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Evaluation of Radiological and Functional Results of Long Bone Diaphyseal Fractures in Children Aged 5-15 Years Who Underwent Titanium Elastic Nail

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Abstract

Objective: In this study, we aimed to evaluate the radiological and functional results of titanium elastic nail (TEN), which was used as a surgical method in pediatric long bone diaphyseal fractures between 5-15 years of age, by comparing it with the clinical features of the patient and the fracture.

Methods: In this study, 44 patients (11 girls, 33 boys) aged 5-15 years (mean 9.86 ±2.84) were included. The clinical features of the patient, family satisfaction, evaluation of the fracture according to Flynn Criteria, time to bone union, stay in the hospital, and school absence was examined.

Results: TEN was applied mostly to the femur (n;18), tibia (n;14), and forearm (n;12) diaphysis fractures, respectively. Most of the fractures were seen as a result of high energy and closed middle diaphysis, the transverse fracture pattern was the most. Most of the fracture surgeries were performed with the closed method. The family satisfaction of the patients was at a high level. In the evaluation of fractures according to Flynn Criteria, most of the results were excellent, but no poor results were observed. Bone union time was higher in patients aged ten years and older and undergoing open surgery, and less in transverse fracture shape ($p<0.05$). The time not to attend school was highest in open fracture type, tibia fractures, and open surgery patients ($p<0.05$). Ulna union time was 13.1 ± 1.8 weeks, which was higher than forearm fractures ($p<0.05$). The hospital stay was 3.50 ± 0.79 / 4.29 ± 1.54 / 3.33 ± 0.49 days in femur/tibia/forearm fractures, respectively, and was the highest in tibia fractures ($p<0.05$).

Conclusions: TEN is an effective and safe method for long bone diaphyseal fractures in children aged 5-15 years, with low complication rates and positive effects on the patient and the health system.

Keywords: Child, long bone fracture, titanium elastic nail, Flynn Criteria

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INTRODUCTION

Child bone fractures are distinguished from the adult bone structure by features such as high remodeling capacity, fewer ligament injuries, and thicker periosteum of the bone structure. Conservative treatment is at the forefront in long bone fractures in children under the age of six (1). When it comes to the 6-16 age group, the variety of treatments accompanied by surgical methods increases. Traction, orthosis, plaster cast, plate or external fixation, and intramedullary nail are used in pediatric long bone fractures (2). Of course, these methods have their own complications. Long hospital stays, inactivity, developing scars, growth plate injuries, and infections are just some of them (3).

With the increasing age of the child, intramedullary fixation has become attractive in children due to the low tolerance to immobilization, some uncomfortable properties of the cast, and lowering the risk of malalignment. Ender and Rush's nails were used in the past, and the emergence of rotational problems created a problem in using these materials (4).

With the description of an elastic intramedullary nail in pediatric long bone fractures, this method gained popularity. With the discovery of titanium elastic nails (TEN), the treatment method for femoral shaft fractures has changed over the years (5, 6). It has found more widespread use for many reasons such as providing primary union without damaging the growth plate, making fewer incision scars, being minimally invasive, low infection rates and hospitalization times and allowing early mobilization (7). It is also used successfully in some metaphyseal fractures. Its disadvantage is that it provides less stability in some complex fractures accompanied by severe soft tissue injuries (8). Although prolongation of union time and compartment syndrome can be observed in children with advanced age and >50 kg, using TEN in cases with correct indications has been an advantageous treatment method (9).

In this study, we aimed to show the radiological and functional results of TEN treatment used as a surgical method in pediatric long bone diaphyseal fractures between 5-15 years of age by comparing with the clinical features of the patient and the fracture.

