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ORIGINAL ARTICLE

Evaluation of factors affecting development of complications in the early surgical treatment of distal tibial epiphyseal fractures

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Distal tibial epiphyseal fractures (DTEFs) constitute 11 to 20% of all epiphyseal fractures, being the second most common cause of epiphyseal injuries following distal radial fractures.[1-3] These fractures have a spectrum of treatment options ranging from conservative management to surgical intervention, contingent upon various factors. Premature physeal closure (PPC) is one of the primary concerns associated with DTEFs, arising from the development of physeal damage.[4,5] It ranks among the most significant complications following DTEFs, leading to angular deformities in the ankle and limb length discrepancies in the extremities.[2-5] Complications related to DTEFs may lead to prolonged treatment time, increased morbidity, recurrent surgical procedures, and high economic costs. Therefore, predicting possible complications is crucial in the treatment of DTEFs.

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ABSTRACT

Objectives: This study aims to investigate the relationships among factors affecting complication development and premature physeal closure (PPC) in patients undergoing surgical treatment within 12 h of the time of injury.

Patients and methods: Between January 2015 and January 2021, a total of 46 patients (37 males, 9 females; mean age: 11.9±2.5 years; range, 6 to 16 years) who were operated within 12 h due to displacement >2 mm after reduction were retrospectively analyzed. Demographics, fracture type (Salter-Harris [SH]), fracture mechanism (Dias & Tachdjian [DT]), accompanying fibula fracture, and initial displacement were assessed with preoperative radiographs. At two years of follow-up, PPC, angular deformity, and length discrepancy were evaluated.

Results: Of the patients, PPC was observed in 21.7%. Angular deformity and length discrepancy were noted in 6.5% of cases. The average initial displacement was 6.8 mm, with no significant correlation between displacement and complications ($p>0.05$). While the rates of PPC varied by fracture type, there was no statistically significant relationship between fracture types and the development of complications ($p>0.05$). Premature physeal closure was more common in fractures caused by the supination-plantar flexion (SPF) mechanism (60%) compared to the pronation-eversion external rotation (PEER) mechanism (5.3%) ($p=0.018$). Angular deformity and length discrepancy were only associated with SH type 3 and 4 fractures. Although fibular fractures accompanied 25% of distal tibial epiphyseal fractures, their presence did not show a significant correlation with complications ($p>0.05$).

Conclusion: Our study findings indicate that factors previously thought to influence the development of complications may be insufficient to predict PPC occurrence in distal tibial epiphyseal fractures, once anatomical reduction is achieved within 12 h. As the preoperative delay shortens, the impact of fracture-related factors on complication development may reduce.

Keywords: Ankle, complication, epiphysis, pediatric, surgery, tibia.

Fracture-related factors such as fracture type, fracture mechanism, initial fracture displacement, and the presence of concomitant fibula fractures may influence the development of complications and have been frequently evaluated in relation to PPC.[2-5] However, there is a limited number of studies examining the effects of these factors while maintaining a consistent preoperative delay, or time until surgery.[2,6-9] As the preoperative delay prolongs, the risk of physeal damage also increases.[8-10] When surgical treatment is performed early, the fracture-related factors which can influence the development of complications have less time to affect the fracture, potentially resulting in less physeal damage. This may alleviate the relationship between these factors and the development of PPC.

In the present study, we aimed to investigate the relationships among factors affecting complication development and PPC in patients undergoing surgical treatment within 12 h of the time of injury.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Kanuni Sultan Süleyman Training and Research Hospital, Department of Orthopedics and Traumatology between January 2015 and January 2021. A total of 118 patients who underwent surgical treatment for DTEF were screened. Inclusion criteria were as follows: Patients no older than 18 years at the end of a two-year follow-up period, with informed consent provided for both treatment and scientific research, and who complied with the recommended treatment and follow-up as advised. Exclusion criteria were as follows: having undergone conservative treatment or multiple reduction attempts, postoperative fracture displacement of more than 2 mm, a follow-up period of less than two years, a history of previous surgery or fracture, early complications such as infection, changes in routine follow-up due to medical reasons, or non-traumatic etiologies. Finally, a total of 46 patients (37 males, 9 females; mean age: 11.9±2.5 years; range, 6 to 16 years) who met the inclusion criteria were recruited. A written informed consent was obtained from the parents and/or legal guardians of the patients. The study protocol was approved by the Kanuni Sultan Süleyman Training and Research Hospital Ethics Committee (date: 25.02.2021, no: KAEK/2021.0275). The study was conducted in accordance with the principles of the Declaration of Helsinki.

