria involved an open proximal tibial physis at the time of surgery. The surgeons established their criteria for treating diaphyseal tibia fractures and their preferences for the SP approach based on the patient's age, maturity, fracture pattern, and ultimately surgeon discretion as there is little evidence for guidance. We analyzed consecutive cases from January 2016 to October 2023.

A sample size calculation determined that an analysis of 29 patients would provide 80% power to detect a 3-degree difference in Medial Proximal Tibia Angle (mMPTA) and Posterior Proximal Tibia Angle (PPTA) with $\alpha = 0.05$. REDCap [11,12] (Vanderbilt University; Nashville, Tennessee) was used to collect demographic parameters, including age, gender, ethnicity, and surgical date. Fracture type, location, and AO classification were documented. Full-length anteroposterior and lateral tibia X-rays confirmed open physis and measurements of the proximal tibia, including mMPTA and PPTA, according to the principles of deformity correction around the knee previously established [13]. Surgical time, estimated blood loss, type of reduction, and implant use were recorded.

All patients underwent reamed IMN fixation through the proximal tibia physis using the suprapatellar approach, as previously outlined [4,14]. We initiated weight-bearing based on individual tolerance levels and began physical therapy postoperatively, with treatment duration tailored to each patient's progress. Patients were followed clinically for a minimum of 1 year (when radiographs were taken) or until physeal closure, documenting time to radiographic union, complications, functional outcomes, and pain scores. A standardized 10-question instrument, created previously for the research group and approved by the IRB (Fig. 2), was administered via telephone follow-up. The questionnaire assessed pain/discomfort, function, and return to normal activities.

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Postoperative radiographs included standardized anteroposterior and lateral views of the tibia to evaluate varus/valgus alignment, recurvatum, or any indicators of partial growth arrest (Fig. 3). To minimize interobserver variability, 1 senior author performed all measurements. Malunion was defined as greater than 5 degrees of angular deformity.

Statistical analysis was performed using SPSS (Version 29, Armonk, NY: IBM Corp). Continuous variables were reported as means with

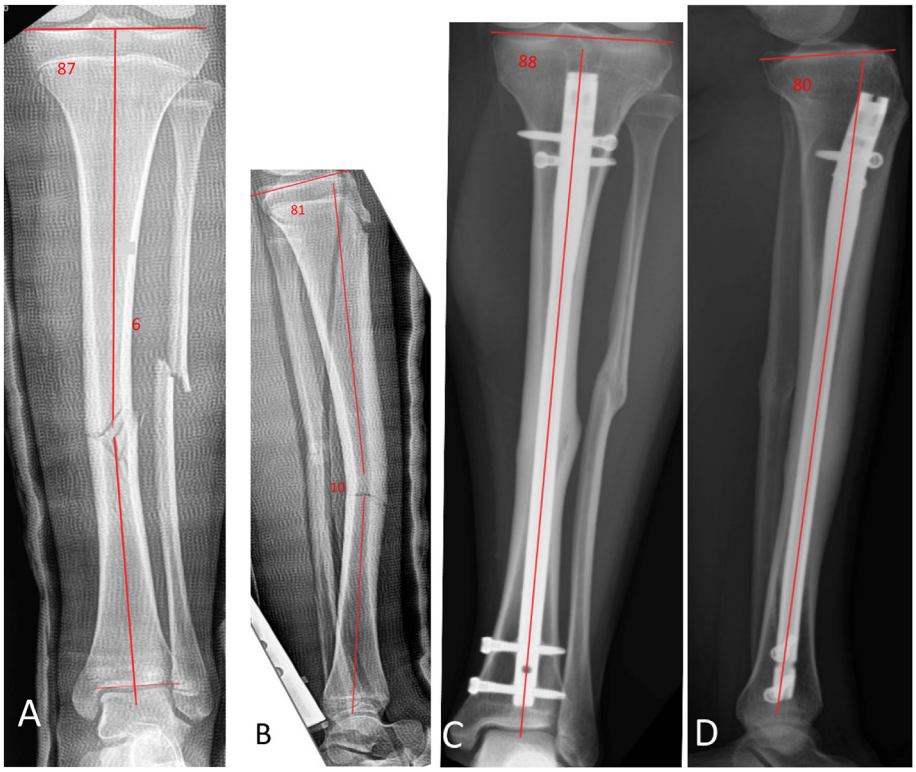


**Figure 3.** This 13-year-old female had a closed midshaft tibia fracture AO 42B3. A: pre-operative anteroposterior view with MPTA 87 and 6 degrees valgus; B: pre-operative lateral view with PPTA 81 and 10 degrees procurvatum; C: post-operative anteroposterior view with MPTA 88 (closed physis); D: post-operative lateral view with PPTA 80 (closed physis).

standard deviations (SD) and 95% confidence intervals (CI). Categorical variables were presented as counts and percentages. We used paired *t*-tests to compare pre- and postoperative radiographic measurements and chi-square tests for categorical variables. Statistical significance was set at $P < .05$.