METHODS

This study was designed as a retrospective cohort and ethical approval was obtained Clinical Research Ethics Committee (Date: 25.02.2022; Decision No: 3/2022.K-18). We conducted this research in compliance with the principles of the Declaration of Helsinki. Between the years 2017-January and 2019-November, child patients with the diagnosis of long bone diaphysis fracture were admitted to our hospital. There were 54 patients aged 5-15 years, to whom we applied titanium elastic nails in their treatment. Pathological fractures caused

by metabolic bone disease, tumors, patients with multiple bone fractures undergoing intensive care treatment, those with neuromuscular disease, and grade 3 open fractures were not included in this study. Between those whom we could reach, the broken bones, fracture side, mechanism, type, shape, location, and type of surgery-anesthesia of 44 patients who underwent TEN were recorded using the information obtained from the hospital archive and outpatient controls. Family satisfaction was evaluated according to whether the child's school adaptation in the postoperative period was good or not by the family's own observations.

Evaluation of bone fractures in terms of healing was carried out by considering Flynn Criteria (10). These consist of Limb length discrepancy, Malalignment, Pain, and Complication parameters. Each parameter is evaluated as excellent, satisfactory, and poor. These criteria were also used in the comparative evaluation of the TEN applied to the patients who underwent casting treatment first and had a loss of reduction in the follow-ups with all the patients. The time of bone union, inability to attend school, full weight-bearing and hospital stay were evaluated by comparing the data of the patient and the broken bone.

Surgical technique

After all the fractures were reduced under the scope, the nail entry points were determined so that the physis lines would not be damaged. In fractures where closed reduction is not possible, the fracture line was opened with a mini-incision and manual reduction was achieved. The total diameter of the TENs was chosen to fill approximately 80% of the bone medulla (3, 6). Nail tips were left under the skin. Antibiotic treatment was applied. Postoperative plaster was applied to all patients for pain control and plasters were continued until the sutures were removed. Range of motion exercises was started after the splint was removed. In lower extremity fractures, patients were mobilized with assistance. The way of pressing and using the upper extremity was adjusted according to the callus tissue in the controls.

Statistical analysis

SPSS 21.0 program was used in our analysis. The chi-square test was used to examine the association between categorical variables. The difference between the numerical variables according to the categorical variables with two groups was analyzed with the t-test, and the difference between the categorical variables with three or more groups was analyzed with the ANOVA test. The statistical level of significance was established at $p < 0.05$.

RESULTS

The mean follow-up time of 44 patients (11 girls, 33 boys) aged 5-15 years (mean 9.86 ±2.84) included in the study was 22.4 (range 16-29) months. TEN was applied mostly to the femur (n;18 mean age; 9,67), tibia (n;14 mean

age; 9,21), and forearm (radius+ulna) (n;12 mean age; 11,92) diaphysis fractures, respectively (Figure 1-3). The mean weight of all patients was 38,42±13,54 kg, and 34,70 ±12,20 kg in those with lower extremity fractures. Grade 1 open fracture was seen in three tibias and two femur fractures. Most fractures were seen on the right side, in boys, as a result of high energy, and the closed, middle diaphysis and transverse fracture patterns were the most common. Most fractures were treated with the closed method and general anesthesia was applied to all patients. The family satisfaction of the patients who underwent TEN treatment was high (Table 1).

Table 1 Distribution of clinical features of patients.

		n	(%)
Bone	Femur	18	40,9
	Tibia	14	31,8
	Forearm (radius+ulna)	12	27,3
Gender	Girl	11	25,0
	Boy	33	75,0
Side	Right	33	75,0
	Left	11	25,0
Fracture mechanism	Low energy	20	45,5
	High energy	24	54,5
Fracture type	Open	5	11,4
	Closed	39	88,6
Fracture shape	Transverse	20	45,5
	Oblique	13	29,5
	Spiral	7	15,9
	Fragmented	4	9,1
Fracture location	Middle	29	65,9
	Proximal	10	22,7
	Distal	5	11,4
Type of surgery	Open	5	11,4
	Closed	39	88,6
Type of anesthesia	General	44	100
	Sedation	0	0
Family satisfaction	Yes	39	88,6
	No	5	11,4

n: number

Given the evaluation of the fractures according to Flynn Criteria, most of the results were excellent, some of them were satisfactory, and no poor results were observed (Table 2). When these criteria are examined in detail; in two femur fractures, limb length discrepancy was observed in the elongation direction of 1.3 and 1.7 cm. One femur fracture had 5-10° varus, three tibia fractures had 5-10° malalignment in the coronal and sagittal planes. As complications, three superficial infections (two in the tibia and one in the femur fracture), and three nail end prominence (one in each bone fracture) were seen. Transient pain of these two types of complications was observed in five patients.