To reduce the time from trauma to reduction, we assessed patients who arrived at our hospital and underwent surgery within a maximum of 12 h. Patient demographics including age, sex, fracture side, and trauma mechanisms were obtained from the hospital records. All radiological measurements and classifications were independently analyzed by three orthopedic surgeons.

Fracture types were classified using the Salter-Harris (SH) classification[8] based on pre-surgery standard ankle anteroposterior (AP) and lateral and mortise direct radiographs (Figures 1 and 2). Fracture mechanisms were classified using the Dias-Tachdjian classification,[10] which includes supination-inversion (SI) (Figure 2), pronation-eversion external rotation (PEER) (Figure 1), supination-plantar flexion (SPF), and supination-external rotation (SER). The amount of initial fracture displacement was determined

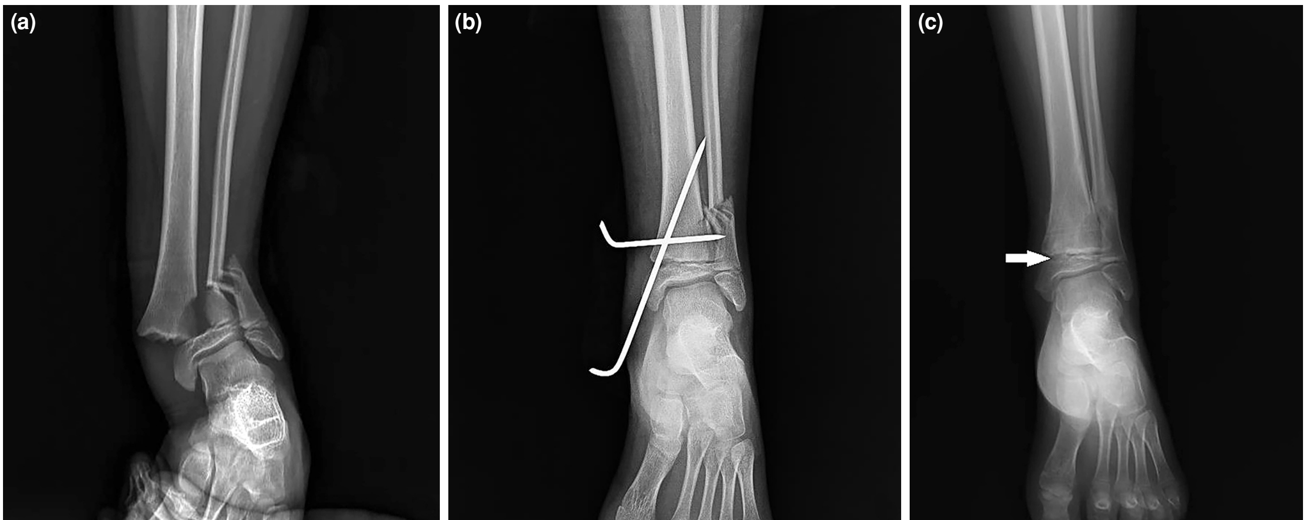

FIGURE 1. (a) Seven-year-old girl, Salter-Harris type 2 distal tibial epiphyseal fractures, pronation-eversion external rotation type fracture mechanism, accompanying fibula fracture. **(b)** Postoperative anteroposterior radiograph. **(c)** First year postoperatively, bone bar formation (arrowed area).

FIGURE 2. (a) 12-year-old boy, SH type 3 DTEF, SI type fracture mechanism, accompanying fibula fracture. **(b)** Preoperative AP radiograph after reduction. **(c)** Preoperative lateral radiograph after reduction. **(d)** Postoperative AP radiograph. **(e)** Postoperative Lateral radiograph. **(f)** First year postoperatively, AP radiograph, PPC is present. Park-Harris line was observed. **(g)** First year postoperatively, Lateral radiograph.

SH: Salter-Harris; DTEF: Distal tibial epiphyseal fractures; SI: Supination-inversion; AP: Anteroposterior; PPC: Premature physeal closure.

before surgery by measuring the most extended distances between the epiphysis and metaphysis or between the fracture fragments on plain radiographs. Concomitant fibula fractures were also recorded.

