Pediatric Distal Tibial Physeal Injuries and Their Role in Premature Physeal Arrest: A Multi-Center Retrospective Study

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Abstract

Aim: To evaluate the impact of factors such as fracture type, initial displacement, reduction method, associated fibular fractures, and trauma mechanism on the occurrence of premature physeal arrest in pediatric distal tibial physeal fractures.

Methods: This retrospective study included 83 pediatric patients who underwent surgical treatment for distal tibial physeal fractures between 2019 and 2024 at two centers. Data on fracture type (Salter-Harris classification, McFarland, tillaux, triplanar), reduction method (open/closed), fixation technique, and mechanism of injury were analyzed. Angular deformities were assessed using lateral distal tibial angle (LDTA) and anterior distal tibial angle (ADTA). Statistical analysis was performed using SPSS software, with significance set at $p<0.05$.

Results: The cohort included 59 males (71%) and 24 females (29%) with a mean age of 12 years. Premature physeal closure was observed in 10 patients (12%), with higher rates in Salter-Harris type 4 (50%) and McFarland fractures (50%). One McFarland fracture resulted in varus deformity, necessitating corrective osteotomy. Among all distal tibial fractures, traffic accident-related injuries were significantly associated with higher rates of physeal arrest. The incidence of premature closure in triplanar and Tillaux fractures was 4.5% and 12.5%, respectively, consistent with literature data.

Conclusion: Salter-Harris type 4 and McFarland fractures, as well as high-energy trauma, are significant risk factors for premature physeal arrest. Patient education and close follow-up are critical for early detection and management of complications. Prospective, randomized studies are warranted to further elucidate these findings.

***Keywords**: Pediatric, distal tibial fracture, physeal injury, lateral distal tibial angle, anterior distal tibial angle*

1. Introduction

Pediatric distal tibial physeal fractures are the most common injuries following distal radius and phalangeal physeal fractures [1]. They account for approximately 11-20% of all physeal fractures [2,3]. Inadequate reduction and joint incongruity may lead to premature physeal closure and deformities [4]. The rates of premature physeal closure following pediatric distal tibial physeal fractures can reach up to 38% [5].

During the rapid growth phase of childhood, the distal tibial physis contributes approximately 5 mm of longitudinal growth per year [6]. Angular deformities and limb length discrepancies may manifest 1 to 2 years following a physeal injury [7].

There is evidence in the literature suggesting that factors such as the Salter-Harris (SH) classification of the fracture, the degree of initial displacement, the magnitude of the physeal gap following surgical intervention, the presence of an associated fibular fracture, and the timing of surgical treatment are significantly correlated with the risk of premature physeal closure [1,2,8]. It has been reported that Salter-Harris type I and II fractures, as well as achieving anatomic reduction, are associated with a reduced risk of premature physeal closure [5].

The literature includes multiple publications examining the relationship between Salter-Harris fracture types and premature physeal closure. However, no studies have comprehensively analyzed Triplane, McFarland, Tillaux, and other Salter-Harris fracture

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types together.

In this study, we aimed to evaluate the impact of initial post-reduction displacement, Salter-Harris (SH) fracture type, the method of reduction, the presence of an associated fibular fracture, and the mechanism of trauma on the occurrence of physeal arrest. Our hypothesis was that the risk of premature physeal closure increases with higher Salter-Harris classifications and greater injury energy.

2. Materials and Methods

This retrospective study was conducted following approval from the Local Ethics Committee (approval number: AEŞH-BADEK-2024-450). Two different centers were included in our study: Ankara Bilkent City Hospital between March 2019- March 2024 and Ankara Etlik City Hospital November 2022-March 2024 Orthopedics and Traumatology Clinic between March 2019-March 2024. The centers included in this study are designated advanced trauma centers, with comparable surgical equipment and a similar level of surgical expertise across all institutions. The study included patients who underwent surgery for pediatric distal tibial fractures involving physics. Patients who were postoperative for at least 6 months and had complete preoperative and postoperative radiological and clinical data were included in the study. Patients with open fractures, patients with pathological fractures, patients with fractures in more than one extremity, and patients who were followed conservatively with a cast were excluded from the study.

Data such as age, gender, affected side, fracture type (Salter-Harris classification, McFarland fracture, Tillaux ,Triplane fracture), amount of displacement after initial reduction, presence of fibula fracture, open or closed reduction, fixation method, mechanism of injury (falling, sports injury, traffic accident), Lateral Distal Tibial Angle (LDTA) and Anterior Distal Tibial Angle (ADTA) at last follow-up were extracted from the database.

