

Safety of Rigid Intramedullary Nailing in Skeletally Immature Tibia Fractures—Risk of Growth Disturbance is Not Zero

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Background: Rigid intramedullary nail (RIMN) fixation is the standard treatment for tibial shaft fractures in adult patients. Recently, this technique has gained favor for usage in skeletally immature patients despite the required violation of the proximal tibial physis. The goal of this paper was to determine whether growth disturbance with resultant deformity could occur after RIMN treatment in patients with open physes.

Methods: A retrospective radiographic review was performed of all patients undergoing RIMN placement for acute tibia fractures at 3 level I Pediatric Trauma Centers between January 2012 and June 2022. Patients with an open proximal tibial physis and radiographic follow-up of at least 6 months were included. Intraoperative radiographs were analyzed to determine the immediate postoperative medial proximal tibial angle (MPTA) and posterior proximal tibial angle (PPTA), as well as the skeletal bone age utilizing the Abbreviated Modified Fels Knee System. The final radiographs were assessed for changes in the MPTA and PPTA.

Results: A total of 43 patients with an average chronological age of 14.5 ± 1.3 years and skeletal age of 14.3 ± 1.0 years met the inclusion criteria. There were a total of 37 males and 6 females with an average follow-up of 18.3 ± 12.7 months. The average change in the MPTA was 1.0 ± 0.9 degrees ($P = 0.566$) with no patients having a change > 3 degrees. The average change in the PPTA was a 2.3 ± 3.8 degrees ($P = 0.007$). Two patients progressed to a recurvatum deformity with 99 and 104 degrees of PPTA. With these 2 patients excluded, the average change in slope remained significant at 1.5 ± 1.6 degrees ($P = 0.019$).

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Conclusion: The use of RIMN in skeletally immature adolescents can lead to a statistically significant, but most likely clinically insignificant change in the posterior slope. Yet, cases of recurvatum deformity can occur in the setting of this procedure. Though our series confirms RIMN are generally safe in treating tibial shaft fractures in skeletally immature adolescents, 2 cases demonstrate that a true risk of a subsequent sagittal deformity does exist.

Level of Evidence: Level IV—retrospective case series.

Key Words: tibia fracture, intramedullary nail fixation, physeal arrest, procurvatum.

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Tibial shaft fractures represent the second most common long bone fracture in children, trailing only forearm fractures. The peak age of incidence of tibia fractures is 10 to 14 years.¹ Most pediatric tibia fractures can be treated with nonoperative management through closed reduction and casting. Cast treatment of tibial fractures in adolescent patients proves to be more challenging with a frequent requirement of cast wedging and prolonged immobilization of > 3 months.² Inability to maintain acceptable alignment with casting occurs more commonly in adolescent patients and fractures occurring secondary to higher energy mechanisms.^{2,3} For these reasons, there has been an increasing interest in the surgical treatment of tibia fractures in adolescent patients.⁴

Typically, surgical treatment of pediatric tibia fractures includes open reduction internal fixation (ORIF) with plate and screw fixation or with flexible nail to avoid possible injury to the proximal physis. Rigid intramedullary nailing (RIMN) is the preferred treatment of skeletally mature patients as it allows stable fixation in a minimally invasive manner. While this is the most common technique for adult tibia fractures, its usage is cautioned in skeletally immature patients as it requires reaming across the anterior proximal tibial physis. Injury to this portion of the physis could theoretically result in a physeal injury with a resulting growth disturbance leading to a recurvatum deformity. In cases of excessive deformity, symptoms can arise leading to the need for surgical correction.^{5,6}

As the interest in RIMN in skeletally immature patients increases, the safety of the procedure regarding potential growth disturbance must be determined. The purpose was to explore the rate of physal disturbance with subsequent deformity after RIMN treatment of skeletally immature patients. Our null-hypothesis was that no clinically significant deformity would occur after RIMN treatment in patients with open physes.

METHODS

Patient Selection

After obtaining Institutional Review Board approval from each institution, a retrospective review of all patients with tibia fractures treated at 3 level I pediatric trauma centers based on the procedural code CPT (Current Procedural Terminology, American Medical Association, Chicago, IL) 27759 was performed. The search included patients treated between January 1, 2012, and June 30, 2022. Tibia fractures treated with rigid intramedullary nail fixation through standard antegrade technique through the proximal tibial physis were included. All included patients had their primary RIMN treatment performed at one of the 3 sites and had at least 6 months of radiographic follow-up. Surgeries were performed by pediatric-fellowship-trained orthopaedic surgeons or current pediatric orthopaedic surgery fellows.