As surgical treatment, closed reduction percutaneous pinning (CRPP) or open reduction/internal fixation (ORIF) was performed. In addition to considering fracture displacement after reduction, surgical treatment decisions were also based on the patient's potential difficulties during follow-up, age, weight, fragment size, intra-articular characteristics of the fracture, and stability. The decision to apply fixation with Kirschner wire (K-wire) or screws was made according to the prespecified variables. Open reduction was performed for closed irreducible fractures. After surgery, all patients were given a short-leg plaster cast and instructed to avoid weight-bearing for four weeks. After four to six weeks, once union was achieved, any remaining K-wires were removed and mobilization was initiated with a short-leg walking cast, allowing partial weight-bearing. Casts were removed entirely after one week and full weight-bearing was permitted.

All patients were followed with plain radiographs at two, four, and six weeks and at three and six months and annually thereafter. During follow-up, PPC was identified by evaluating Park-Harris lines (Figure 2f) and bone bar formation (Figure 1c). The closure level of the distal tibial epiphysis was assessed according to the grading system established by Zhu et al.[11] Using this grading system, a tibial epiphysis classified as Grade 0-1-2 was categorized as "No PPC," while cases classified as Grade 3-4-5 were categorized as "PPC Present".[11] Bilateral lower extremity orthoroentgenograms were taken at the first-year and second-year follow-up visits to standardize complication rates. Angular deformity in the operated joint and limb length discrepancy were measured. Length differences between the intact and fractured tibia of ≥2 mm indicated a complication.

In the second-year postoperative orthoroentgenograms, both the operated and non-operated ankles of the patients were evaluated. To determine the normal angles of the ankle, the degrees of the tibia-ankle surface (TAS) angle in the AP plane (Figure 3a) and the tibia-lateral surface (TLS) angle in the lateral plane (Figure 3b) were measured for the non-operated tibia according to the method specified in the literature.[12] The literature-specified average ranges for these measurements are 91° to 93° and 80° to 81°, respectively.[12] Deviations of 3° above or below the TAS angle and 2° above or below the TLS angle measured from the normal tibia were considered to be within the normal range. Angular deformity in the ankle was presumed to have developed if the

