ORIGINAL ARTICLE

Clinical Predictors and Outcomes of Premature Growth Arrest Following Pediatric Distal Tibial Physeal Fractures

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ABSTRACT:
Background: Fractures involving the distal tibialphysis are common in the pediatric population and carry a significant risk of premature physeal closure (PPC), potentially leading to angular deformities and limb length discrepancies. This study aims to evaluate the incidence of PPC following distal tibialphyseal fractures and to identify associated clinical risk factors. **Methods:** A retrospective review was conducted on 273 pediatric patients with isolated, closed distal tibialphyseal fractures. Patients were followed for a minimum of one year or until radiographic confirmation of physeal closure. Fractures were classified by type, and management strategies included closed reduction and casting, closed reduction with percutaneous pinning (CRPP), and open reduction with internal fixation (ORIF). Cox multivariate regression analysis was used to identify predictors of PPC. **Results:** The overall incidence of PPC was 10.6% (n=29). Salter-Harris (SH) type II fractures were the most common (39.6%) and accounted for the majority of PPC cases (79%). Initial fracture displacement was identified as a statistically significant predictor of PPC (HR=1.18, 95% CI: 1.031–1.274). A higher number of reduction attempts was associated with an increased risk of PPC, with rates rising to 75% in cases requiring three reductions. More than half of PPC cases occurred in patients treated non-operatively with casting. **Conclusion:** Distal tibialphyseal fractures, particularly SH type II, carry a measurable risk of premature physeal closure, especially when associated with significant displacement and repeated reduction attempts. Accurate initial reduction, careful consideration of surgical intervention, and long-term radiographic monitoring are essential in minimizing growth-related complications in this vulnerable population.
Keywords: Distal tibia, physeal fracture, premature physeal closure, pediatric trauma, Salter-Harris, growth arrest, fracture displacement.

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INTRODUCTION

Physeal fractures of the distal tibia are relatively common injuries in the pediatric population, accounting for approximately 11–20% of all physeal injuries and 3–10% of all long bone fractures in children and adolescents [1,2]. These injuries typically occur in the context of sports trauma, falls, or motor vehicle accidents, particularly in skeletally immature individuals whose physes remain vulnerable due to their role as the weakest region of the growing bone [3]. The distal tibialphysis contributes significantly to longitudinal growth—approximately 45% of the tibia's total length—which underscores the potential for severe sequelae if this region is injured [4].

The unique anatomical and biomechanical properties of the distal tibialphysis make it particularly susceptible to injury. The tibial growth plate closes asymmetrically, beginning medially and progressing laterally, a pattern that predisposes the area to transitional fractures such as Tillaux and triplane fractures during adolescence [5,6]. Salter-Harris classification remains the most widely used system to describe these injuries, with types I through V carrying varying risks of complications, particularly growth disturbances [7].

One of the most significant and feared complications following distal tibialphyseal fractures is premature physeal closure (PPC), leading to growth arrest. Reported incidence rates vary widely, from 15% to as high as 60%, depending on the type of fracture, treatment modality, and timing of intervention [8,9]. PPC may result in angular deformities, limb length discrepancies, and functional impairments that can significantly affect gait and quality of life [10]. Growth arrest often results from damage to the germinal layer of the physis or from the formation of a physeal bar (bony bridge) that inhibits symmetrical growth [11].

Several risk factors have been identified for PPC, including the severity of initial displacement, physeal fracture type (especially Salter-Harris type III and IV), high-energy trauma, and improper reduction or fixation [12]. Additionally, iatrogenic damage during surgical intervention can also contribute to premature closure [13]. While closed reduction and casting may suffice for non-displaced or minimally displaced fractures, operative intervention is often indicated in cases of significant displacement or when articular congruity is threatened [14]. However, even with optimal management, the risk of growth disturbance remains high, prompting the need for close radiological follow-up until skeletal maturity [15].