Radiographic measurements were conducted using the Picture Archiving and Communication System (PACS). Radiological measurements were made by an experienced orthopedic surgeon. Angular deformity of the ankle was measured using a line drawn parallel to the tibial plafond and a second line drawn parallel to the tibial shaft based on AP and lateral radiographs (Figure 1) [9].

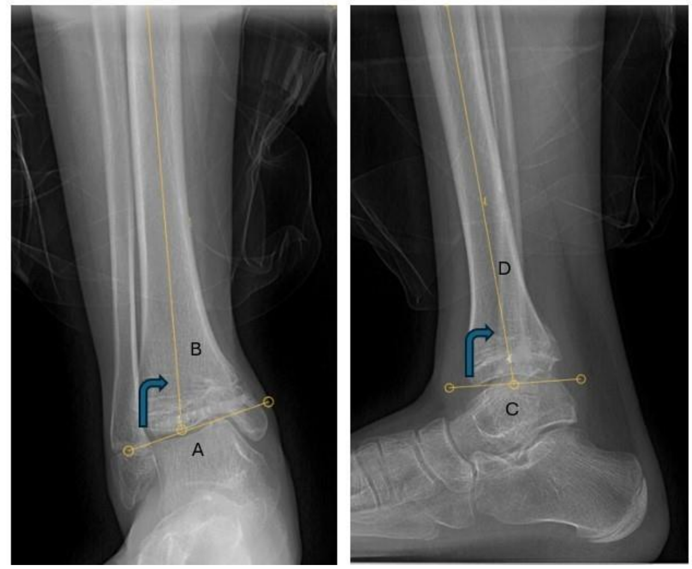
2.1. Statistical analysis

SPSS version 21.0 software (IBM Corp., Armonk, NY, USA) was utilized for statistical analysis. The normality of variable distributions was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests, as well as Q-Q plots and histograms. Variables with normal distributions were presented as mean ± standard deviation, while non-normally distributed variables were reported as median (minimum-maximum) values. Categorical data were expressed as frequency (percentage).

For comparisons, the Pearson Chi-square test was employed for categorical variables with sufficient observations, while Fisher's Exact test was used for those with insufficient observations. Post hoc analyses for statistically significant results involving more than two categories were conducted using the Bonferroni method. For continuous variables, Student's t-test was applied to compare two independent groups with normal distributions, whereas the Mann-Whitney U test was used for non-normally distributed variables. A p-value of <0.05 was considered statistically significant.

Figure 1

Measurement of angular deformity patients



A. Line drawn parallel to the tibial plafond on the anteroposterior radiograph, B. Line drawn along the tibial medullary axis on the anteroposterior radiograph, C. Line drawn parallel to the tibial plafond on the lateral radiograph, D. Line drawn along the tibial medullary axis on the lateral radiograph.

Figure 2

Postoperative radiographies

A. Early postoperative anteroposterior radiograph, B. Early postoperative lateral radiograph, C. 6th-month postoperative anteroposterior radiograph, D. 6th-month postoperative lateral radiograph, E. 6th-month postoperative limb length radiograph

3. Results

A total of 83 patients, comprising 59 males (71%) and 24 females (29%), were included in the study. The mean age of the patients was 12 years (8–15 years). Among the cases, 42 patients (50.7%) underwent surgery on the right side, while 41 patients (49.3%) had surgery on the left side.

Among the patients, 4 (4.8%) were diagnosed with McFarland fractures, 27 (32.5%) with Salter-Harris (SH) type 2 fractures, 15 (18%) with SH type 3 fractures, 6 (7.2%) with SH type 4 fractures, 8 (9.6%) with Tillaux fractures, and 23 (27.7%) with triplanar fractures (**Table 1**). During surgery, a closed reduction was performed in 70 patients (84.4%), while open reduction was performed in 13 patients (15.6%). Fixation methods included cannulated screws in 56 patients (64.7%), K-wires in 25 patients (30.1%), and a combination of both K-wires and cannulated screws in 2 patients (2.4%) (**Table 1**).

Premature physeal closure was observed in 10 patients (12%). Among six patients with SH type 4 fractures, three experienced physeal closure. Additionally, two out of four patients with McFarland fractures developed premature physeal closure, and one of these cases progressed to varus deformity. The patient with varus deformity underwent corrective osteotomy at the sixth month post-injury. Analysis of the mechanism of injury revealed that fractures resulting from traffic accidents were significantly associated with an increased incidence of premature physeal closure (**Table 2**).

It was determined that the amount of residual displacement after the initial reduction and the presence of an associated fibular fracture had no significant effect on the incidence of premature physeal closure (**Table 2**).