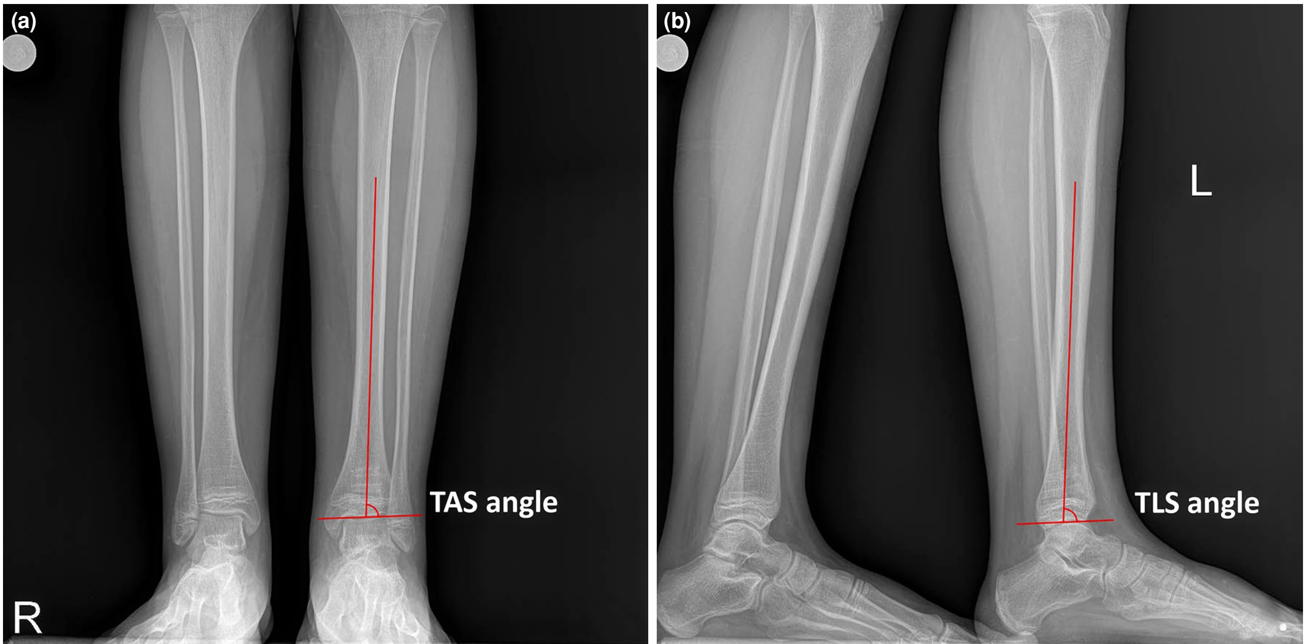

FIGURE 3. (a) The tibial anterior surface (TAS) angle is defined as the angle between the tibial axis and the distal tibial articular surface on the weight-bearing anteroposterior radiograph. **(b)** The tibial lateral surface (TLS) angle is defined as the angle between the tibial axis and the distal tibial articular surface on the weight-bearing lateral radiograph.

TAS and TLS angles of the operated tibia did not fall within these specified normal ranges.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 22.0 software (IBM Corp., Armonk, NY, USA). The compliance of the evaluated parameters to normal distribution was evaluated using the Shapiro-Wilk test. Descriptive data were presented in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The Kruskal-Wallis test was used to

TABLE I
Distribution of patients data (n=46)

		n	%	Mean±SD	Median	Min-Max
Demographic findings	Age (year)			11.9±2.5		6-16
	Sex					
	Male	37	80.4			
	Female	9	19.6			
	Side					
	Right	21	45.7			
	Left	25	54.3			
	Injury mechanism					
	OVTA	1	2.2			
	Fall	38	82.6			
	IVTA	7	15.2			
Surgical methods	Fixation material					
	K-wire	33	71.8			
	Screw	13	28.2			
	CRPP	20	43.5			
	ORIF	26	56.5			
Factors affecting development of complications	Initial displacement (mm)			6.8±5.8	6	0-26
	Salter Harris classification					
	II	18	39.1			
	III	11	23.9			
	IV	17	37			
	Dias & Tachdijan classification					
	SI	20	43.5			
	PEER	19	41.3			
	SPF	5	10.9			
	SER	2	4.3			
	Concomitant fibula fracture					
	No	21	45.7			
	Yes	25	54.3			
Complications	Premature physeal closure					
	No	36	78.3			
	Yes	10	21.7			
	Angular deformity					
	No	43	93.5			
	Yes	3	6.5			
	Limb length discrepancy (mm)			0.17±0.71	0	0-4

SD: Standard deviation; OVTA: Out of vehicle traffic accident; IVTA: In-vehicle traffic accidents; K-wire: Kirschner wire; CRPP: Closed reduction percutaneous pinning; ORIF: Open reduction internal fixation; SI: Supination-inversion; PEER: Pronation-eversion-external rotation; SPF: Supination-plantar flexion; SER: Supination-external rotation.

TABLE II Inter-rater reliability results of orthopedic surgeons using ICC and Fleiss' kappa		
Test type	Reliability coefficient	95% CI
ICC	0.82	0.75-0.90
Fleiss' kappa	0.76	0.70-0.82

ICC: Intraclass correlation coefficient; CI: Confidence interval.

compare quantitative data and parameters that did not show normal distribution between the groups. The Mann-Whitney U test was used to compare parameters that did not show normal distribution between the groups. The Fisher exact test and Freeman-Halton test were used to compare qualitative data. The Spearman rho correlation analysis was conducted to examine the relationships between parameters that did not comply with normal distribution. A p value of <0.05 was considered statistically significant.

RESULTS

Of the patients, DTEFs resulted from falls in 82.6%, in-vehicle traffic accidents (IVTAs) in 15.2%, and out-of-vehicle traffic accidents (OVTAs) in 2.2% (Table I). While CRPP was applied for 43.5% of the patients, ORIF was applied for 56.5% (Table I). Three patients with angular deformity had intra-articular fractures classified as SH type 3 or 4 (Table II). According to the SH classification, there was no statistically significant difference between the rates of PPC, length discrepancy, and angular deformity complications for any fractures (p>0.05) (Table III).