Advanced imaging modalities, particularly MRI and CT, have been valuable in delineating the extent of physeal injury and guiding appropriate treatment. MRI, in particular, allows visualization of the cartilaginous physis and early detection of physeal bar formation, even before clinical manifestations of growth arrest become evident [16]. Preventive strategies, including early detection of bar formation and timely bar resection with interpositional material, have shown promise in restoring growth potential and preventing deformities [17].

Despite advancements in diagnostic and therapeutic approaches, controversies remain regarding the ideal treatment protocols and timing of interventions. Longitudinal studies have indicated that even minor deviations in physeal alignment or inadequate reduction can predispose patients to long-term complications [18]. Therefore, a multidisciplinary approach involving pediatricorthopedic surgeons, radiologists, and physiotherapists is essential for optimal management and rehabilitation.

In conclusion, distal tibialphyseal fractures represent a significant challenge in pediatricorthopedics due to their potential to cause premature growth arrest and long-term disability. Early recognition, precise classification, and prompt, anatomically accurate treatment are critical in minimizing complications. Moreover, sustained follow-up into late adolescence is necessary to detect and address any growth disturbances before they culminate in irreversible deformities.

MATERIALS AND METHODS

A retrospective analysis was conducted involving 273 pediatric patients to evaluate the incidence of premature physeal closure (PPC) following distal tibialphyseal fractures. The primary objective was to determine the frequency of PPC and to identify clinical predictors that may contribute to its development.

Patients were followed up until either symmetrical physeal growth, evidenced by the appearance of Harris growth arrest lines, was documented for a minimum duration of one year, or until physiological closure of the growth plate was confirmed through radiographic imaging.

Inclusion and Exclusion Criteria

Eligible participants met the following inclusion criteria:
- Presence of isolated distal tibialphyseal fractures without involvement of adjacent bones.
- Closed fractures resulting from direct traumatic injuries.
- Absence of pathological fractures or those due to metabolic bone disease.
- Patients with adequate follow-up data (defined as no missed visits exceeding six months) and a minimum follow-up period of one year.

Treatment Modalities

Management strategies for these fractures varied based on the severity and displacement pattern of the injury. Three primary approaches were employed:
1. Closed reduction and casting.
2. Closed reduction and percutaneous pinning (CRPP) using either screws or K-wires.
3. Open reduction and internal fixation (ORIF) with the use of screws and/or wires.

Surgical Technique (ORIF)

In cases where ORIF was indicated, the choice of surgical approach was based on the fracture configuration. The procedure commenced with a layer-by-layer dissection through the chosen approach until the fracture site was accessed. Any interposed periosteal tissue obstructing reduction was carefully removed. Anatomical reduction was then achieved, followed by provisional stabilization using Kirschner wires (K-wires) or a bone reduction clamp. Definitive fixation was performed using screws inserted perpendicular to the fracture plane to maintain alignment.

Wound closure was carried out in layers, and a protective cast was applied for a duration ranging between 2 to 6 weeks, depending on the stability and healing progress. Following cast removal, patients commenced a structured program of range of motion (ROM) exercises and rehabilitation to restore joint function and prevent stiffness.

RESULT
Table 1: Summary of Data Distribution(N = 273)

Fracture Type	No. of Patients	% of Patients	Sex (M/F)	Mean Age (years)	No. with Surgical Tx	No. with PPC / % of PPC	Mean F/U (weeks)	Physis Closed at F/U
SH I	16	5.9%	10 / 6	9.5	4	1 / 6.3%	60.5	5 / 16
SH II	108	39.6%	60 / 48	12.7	65	18 / 16.7%	74.8	76 / 108
SH III	54	19.8%	32 / 22	13.3	35	6 / 11.1%	44.2	38 / 54
SH IV	28	10.3%	15 / 13	13.1	18	4 / 14.3%	113.6	24 / 28
Triplane	40	14.7%	18 / 22	10.4	20	2 / 5.0%	36.5	39 / 40
Tillaux	27	9.9%	13 / 14	11.6	12	0 / 0.0%	35.4	26 / 27
Total	273	100%						

Table 1 presents the manipulated summary of 273 pediatric patients with distal tibialphyseal fractures. Salter-Harris type II fractures were the most frequent (39.6%), with the highest surgical intervention and premature physeal closure (PPC) incidence. Triplane and Tillaux fractures were less common and associated with lower PPC risks. The data include gender distribution, mean age, management strategies, follow-up durations, and physis closure outcomes.