The mean lateral distal tibial angle (LDTA) and anterior distal tibial angle (ADTA) values for the patients were within normal limits, except for one patient. In a patient with a McFarland fracture, the LDTA was measured at 104°, indicating the presence of varus deformity (**Figure 2**). Notably, the ADTA values were found to be within normal limits in all patients, including the patient with varus deformity (**Table 3**).

Table 1

Summary of Patient Data for Patients

		n=83[1]
Gender	❖ Male	59 (71.0%)
	❖ Female	24 (29.0%)
Age (years)		12 (8-16)
Side	▪ L	41 (49.3%)
	▪ R	42 (50.7%)
Fracture Type	❖ McFarland	4 (4.8%)
	❖ SH-Type 2	27 (32.5%)
	❖ SH-Type 3	15 (18.0%)
	❖ SH-Type 4	6 (7.2%)
	❖ Tillaux	8 (9.6%)
	❖ Triplanar	23 (27.7%)
Surgery	▪ Cannulated Screw	56 (67.4%)
	▪ K-wire	25 (30.1%)
	▪ Both	2 (2.4%)
Post-Reduction Displacement (mm)		2.4 (1.0-9.2)
Physis closed	❖ Open	73 (88%)
	❖ Closed	10 (12%)
Reduction Methods	▪ Open	13(15.6%)
	▪ Closed	70 (84.4%)
Fibula Fracture	❖ Yes	14 (16.8%)
	❖ no	69 (83.1%)
Last Follow-up LDTA (degrees)		89 (88-104)
Last Follow-up ADTA		80 (78-84)
Injury Mechanism	▪ Fall	37 (44.5%)
	▪ Sports injury	36 (43.3%)
	▪ Traffic accident	10 (12%)

[1]:n (%), median(min.-max.)
ADTA: Anterior Distal Tibial Angle
LDTA: Lateral Distal Tibial Angle

Table 2

The data of patients between premature physeal closure group and open physis group

		Open Physis, N=73[1]	Premature Physeal Closure, N=10[1]	p
Gender	❖ Male	52 (71.2%)	7 (70%)	>0.999[2]
	❖ Female	21 (28.7%)	3 (30%)	
Age (years)		12 (8-15)	13 (9-15)	0.684[3]
Side	▪ Left	34 (46.5%)	7 (70%)	0.085[2]
	▪ Right	39 (53.5%)	3 (20%)	
Fracture Type	❖ McFarland	2 (2.7%)	2 (20%)	0.015[2]
	❖ SH type 2	26 (35.6%)	1 (10%)	
	❖ SH type 3	15(20.5%)	2 (20%)	
	❖ SH type 4	3 (4.1%)	3 (30%)	
	❖ Tillaux	7 (9.5%)	1(10%)	
	❖ Triplane	21 (28.7%)	1 (10%)	
Post-Reduction Displacement (mm)		2.4 (1.0-9.2)	2.5 (1.6-5.1)	0.619[3]
Reduction	▪ Open	8 (10.9%)	4 (40%)	0.054[2]
	▪ Close	65 (89.0%)	6 (60%)	
Fibula Fracture	❖ Yes	10 (13.6%)	4 (40%)	0.076[2]
	❖ No	63 (86.4%)	6 (60%)	
Last Follow-Up LDTA (degrees)		89 (88-90)	89 (88-104)	0.837[3]
Last Follow-Up ADTA (degrees)		80 (78-84)	82 (80-84)	0.107[3]
Trauma Mechanism	▪ Fall	36 (49.3%)	2 (20%)	0.015[2]
	▪ Sports injury	33 (45.2%)	4 (40%)	
	▪ Traffic accident	4 (5.4%)	4 (30%)	

[1]: n(%); Median (min.-max.), [2]: Fisher exact Test, [3]: Mann-Whitney U Test

Table 3

The data of patients in premature physeal closure group

No	Gender	Age (Years)	Side	Fracture Type	Surgery	Initially Displacement	Reduction Type	Fibula Fracture	Deformity	Last Follow-up LDTA (°)	Last Follow-up ADTA (°)	Trauma Mechanism
1	Male	14	L	Triplanar	Cannulated screw	2.5	Close	Yes	No	89	82	Fall
2	Female	10	L	McFarland	Cannulated screw	2.5	Open	No	No	91	84	Sports Injury
3	Male	14	L	Tillaux	Cannulated screw	4.8	Open	No	No	89	82	Fall
4	Male	13	R	SH Type 2	Cannulated screw	1.8	Close	No	No	89	81	Traffic Accident
5	Male	14	L	SH Type 3	Cannulated screw	2.2	Close	Yes	No	88	83	Sports Injury
6	Male	9	L	SH Type 3	K-wire	1.6	Close	No	No	89	80	Fall
7	Male	15	L	SH Type 4	Cannulated screw	5.1	Open	No	No	89	80	Sports Injury
8	Male	11	L	SH Type 4	Cannulated screw	3.5	Close	Yes	No	89	80	Traffic Accident
9	Male	13	R	SH Type 4	K-wire	2.4	Close	No	No	88	82	Sports Injury
10	Female	12	R	McFarland	K-wire and cannulated screw	2.2	Open	No	Yes	104	82	Traffic Accident