TABLE III

Characteristics of patients with physeal premature closure

Patients with physeal premature closure	Fracture type (Salter Harris)	Fracture mechanism (Dias & Tachdijan)	Concomitant fibula fracture Yes (+), No (–)	Displacement (mm)	Limb length discrepancy (L), angular deformity (A) No (–)
1	II	SPF	–	0	–
2	IV	SPF	–	7	L, A
3	III	SI	–	1	–
4	III	SI	–	6	L, A
5	III	SI	–	4.7	A
6	II	PEER	+	18	–
7	IV	SER	+	12	–
8	IV	SI	+	4.1	–
9	II	SPF	+	5	–
10	III	SI	+	8	L

SPF: Supination-plantar flexion; SI: Supination-inversion; PEER: Pronation-eversion-external rotation; SER: Supination-external rotation.

TABLE IV

Relationship between fracture type (Salter-Harris classification) and complications

	Salter Harris classification						
	II		III		IV		
Fracture type-complications	n	%	n	%	n	%	*p*
Pyseal premature closure							0.439‡
No	15	83.3	7	63.6	14	82.4	
Yes	3	16.7	4	36.4	3	17.6	
Angular deformity							0.171‡
No	18	100	9	81.8	16	94.1	
Yes	0	0	2	18.2	1	5.9	
Limb length discrepancy							0.171‡
No	18	100	9	81.8	16	94.1	
Yes	0	0	2	18.2	1	5.9	

‡ Fisher Freeman Halton test; p<0.05: Statistically significant.

TABLE V
Relationship between fracture mechanism (Dias & Tachdjian) and complications

	Dias & Tachdjian								
	SI		PEER		SPF		SER		
	n	%	n	%	n	%	n	%	*p*
Pyseal premature closure									0.022*‡
No	15	75	18	94.7	2	40	1	50	
Yes	5	25	1**	5.3	3**	60	1	50	
Angular deformity									0.273‡
No	18	90	19	100	4	80	2	100	
Yes	2	10	0	0	1	20	0	0	
Limb length discrepancy									0.273‡
No	18	90	19	100	4	80	2	100	
Yes	2	10	0	0	1	20	0	0	

SI: Supination-inversion; PEER: Pronation-eversion-external rotation; SPF: Supination-plantar flexion; SER: Supination-external rotation; ‡ Fisher Freeman Halton test; * $p<0.05$; ** The rate of PPC development following the SPF mechanism (60%) was statistically higher than the rate following the PEER mechanism (5.3%) ($p=0.018$; $p<0.05$).

TABLE VI
Relationship between concomitant fibula fracture and complications

	Concomitant fibula fracture				
	Yes		No		
	n	%	n	%	*p*
Physeal premature closure					0.516‡
No	16	76.2	20	80	
Yes	5	23.8	5	20	
Angular deformity					0.088‡
No	18	85.7	25	100	
Yes	3	14.3	0	0	
Limb length discrepancy					0.433‡
No	19	90.5	24	96	
Yes	2	9.5	1	4	

‡ Fisher exact test; $p<0.05$: Statistically significant.

TABLE VII
Relationship between initial displacement and complications

	Initial displacement (mm)		
	Mean±SD	Median	*p*
Physeal premature closure			0.883‡
No	6.86±6.02	6	
Yes	6.58±5.26	5.5	
Angular deformity			0.859‡
No	6.86±6	6	
Yes	5.9±1.15	6.5	
Limb length discrepancy			0.435‡
No	6.78±6	5	
Yes	7±5.8	6	

SD: Standard deviation; ‡ Mann-Whitney U test; $p<0.05$: Statistically significant.

The incidence of PPC differed statistically according to the fracture mechanisms as defined by Dias and Tachdjian (p=0.022). Pairwise comparisons revealed that the incidence of PPC after the PEER-type fracture mechanism (5.3%) was significantly lower than that with SPF (60%) (p=0.018 and p<0.05, respectively). However, there was no significant difference in the incidence of PPC with other fracture mechanisms (p>0.05). Furthermore, no significant relationship was found between the complications of angular deformity or length discrepancy and fracture mechanism (Table IV).

No statistically significant correlation was found between fibula fractures accompanying DTEFs and the development of PPC and other complications (p>0.05) (Table V). In addition, there was no statistically significant correlation between the amount of fracture displacement measured at baseline and the incidence of complications (p>0.05) (Table VI).