## Results

A total of 35 patients ages 11 to 16 (mean 14.7 years, SD 1.1) met the inclusion criteria. Male patients comprised 60% (21/35) with a mean follow-up of 12.4 months. Most fractures (26/35; 74%) were closed. The most common fracture pattern was OA42A1-3 (20/35, 57%). Fracture union occurred within 9 weeks in 79% of cases (Table 1). About 31% (11/35) of the patients had at least 2 years of remaining growth according to chronological age (reference values - female 14, male 16) Based on the injury radiographs, we retrospectively determined the Modified Fels skeletal age for female patients was 13.35 (range 11.63–14.56) and for male patients was 14.87 (range 13.78–16.28).

The mechanical Medial Proximal Tibial Angle (mMPTA 85–90 degrees) and Posterior Proximal Tibial Angle (PPTA 77–84 degrees) were normal in all pre-operative patients (mean 87.7 and 79.00); there were no statistically significant changes in mMPTA and PPTA over the follow-up period (mean 87.9 and 78.7) (Table 2).

Three patients experienced complications; 2 of them developed non-union consequences of open fracture type III (Gustilo-Anderson) secondary to gunshot wounds requiring secondary procedures to achieve bone union, and 1 developed a surgical site infection that was resolved with antibiotic therapy.

**Table 1**
Tibia shaft fractures characteristics/classifications.

| | Frequency | Percent |
|---|---|---|
| **Location** | | |
| Distal shaft | 19 | 54.29 |
| Midshaft | 12 | 34.29 |
| Proximal shaft | 4 | 11.43 |
| **Type** | | |
| Closed fracture | 26 | 74.29 |
| Open fracture | 9 | 25.71 |
| **Open** | | |
| Type 1 | 1 | 11.11 |
| Type 2 | 1 | 11.11 |
| Type 3 (Gustilo-Anderson) | 7 | 77.78 |
| **Anatomic classification** | | |
| Comminute | 14 | 40.00 |
| Oblique | 12 | 34.29 |
| Spiral | 4 | 11.43 |
| Transverse | 5 | 14.29 |
| **AO - classification** | | |
| 42A1-2-3 | 20 | 57.14 |
| 42B1-2-3 | 6 | 17.14 |
| 42C1-2-3 | 9 | 25.71 |
| **Healing** | | |
| 12 wk | 14 | 41.18 |
| 8 wk | 5 | 14.71 |
| 9 wk | 8 | 23.53 |
| >12 wk | 7 | 20.59 |

**Table 2**
Overall aspect of patients and measurements.

| Variable | N | Mean | Std Dev | Minimum | Maximum |
|---|---|---|---|---|---|
| Age | 35 | 14.70 | 1.07 | 11.73 | 16.05 |
| Body mass index | 20 | 25.78 | 6.40 | 16.48 | 39.21 |
| FU - months | 35 | 12.37 | 8.92 | 0.69 | 39.52 |
| EBL - mL | 34 | 130.29 | 93.43 | 20.00 | 400.00 |
| MPTA - pre | 35 | 87.71 | 1.22 | 86.00 | 91.00 |
| PPTA - pre | 35 | 79.00 | 1.83 | 76.00 | 82.00 |
| MPTA - post | 35 | 87.94 | 1.34 | 85.00 | 90.00 |
| PPTA - post | 35 | 78.74 | 1.77 | 76.00 | 82.00 |
| VAS | 30 | 1.70 | 2.54 | 0 | 10.00 |
| Satisfaction | 30 | 9.56 | 0.85 | 7.00 | 10.00 |

*FU - months, follow-up in months; EBL-mL, estimated blood loss in milliliters during surgical procedure; MPTA - pre, medial proximal tibia angle - pre-operative; PPTA-pre, posterior proximal tibia angle - pre-operative; MPTA - post, medial proximal tibia angle - post-operative; PPTA-post, posterior proximal tibia angle - post-operative; Std Dev, standard deviation; VAS, Visual Analog Scale for pain.*

Thirty patients (86%) completed the follow-up questionnaire. The reported VAS pain scale (0–10) averaged 1.87 (SD 2.6, 95% CI 0.9–2.8) at the final follow-up. Most patients (26/30, 87%) reported returning to full activities, with the operative leg functioning comparably to the contralateral leg in 77% of cases (23/30). Overall satisfaction on a scale of 0–10 was 9.56 (SD 0.9, 95% CI 9.2–9.9).