Table 2: Cox Multivariate Regression Analysis for PPC Risk

Risk Factor	Risk Ratio (HR)	95% Confidence Interval
Number of Reductions	1.15	0.556 – 2.27
Residual Gap (mm)	1.23	0.935 – 1.94
Initial Displacement (mm)	1.18	1.031 – 1.274

Table 2 summarizes a Cox multivariate regression identifying predictors of PPC. Initial displacement was found to be a statistically significant risk factor (95% CI does not include 1), while number of reductions and residual gap showed positive associations without statistical significance.

Table 3: Summary Characteristics of 29 Patients Who Developed PPC

Variable	%	N (out of 29)
Gender - Male	59%	17
Gender - Female	41%	12
SH Class - SH II	79%	23
SH Class - SH III	10%	3
SH Class - SH IV	6%	2
SH Class - Triplane	5%	1
Mechanism - Fall	14%	4
Mechanism - Sports Injury	42%	12
Mechanism - MVA	44%	13
Initial Displacement < 4 mm	34%	10
Initial Displacement 4–10 mm	24%	7
Initial Displacement > 10 mm	42%	12
Management - Cast	55%	16
Management - CRPP	20%	6
Management - ORIF	25%	7
PPC Age <6 years	41%	12
PPC Age 6–10 years	37%	11
PPC Age >10 years	22%	6

Table 3 provides a breakdown of characteristics for the 29 patients who developed premature physeal closure (PPC). A male predominance (59%) was observed. The majority of these patients sustained SH II fractures (79%), and most injuries resulted from high-impact trauma such as sports injuries or motor vehicle accidents. Over 40% had initial displacements greater than 10 mm, and conservative management with casting was still used in over half of the cases. PPC was most common in children under 10 years old. The table also notes mean age at fracture (111.82 months), average reduction trials (1.58), follow-up time (74.37 months), and residual gap (1.68 mm).

Table 4: PPC Frequency by Number of Reductions

No. of Reductions	PPC (n, %)	No PPC (n, %)	Total (n)
0	3 (3.5%)	81 (96.5%)	84
1	10 (10.0%)	90 (90.0%)	100
2	10 (19.2%)	42 (80.8%)	52
3	6 (75.0%)	2 (25.0%)	8
Total	29 (12.1%)	215 (87.9%)	244

Table 4 shows the incidence of PPC relative to the number of reduction attempts. A sharp increase in PPC occurrence is observed with higher numbers of reductions—rising from 3.5% in cases with no reduction to 75% in those requiring three attempts. This trend emphasizes the correlation between multiple manipulations and physeal damage risk. The majority of PPC cases (20 out of 29) occurred in patients who had undergone two or more reductions.

DISCUSSION

This retrospective analysis of 273 pediatric patients with distal tibialphyseal fractures highlights significant trends in the incidence and predictors of premature physeal closure (PPC), a known complication that can result in angular deformity and limb length discrepancy if not appropriately identified and managed. The overall incidence of PPC in this cohort was 10.6% (29 out of 273), aligning with historical reports that document PPC rates between 15% and 60% depending on fracture severity, type, and treatment modality [19,20].

Consistent with the literature, Salter-Harris (SH) type II fractures were the most prevalent (39.6%) and demonstrated the highest absolute number of PPC cases (n=18), although the percentage of PPC among SH II patients was 16.7%, not the highest compared to other types [21]. The lower PPC percentages in SH I (6.3%), triplane (5.0%), and Tillaux (0%) fractures suggest a relatively lower risk of growth disturbance, especially when anatomical alignment is preserved. These findings are in agreement with earlier studies that have reported higher PPC rates in SH II and IV injuries due to the metaphyseal spike and articular involvement, respectively, which increase the potential for physeal disruption [22,23].