DISCUSSION

Many studies have reported that as preoperative delay increases, the success of postoperative remodeling decreases and the risk of epiphyseal damage rises.[8-10] Rang[9] showed that healing began immediately after a fracture and that reductions performed after one week could disrupt the healing process. Salter and Harriss[8] suggested that the ideal time for reduction in cases of epiphyseal fractures was within the first 24 h, suggesting that surgeries performed after 10 days could result in epiphyseal damage. Tachdjian[10] supported these views, emphasizing the importance of prompt surgical intervention, particularly in cases of intra-articular fractures such as SH types 3 and 4.

In the literature, there is a limited number of controlled studies directly assessing the effect of preoperative delay on the development of complications.[2,6,8,9] In a study by Egol et al.,[6] preoperative delay durations were categorized for SH type 1-2 epiphyseal fractures and no significant differences were observed between the groups in terms of complication development. However, the authors reported that their results might not be applicable to SH type 3-4 fractures. Petratos et al.[7] also evaluated all types of epiphyseal fractures in an uncontrolled study and reported that five out of six patients with preoperative delay of more than 24 h developed PPC. However, the authors could not explain that outcome due to the lack of sufficient literature.

In our study including 46 patients with SH fractures of type 3 and 4, the preoperative delay was limited to 12 h and the factors influencing complication development were not found to be associated with PPC in patients who underwent surgery within this timeframe. We believe that the only notable difference observed among fracture mechanisms was likely due to early surgical interventions, which effectively minimize fracture-related factors. Our study is the first to report on the factors affecting the development of complications in patients who underwent surgical treatment within 12 h and we anticipate that our findings will provide a basis for future research focused on evaluating complications associated with preoperative delay. As access to hospitals improves, preoperative preparation times shorten, and diagnostic methods advance, the importance of minimizing the effects of fracture-related factors in the early period may become increasingly evident. Factors affecting the development of complications in patients undergoing early surgery is likely to become a significant topic of discussion in the future. In this context, our findings may serve as a significant reference for future controlled studies classifying patients according to preoperative delay durations.

Considering the demographic characteristics of our patient group, we observed certain similarities with previous studies regarding sex distribution, fracture side, trauma severity, and average age.[2,3,5] The extent of energy involved in trauma may be associated with PPC. Typically, the intensity of trauma varies and it influences the risk of physeal closure.[13] Aitken[14] reported that epiphyseal damage associated with the energy of the trauma contributed to PPC. However, there is still controversy regarding whether high-energy traumas directly cause epiphyseal damage.[3] In our study, we observed low-energy trauma in seven cases of PPC, while high-energy trauma was evident in three cases. However, trauma severity was not one of the fracture-related criteria in this study. We only examined to assess the distribution of patients without performing any statistical analysis for trauma severity. Although PPC is the most significant complication which arises after DTEF,[15] there are varying findings regarding its frequency. While Schurz et al.[16] reported a PPC frequency of 0.2% in their study, it has been documented to be as high as 42% in other studies.[3,17-20] Jalkanen et al.,[3] in a meta-analysis evaluating key studies on this topic, reported the average frequency of PPC development in the literature to be 13%. In our study, we observed a PPC incidence of 21.7%. The SH type 2-3 and 4 fractures included in our study were surgically treated within 12 h to achieve anatomical reduction if the displacement after reduction exceeded 2 mm. Although previous studies have shown that early anatomical reduction and surgery may decrease the incidence of PPC, the literature lacks sufficient data and discussion on the importance of this approach.[2,6,7,18,19,21] Taken together, our study indicates that, even when SH type 1 fractures are not considered, comparable complication rates can be achieved with early intervention and anatomical reduction.

The relationships between initial and residual displacement amounts, complications, and the mechanisms causing complications remain controversial.[17-20,22-24] While the amount of residual displacement and the frequency of reduction provide insight into periosteal entrapment and damage resulting from reduction, the initial displacement indicates physeal damage and blood supply disturbances during trauma.[22-24] Since we operate patients with residual displacement of 2 mm or more in our clinic, we attempted to evaluate the relationship between the initial displacement amount and complication rates in this study. However, we did not observe a statistically significant relationship between these two variables. Margalit et al.[24] found that the rate of PPC increased with more severe initial displacement. While the initial amount of displacement may offer prognostic guidance, early reduction and surgical intervention could alter those initial outcomes. To date, few studies have concurrently evaluated the initial displacement amount and the time until surgery.[17] We suggest that the early admission and prompt reduction times of the patients in our study cohort may have reduced the relationship between initial displacement and complications. However, more comprehensive studies with larger patient populations are warranted to thoroughly examine the relationships among initial displacement amount, number of reductions, time until surgery, and PPC development.