## Discussion

The management of tibial shaft fractures in skeletally immature patients remains challenging, with concerns regarding physeal damage from IMN. While multiple surgical options, such as plates, elastic nails, and conservative management, exist, the optimal treatment strategy remains debated. Adult literature demonstrates superior outcomes with IMN compared with non-operative management for tibial shaft fractures, including lower non-union rates and improved function [15,16]. However, limited data exist regarding outcomes and physeal effects in adolescent patients. Our study addressed this knowledge gap by evaluating the safety and efficacy of IMN in patients with open physes.

Various surgical approaches have been developed to address complications associated with IMN, particularly anterior knee pain, and reduction difficulties [8]. The suprapatellar approach has gained popularity in tibia shaft fracture treatment. Despite numerous reports validating its efficacy, safety, and reduced incidence of anterior knee pain in adults, its use in skeletally immature patients remains poorly documented [17–19].

Our findings demonstrated that suprapatellar IMN in patients with open proximal tibial physes resulted in high patient satisfaction (mean 9.56/10), no significant radiographic evidence of physeal damage, maintained tibial alignment without late changes, and no clinical evidence of growth disturbance at one-year follow-up. These results suggested minimal soft tissue and physeal trauma. These results were consistent with those reported by Court-Brown et al., who used the infrapatellar approach [5].

Court-Brown et al. documented a 38% incidence of knee pain, particularly when patients were kneeling or running, which aligns with our study's findings of a 43% incidence. Despite these reports of mild knee pain, 87% of our patients indicated they could resume full activities, with 78% noting the operative leg was as functional as the contralateral leg. Jones et al. compared adult patients treated with suprapatellar and infrapatellar tibial nails and found no significant difference in anterior knee pain between the 2 groups, reporting 40% knee pain for the suprapatellar approach and 55% for the infrapatellar [20]. Keating et al. also noted a 57% incidence of anterior knee pain with the infrapatellar

approach, particularly when the nail was inserted through the patella tendon, concluding that knee pain post-tibial nailing is multifactorial [21].

Our study had some limitations. We used a non-validated questionnaire for pain assessment, and knee pain was evaluated subjectively. Our relatively small sample size of 35 patients was another limitation, as was the study's retrospective design and the single-center experience. Additionally, physes were determined to be open or closed instead of being further subdivided by the growth remaining. We acknowledge that suprapatellar nailing in patients under 10 years old or a large amount of growth remaining may result in an increased risk to the physis. However, our study analyzed the effects of IMN using a suprapatellar approach in a cohort with open growth plates and patients older than age 10.

Our findings demonstrated no statistically significant changes in pre-operative and post-operative mMPTA and PPTA, suggesting no disruption to the growth plate from the suprapatellar approach in patients between 11 and 16 years old. However, using alternative techniques in adolescents with significant growth potential remains reasonable. Despite some complaints of knee pain, our data indicated that patients could return to full activities, suggesting that IMN using the suprapatellar approach is a viable treatment for pediatric patients. Additional research is needed, including prospective, multicenter studies with larger cohorts that directly compare suprapatellar approaches with infrapatellar approaches in children, as well as analysis of angular deformities and limb length discrepancy.

## Additional links

- **Journal of Pediatric Orthopaedics:** Standardized In-harness Ultrasound Protocol Improves Success Rate of Brace Treatment for Dislocated Hips

## Ethics approval and consent

This study was approved by the Institutional Review Board of the University of Tennessee Health Science Center (#23-09734-XP).

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

## Author contributions

**Carlos D. Pargas-Colina:** Writing – original draft, Visualization, Project administration, Methodology, Investigation, Conceptualization. **Tori J. Coble:** Methodology, Investigation. **Sara E. Davis:** Methodology, Investigation. **David D. Spence:** Writing – review & editing, Supervision. **Jonathan K. Rowland:** Writing – review & editing, Project administration, Methodology. **Derek M. Kelly:** Writing – review & editing, Supervision. **Benjamin W. Sheffer:** Writing – review & editing, Supervision.

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## Declaration of competing interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: David D. Spence reports a relationship with OrthoPediatrics that includes: funding grants. Derek M. Kelly reports a relationship with OrthoPediatrics that includes: consulting or advisory. David D. Spence reports a relationship with Pediatric Orthopaedic Society of North America that includes: board membership. Derek M. Kelly reports a relationship with Pediatric Orthopaedic Society of North America that includes: board membership. Drs. Spence, Kelly and Sheffer receive publishing royalties from Elsevier. 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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