Radiographic Evaluation

Injury radiographs were evaluated to determine the skeletal age based on the Abbreviated Modified Fels knee system.⁷ Injury films were also analyzed to determine the medial proximal tibial angle (MPTA) and posterior proximal tibia angle (PPTA) at the time of surgery (Fig. 1).⁸ The position of the proximal end nail was recorded as above or below the physis at both the time of initial implantation and at final radiographic follow-up. Final radiographs were analyzed to determine the final PPTA and MPTA.

Statistical Analysis

Basic descriptive statistics are reported. Continuous data were evaluated with the Levene test of homogeneity of variances. Changes in MPTA and PPTA measured intraoperatively and at final follow-up were evaluated with the Wilcoxon signed-ranks test. No a priori power analysis was performed. Statistical analysis was conducted using IBM SPSS Statistics (version 29, IBM Corp, Armonk, NY). Statistical significance was defined as $P < 0.05$.

RESULTS

Forty-three patients met the inclusion criteria and consisted of 37 males and 6 females with an average follow-up of 18.3 ± 12.7 months (range: 6 to 49 mo). The mean chronological age was 14.5 ± 1.3 years (range: 11.2 to 17.1 y) with a mean skeletal age of 14.3 ± 1.0 years (range: 11.6 to 16.7 y). Six nails were implanted with the most proximal extent of the nail distal to the proximal

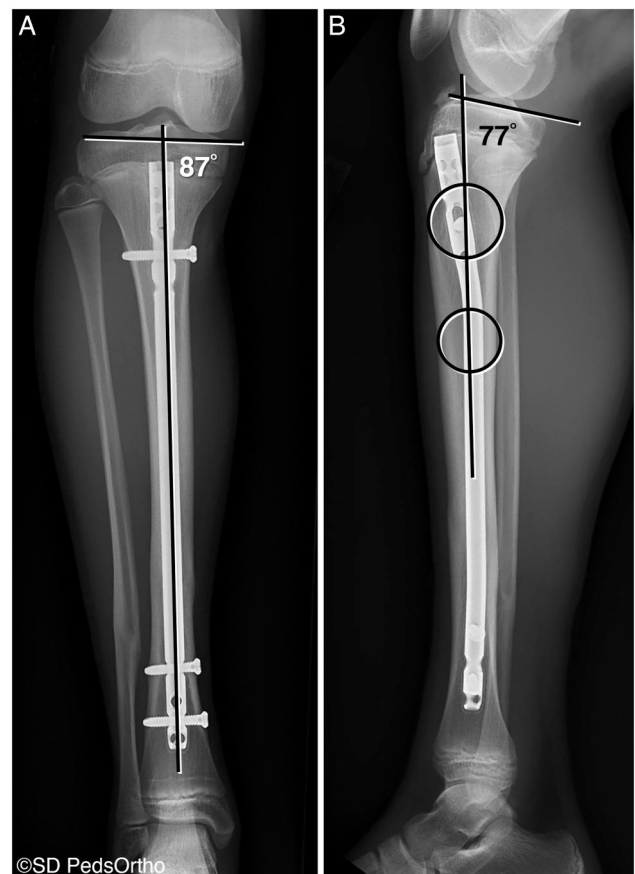


FIGURE 1. Technique for assessment of MPTA (A) and PPTA (B).

tibial physis while 37 nails were placed above the physis. Three patients had endcaps placed to ensure the nail was proximal to the physis.

The average change in the MPTA was 1.0 ± 0.9 degrees ($P = 0.566$) with no patients having a change > 3 degrees. The average change in the PPTA was 2.3 ± 3.8 degrees ($P = 0.007$). Two patients progressed to a true recurvatum deformity with 99 and 104 degrees PPTA, which represents a 5% rate of physal disturbance with subsequent deformity. With these 2 patients excluded, the average change in slope remained statistically, but unlikely clinically significant at 1.5 ± 1.6 degrees ($P = 0.019$). All other patients maintain a PPTA within normal limits (PPTA ≤ 84 degrees).