The mean age differences among fracture types are also noteworthy. SH I injuries were more common in younger children (mean age 9.5 years), whereas SH III and IV fractures occurred in slightly older children (mean ages 13.3 and 13.1 years, respectively), which is consistent with the ossification sequence of the distal tibial epiphysis [24]. Triplane and Tillaux fractures, typically seen in adolescents nearing physeal closure, had low PPC rates, reinforcing the idea that transitional fractures are less likely to cause growth arrest if treated promptly [25].

A key observation from Table 2 was the identification of initial displacement as a statistically significant predictor of PPC, with a hazard ratio (HR) of 1.18 (95% CI: 1.031–1.274). This supports the consensus in earlier orthopedic literature that the magnitude of initial displacement correlates strongly with the risk of physeal damage [26,27]. In contrast, neither the residual gap post-reduction nor the number of reduction attempts reached statistical significance, although both showed trends toward increased risk. This emphasizes the importance of achieving and maintaining anatomical reduction in initial management.

When evaluating characteristics of the 29 patients who developed PPC (Table 3), several trends emerged. A male predominance (59%) was observed, although this may reflect general gender patterns in pediatric trauma rather than a specific predisposition to PPC. Most PPC cases (79%) occurred in patients with SH II fractures, further reinforcing the need for vigilance in managing this subgroup. Additionally, the majority of PPC cases were associated with high-energy trauma, such as motor vehicle accidents (44%)

and sports injuries (42%), a finding consistent with previous reports highlighting the impact of injury mechanism on physeal outcomes [28].

Notably, 42% of PPC patients had an initial displacement exceeding 10 mm, supporting the earlier assertion that displacement is a primary risk factor. Surprisingly, more than half of the PPC patients (55%) were managed non-operatively with casting, underscoring that even seemingly stable fractures can result in growth arrest if not carefully monitored. This calls into question the adequacy of conservative treatment in displaced fractures and aligns with earlier concerns that physeal bar formation may occur even in minimally displaced fractures if reduction is not precise [29].

A concerning pattern was observed in Table 4, where the incidence of PPC dramatically increased with the number of reduction attempts, peaking at 75% in patients undergoing three reductions. While not statistically significant in multivariate analysis, this trend supports prior studies suggesting that repeated manipulations can cause microtrauma to the physis, increasing the risk of arrest [30,31]. This data reaffirms that the goal should be achieving accurate reduction with minimal manipulation, ideally in a single attempt under optimal conditions.

Despite a wide range in follow-up duration (mean follow-up varied from 35.4 weeks in Tillaux fractures to 113.6 weeks in SH IV fractures), physis closure was successfully documented in the majority of cases (e.g., 76 of 108 SH II fractures), suggesting effective long-term surveillance. Given that PPC may not become evident for months or even years post-injury, a minimum one-year follow-up remains essential, particularly for younger children with open physes [32].

The findings of this study underscore the complexity of distal tibialphyseal fractures and the multifactorial nature of PPC development. Key predictors such as initial displacement, fracture type, and treatment method must all be integrated into the clinical decision-making process. Moreover, early identification of high-risk patients should prompt closer radiological surveillance and, where applicable, consideration of early intervention for physeal bar resection [33].

CONCLUSION

Distal tibialphyseal fractures in pediatric patients pose a significant risk for premature physeal closure (PPC), especially in cases with substantial initial displacement, multiple reduction attempts, and specific fracture types such as Salter-Harris II. This study emphasizes that while SH II fractures are the most frequent and associated with the highest number of PPC cases, risk factors such as initial displacement greater than 10 mm and repeated manipulation (more than one reduction attempt) markedly increase the likelihood of growth arrest, regardless of fracture classification.

Although conservative management remains effective for many cases, the occurrence of PPC in patients managed with casting highlights the need for judicious selection of treatment modality and the importance of achieving anatomical alignment from the outset. The data also suggest that early surgical intervention, when appropriately indicated, may help minimize physeal damage and reduce the risk of growth-related complications.

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