The SH classification is a radiological classification that evaluates the relationship of the fracture line with the epiphysis. It is commonly utilized to categorize fractures and ascertain their prognosis.[8,10] While previous studies did not yield statistically significant results regarding the relationship between SH fracture types and complications, a meta-analysis conducted by Jalkanen et al.[3] examined 12 pivotal studies. They reported that complications after SH type 1, 2, 3, and 4 fractures were observed at rates of 3%, 17%, 8%, and 20%, respectively. In the aforementioned study, SH type 2 fractures exhibited worse outcomes compared to other types. In our study, the complication rates were 16.7% for SH type 2 fractures, 36.4% for SH type 3, and 17.6% for SH type 4. According to these results, there were no statistically significant differences between SH classifications and complication rates. We attribute the lower rate of complications in cases of SH type 2 fractures observed in this study, contrary to findings in the literature, to the exclusion of patients treated with conservative methods.

The Dias-Tachdjian classification describes the developmental model of DTEFs and the forces applied to them. Fracture mechanisms guide the choice of reduction techniques and surgical interventions, as they help predict the type of fractures that may subsequently develop.[10] The literature reports that the PEER mechanism, which typically results in SH type 2 fractures, can lead to PPC rates similar to those seen with the SI and SER mechanisms, which are capable of causing SH type 3 and 4 fractures.[13,17,20,24,25] Oktay et al.[17] suggested that fracture mechanisms could be used to predict PPC risk taking the fracture types into consideration.

In the current study, a significant difference in PPC development rates was observed according to the fracture mechanism. However, pairwise comparisons performed to determine the source of this difference revealed that it was solely due to the higher PPC rate following the SPF mechanism (60%) compared to the PEER mechanism (5.3%). No significant differences in PPC rates were observed among other fracture mechanisms. These findings suggest that, in our study group, there was no overall relationship between fracture mechanism and PPC development. We consider the higher PPC rate following the SPF mechanism compared to the PEER mechanism to be an exception specific to these two mechanisms. However, this difference in PPC rates between these two mechanisms is inconsistent with the literature. We attribute this to the fact that all patients in our study group underwent surgical treatment. Studies considering the PEER fracture mechanisms as being of higher risk for PPC have often included SH type 2 fractures treated conservatively.[17,20,24-26] Since SH type 2 fractures can lead to transepiphyseal damage, unexpected complications may arise following conservative treatment.[13,24] Therefore, in studies that include conservative treatment outcomes, the complication rates of fractures that might have had more favorable outcomes with surgical intervention could be misleading. Moreover, there are limited data in the literature regarding the rates of PPC development following different fracture mechanisms in cases of SH type 2 fractures treated exclusively with surgery.

In SH type 2 fractures resulting from the PEER mechanism, the fracture can be fully controlled with a medial approach and periosteal entrapment can be completely corrected. Reduction can be directly visualized during surgery. In contrast, surgical approaches for the SPF mechanism provide a more limited field of view, and controlling the fracture is more challenging due to the pulling force of the Achilles tendon. Periosteal entrapment and fracture reduction are often not directly visible through the incision line. Although the displacement of the posterior fracture may appear to be reduced in the lateral plane on direct radiographs, the vertical displacement caused by the pulling force of the Achilles tendon may not be adequately assessed. Therefore, despite the similarity of transepiphyseal SH type 2 fractures resulting from the SPF and PEER mechanisms, the rates of PPC development in our patients treated exclusively with surgery may differ from those reported in the literature. To better understand the effect of PEER and SPF fracture mechanisms on complication development in cases of surgically treated SH type 2 fractures, further large-scale studies analyzing postoperative fracture reduction and using computed tomography are needed.