Details of Patients Progressing to Recurvatum

Patient 1's radiographic sequence can be seen in Figure 2. This is a male with a chronological age of 13.4 years and a modified Fels age of 13.1 years. He underwent RIMN through an infrapatellar approach utilizing a 12 mm entry reamer and placement of a 10 mm intramedullary nail. The patient experienced successful fracture healing and returned to all activities. The patient returned secondary to discomfort associated with the



FIGURE 2. (A) A 13.4-year-old male with a tibial shaft fracture and preoperative PPTA 83°. (B) 1-month follow-up reveals early healing and appropriate alignment. The nail was seated distal to the physal scar at the time of surgery (C) A 2.5-year follow-up demonstrates a subsequent procurvatum deformity (PPTA 104°).

proximal interlocking screws 2.5 years after surgery. A recurvatum deformity was identified radiographically with a 21-degree change in PPTA. The patient's only complaint was pain at the proximal screw heads, and therefore, hardware removal was performed without correction of the deformity.

Patient 2's radiographic sequence can be seen in Figure 3. This is a 13.2-year-old male with a modified Fels age of 12.5 years who was also found to have developed a recurvatum deformity with subsequent follow-up. He underwent RIMN fixation through a suprapatellar approach. A 12 mm entry reamer was used and an 11 mm rigid nail was placed. He experienced an uneventful postoperative course and demonstrated successful healing of the fracture before being lost to follow-up 5 months after surgery. Radiographs at 5 months revealed no obvious growth disturbance. The patient subsequently presented 2 years after the original procedure secondary to a patellofemoral dislocation. Injury radiographs revealed a 14-degree change in the tibial slope from radiographs at the time of RIMN

treatment. The patient reported that he had returned to sports without symptoms before the new injury. The patellofemoral dislocation was treated successfully with nonoperative management. The proximal screws were removed due to prominence; however, no treatment was performed for the recurvatum deformity.

DISCUSSION

Multiple studies have identified that the rate of surgical treatment of pediatric tibia fractures continues to increase.^{9,10} More recently, publications evaluating RIMN in skeletally immature patients have begun to appear and demonstrate no resultant growth abnormalities.^{11,12} The primary objective of this investigation was to determine the safety of rigid intramedullary nail placement across an open proximal tibial physis for treatment of a tibial shaft fracture. With violation of the physis, at least a theoretical risk of subsequent physal disturbance exists. To our knowledge, this is the first study to demonstrate cases of physal

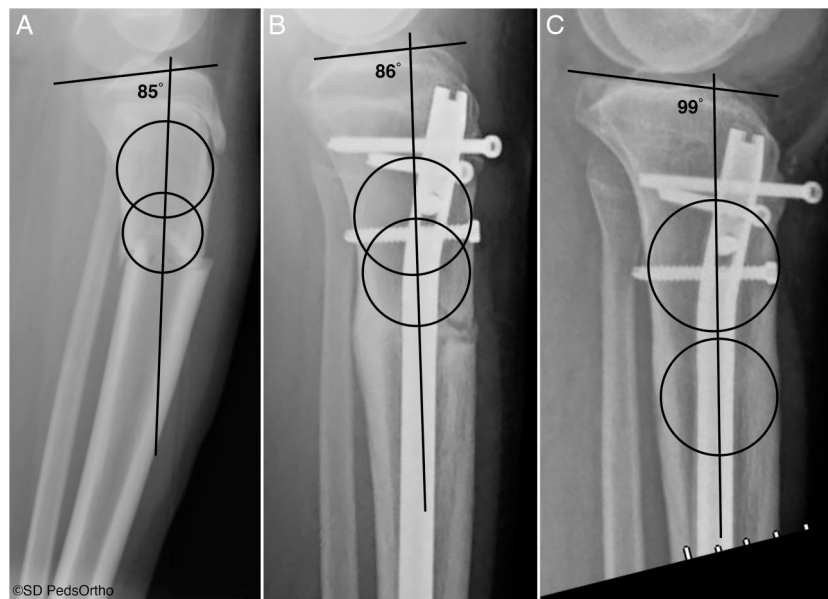


FIGURE 3. (A) 13.2-year-old male with an upper third diaphyseal tibial fracture and a preoperative PPTA of 85°. (B). Five months after RIMN, early healing is seen, and no obvious growth disturbance. (C). Two-year follow-up demonstrates a growth disturbance with resulting sagittal plane deformity (PPTA 99°). The proximal end of the IMN remains above the physal scar.

disturbance and subsequent deformity secondary to RIMN in skeletally immature patients. As this procedure has increased in popularity over the last few years, it is vital that the surgeon understands the associated risks of growth disturbance to appropriately manage and counsel patients. Although the true incidence and natural history of genu recurvatum is not known, patients can present with symptoms of pain, weakness, instability and possible ligamentous injury, or altered knee range of motion requiring surgical treatment.^{5,6,13,14}

Court-Brown et al¹⁵ published a series of 36 adolescent patients treated with RIMN. The authors reported no radiographic evidence of significant growth arrest but does not report how this was assessed. A bone age was not reported but mean chronological age was 15 years in males and 14 years in females.¹⁵ MRI evaluation of the knee demonstrates that the proximal tibial physis is closed centrally at a mean age of 16 years in males and 14 years in females.^{16,17} This cohort would therefore consist of a population of patients with anticipated minimal growth remaining.