4. Discussion

The most significant finding of our study is that Salter-Harris type 4 fractures and McFarland fractures are associated with a significantly higher incidence of premature physeal arrest. Another key result is that injuries resulting from traffic accidents are more frequently associated with premature physeal arrest compared to those caused by simple falls or sports-related injuries.

Several risk factors contribute to premature physeal arrest following pediatric distal tibial physeal fractures, including the type of fracture, mechanism of injury, initial displacement, number of reduction attempts, quality of reduction, and patient age. In a study conducted by Rohmiller et al.[10], growth disturbances of the physis were observed in 39.6% of cases involving Salter-Harris (SH) type 1 and type 2 fractures. In a study conducted by Barmada et al., premature physeal arrest was most commonly observed in Salter-Harris (SH) type 3 and type 4 fractures. Additionally, SH type 1 and type 2 fractures were identified as the second most frequent types associated with physeal arrest [5]. In various studies, differing results have been reported due to the heterogeneity of study groups and a predominant focus on fracture classification rather than the mechanism of injury. Similarly, in our study, premature physeal arrest was most frequently observed in Salter-Harris (SH) type 4 fractures.

The fractures referred to as McFarland fractures, involving the medial malleolus, can be classified as Salter-Harris (SH) type 4 or type 5 fractures [8]. It has been reported that physeal bar formation can occur in up to 50% of McFarland fractures [1,8,11]. In a study conducted by Petratos et al.[8], the incidence of premature physeal arrest in McFarland fractures was reported to be 35%. In our study, both McFarland fractures were classified as SH type 4 fractures, and the observed physeal bar formation was consistent with the literature. Among all distal tibial fractures involving the physis in our study, only one McFarland fracture resulted in a varus deformity requiring surgical correction. This patient underwent corrective osteotomy at the sixth month post-injury.

In older pediatric populations, triplanar and Tillaux fractures are typically associated with a low risk of premature epiphyseal plate closure[5]. The literature reports a frequency of premature epiphyseal closure in triplanar fractures ranging between 4% and 21% [5,12]. In our study, the incidence of premature epiphyseal closure in triplanar fractures was found to be 4.5%, which is consistent with the reported range in the literature. Although premature physeal closure has not been reported in the literature following Tillaux fractures, in our study, physeal arrest was observed in 12.5% of Tillaux fractures [13]. This high rate is thought to be attributable to the small sample size in this group and the relatively lower average age of the patients.

Several studies have highlighted a significant association between the mechanism of injury and the occurrence of premature epiphyseal arrest. Rohmiller et al.[10] reported that pronation-abduction type injuries are more frequently linked to premature physeal arrest compared to supination-external rotation type injuries. Furthermore, it has been proposed that the energy magnitude of the trauma plays a significant role in determining the likelihood of premature physeal arrest[14]. Physeal arrest was observed more frequently in patients with fractures resulting from traffic accidents. We hypothesize that the likelihood of premature physeal arrest increases with the energy level of the trauma.

The retrospective nature of our study and the relatively small sample size represent its primary limitations. However, the inclusion of diverse fracture types, such as Salter-Harris, triplanar, McFarland, and Tillaux fractures, and the comparative analysis of these groups are considered valuable contributions to the existing literature. Nevertheless, further prospective, randomized studies are needed to provide more robust evidence on this topic.

5. Conclusion

High-energy trauma, Salter-Harris type 4 fractures, and McFarland fractures are significant risk factors for premature physeal arrest. In this context, it is crucial to inform the parents of the affected children about these risks and emphasize the importance of close follow-up in these cases to monitor for potential complications.

Statement of ethics

This study was approved by the Ethics Committee of Ankara Etlik City Hospital Ethics Committee (2024-450) The study was performed according to the Declaration of Helsinki.

Source of Finance

The authors declare that they have received no financial support for this study

Conflict of interest statement

The authors declare that they have no conflict of interest.

Availability of data and materials

The data supporting the conclusion of this article will be available by the authors without undue reservation.

Author contributions

Concept: YE/ASN, Design: ASN/ŞG/TT, Literature search: YE/EV/EA/TT, Data Collection and Processing: ASN/ŞG/EA, Analysis or Interpretation: TT/EV/ŞG, Writing: YE/ASN/EV

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