Furthermore, the literature presents diverse perspectives regarding the associations between concomitant fibula fractures and complications. Several studies have suggested that initial displacement and subsequent complications increase in DTEF cases accompanied by fibula fractures.[15,23] Conversely, Spiegel et al.[13] showed that concomitant fibula fractures did not increase the complication rate. In our study, despite observing a higher rate of displacement in cases of DTEFs with accompanying fibula fractures, we found no statistically significant increase in the complication rate.

In the literature, it has been reported that angular deformity frequently develops following the PEER mechanism in cases of SH type 2 fractures.[17,25,26] In our study, angular deformity was observed in three patients. Two of those patients experienced the SI type of fracture mechanism, while one experienced the SPF type of fracture mechanism. The absence of angular deformity following fractures caused by the PEER mechanism in our study stands in contrast to results presented in the literature.[27] Studies which reported a high incidence of angular deformity with the PEER mechanism usually evaluated SH type 2 fractures, including the results of conservative treatment.[17,20,24,25] However, SH type 2 fractures are described as unpredictable due to their transphyseal extension.[13,24] Therefore, the outcomes of conservative treatment of SH type 2 fractures resulting from the PEER mechanism still remain controversial.[18-21,24] We attribute the difference between our results and those in the literature to the fact that all fractures in our study were surgically reduced within 12 h. Surgical reduction minimized early trauma to the physis by reducing the impact of factors such as periosteal interposition and physeal displacement in cases of SH type 2 fractures. Additionally, Oktay et al.[17] reported that, although they did not observe a statistically significant difference, angular deformity occurred frequently following the SI fracture mechanism as it did with the PEER mechanism. This was particularly noted in the context of the development of SH type 3 and 4 fractures following the SI mechanism. The aforementioned authors suggested that fracture mechanisms and fracture classifications should be considered together in predicting complications. In our study, due to the small number of patients with angular deformity, we were unable to statistically evaluate this complication. However, the three patients with angular deformity had intra-articular fractures classified as SH type 3 or 4. We believe that, in the group of patients who underwent early surgical intervention, the risk of angular deformity related to physeal damage was reduced; however, the risk of angular deformity due to joint irregularity caused by intra-articular fractures remained unchanged.

Nonetheless, there are several limitations to this study. First, we did not include a control group of patients who underwent surgery at later time periods and so our findings reflect only the outcomes of those who underwent surgery within 12 h. The lack of a control group prevented us from directly assessing the effect of preoperative delay on the development of complications. However, we were able to evaluate the factors affecting complication development in patients operated within 12 h. Our study is, thus, unique due to the short preoperative delay and early intervention. Our findings may offer valuable insights for future studies involving control groups, particularly regarding patient outcomes within this treatment timeframe.

Another limitation of our study is the low incidence of angular deformity and limb length discrepancy complications, which restricted our ability to obtain statistically significant results for all complications. Further larger-scale studies may yield more detailed findings on this subject.

Third, we also faced challenges in the measurement of limb length discrepancy. To minimize age-related limitations, we measured limb length discrepancy in patients with two years of follow-up, as recommended in the literature.[15] However, the threshold for defining "length discrepancy" varies according to the child's growth stage.[28,29] Therefore, it is crucial to consider the child's growth stage and calculate limb length discrepancy relative to that stage. Without assessments performed alongside a staging system such as Tanner growth staging,[28] it is difficult to accurately compare limb length discrepancies between children at different growth stages. In the literature, there is no study considering this factor while measuring limb length discrepancy.

Finally, our study did not evaluate tibiofibular joint congruity, which is another limitation in the measurement of limb length discrepancy. Some studies suggest that length discrepancies in the tibia alone may not always result in measurable deficits.[30] In our study, we identified limb length discrepancy in three patients. However, despite measuring angular deformities, we did not assess the relationship between the tibia and fibula, which may have led to an incorrect estimation of the number of patients with limb length discrepancy.

In conclusion, the factors affecting the development of complications are of utmost importance in tailoring treatment decisions for DTEFs. However, in our patients who underwent surgery within 12 h of the initial trauma, we did not observe the expected relationships between fracture-related factors and the occurrence of PPC, as reported in the literature. This finding indicates that, when early anatomical reduction is achieved, fracture-related factors may have less impact on the physis. To gain a clearer understanding of how the influence of these factors changes with different preoperative delay durations, controlled studies with larger patient groups and varying preoperative delay times are warranted.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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