More recently, 2 additional studies have been published assessing RIMN in skeletally immature patients. Koshinski and colleagues evaluated 37 patients with open physes undergoing RIMN for tibial shaft fractures. Twenty-two of these patients had follow-up radiographs of at least 6 months and demonstrated no change in the tibial slope.¹² It is important to note that almost 60% of the group was classified as tibial tubercle ossification stage 3, which indicates that the tibial tubercle has fused to the metaphysis and has only a small inferior notch remaining. This would suggest that minimal growth remained in the majority of the patients evaluated.

In addition, Pargas-Colina and colleagues reported on a series of skeletally immature patients undergoing RIMN through the suprapatellar approach specifically. A total of 35 patients were included and underwent radiographic evaluation for deformity based on evaluation of PPTA and MPTA measurements on final radiographs. No cases of apparent growth disturbance were identified, with a mean follow-up of just over 12 months, ranging from 0.69 to 39.52 months.

In this current study, we similarly found no significant change in the coronal plane based on a radiologic assessment of the MPTA. With a path across the physis located at a central position in the coronal plane, it would be anticipated to have a lower likelihood of physal disturbance. Much of the concern for risk is associated with injury to the anterior portion of the physis producing a sagittal plane deformity. Asymmetric growth with maintained posterior growth and slowed anterior growth would be anticipated to decrease tibial slope or increase the PPTA (Fig. 4).¹⁸ Although this study is the first to identify a statistically significant change in the sagittal alignment, the average decrease of 2.3 degrees is not anticipated to be clinically significant as all but 2 patients possessed a final PPTA within normal limits.

The importance of our findings is demonstrated in identifying 2 cases of iatrogenic physal disturbance and resulting deformity secondary to RIMN across an open physis. Although the possibility of a subsequent deformity is often discussed, no case reports to date have demonstrated a secondary recurvatum deformity from RIMN. In our series of 43 patients across 3 institutions, we identified 2 such cases, for a rate of 5%. It is important



FIGURE 4. MRI performed 9 months after RIMN for secondary to a new injury. Arrow identifies an asymmetric Park-Harris growth resumption line approximating the anterior tibial physis at the location of the intramedullary nail. The obliquity of the line indicates less growth anteriorly compared with growth posteriorly along the physis.

to note that the proximal portion of the nail in one patient who went on to develop recurvatum was implanted distal to the physis, leaving a physeal gap, which is typically recommended against. Physeal gaps have been shown to lead to physeal bars in animal studies.¹⁹ However, recurvatum also developed in a patient whose nail was noted to be left above the physis and all interlocking screws were placed beneath the physis. In addition, the proximal nail maintains its position above the physis at completion of growth. The concern remains that the requirement of reaming across this proximal tibial physis can lead to irreversible injury to the physis. Animal studies have suggested that violation of 7%²⁰ or 8%²¹ can lead to significant growth inhibition. Kha et al. found that reamers of 12 mm violated on average 3.5% to 5.2%, with a maximum of 6.3% in one skeletally immature subject²². This would suggest that large reamers used in an imperfect manner with excessive motion during entry and removal could exceed the 7% threshold that is felt to be critical.

The study possesses limitations germane to all retrospective studies including data collection being limited to data available in the medical record, lack of standardized follow-up, lack of patient reported outcomes, and no specific protocol to guide indications for tibial RIMN and at what age to consider the procedure. In addition, standing long leg radiographs were not consistently obtained and therefore limb length inequalities could exist that were not found in the chart review. Our study, which is the largest study to date evaluating RIMN in skeletally immature patients, includes surgeons across 3 institutions with varying years of experience representing a heterogeneous approach and decision making to adolescent tibia fractures.

In conclusion, this study supports early reports that minimal or no significant change in sagittal or coronal plane alignment is anticipated in most adolescent patients undergoing RIMN fixation for treatment of a fracture. However, the findings of this study are critical as the risk growth of disturbance is not zero as previously published. We identified 2 cases of growth disturbance for a rate of 5%. Although neither patient required additional treatment to address the deformity, surgeons and patients should be aware of the potential for a growth disturbance secondary to RIMN fixation in a skeletally immature adolescent.

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