Table 2. Evaluation of patients according to Flynn Criteria.

Flynn Criteria	Excellent, n (%)	Satisfactory, n (%)	Poor, n (%)
Limb length discrepancy	42 (95,5)	2 (4,5)	None
Malalignment	40 (90,9)	4 (9,1)	None
Pain	39 (88,7)	5 (11,3)	None
Complication	38 (86,4)	6 (13,6)	None

In evaluating patients who underwent surgery due to reduction loss after plaster treatment first according to Flynn Criteria, the results were excellent in ten, and satisfactory in three patients. When the four parameters were evaluated according to all cases in these patients, the two most affected criteria were malalignment and complication (Table 3) ($p<0.05$).

Bone union time was higher in patients aged ten years and older and undergoing open surgery, and less in transverse fracture type (p<0.05). The time not to attend school was highest in open fracture type, tibia fractures, and open surgery patients (p<0.05) (Table 4). Ulna union time was 13.1 ± 1.8 weeks, and union time was higher than forearm fractures (p<0.05).

Table 3. Evaluation of the cases who were cast first and then operated according to Flynn Criteria with all patients

Flynn criteria (All patients)		**Flynn criteria for those who were cast first and then operated**			
		Excellent, n (%)	Satisfactory, n (%)	Poor, n (%)	P
Limb length discrepancy	Excellent	10 (100)	3 (100)		
	Satisfactory			*None*	>0,05
	Poor		*None*		
Malalignment	Excellent	10 (100)	1 (33,3)		
	Satisfactory	*None*	2 (66,7)	*None*	**<,005***
	Poor		*None*		
Pain	Excellent	10 (100)	3 (100)		
	Satisfactory		*None*	*None*	>0,05
	Poor				
Complication	Excellent	10 (100)	1 (33,3)		**<,005***
	Satisfactory	*None*	2 (66,7)	*None*	
	Poor		*None*		

P; significance

Table 4. Evaluation of bone union and school absence time with clinical characteristics.

		Bone union time (w), mean ± sd	P	Not to attend school (w), mean±sd	P
Age [b]	*9 ≤*	7,43±1,33	**,000***	6,86±2,43	0,249
	10 ≥	12,17±1,83		7,91±3,50	
Gender [b]	*Girl*	8,91±2,47	0,186	7,0±3,03	0,614
	Boy	10,24±2,96		7,55±3,09	
Fracture mechanism [b]	*Low energy*	9,80±3,02	0,821	6,85±3,13	0,272
	High energy	10,0±2,81		7,88±2,97	
Broken bone [a]	*Femur*	9,83±2,94	0,889	8,19±1,68	**,000***
	Tibia	9,71±3,12		9,29±1,33	
	Forearm	10,25±2,70		3,0±0,85	
Fracture location [a]	*Middle*	10,03±3,03	0,632	7,14±3,15	0,82
	Proximal	9,20±2,30		7,90±3,21	
	Distal	10,60±3,29		8,0±2,45	
Fracture shape [a]	*Transverse*	6,57±0,79	**,001***	7,55±3,09	0,856
	Oblique	9,31±2,95		7,0±3,42	
	Spiral	11,20±2,53		7,0±2,52	
	Fragmented	9,8±2,82		7,1±2,95	
Fracture type [b]	*Open*	11,0±3,0	0,374	9,60±0,55	**,000***
	Closed	9,77±2,87		7,13±3,13	
Type of surgery [b]	*Open*	14,0±0,71	**,000***	9,40±3,65	**,001***
	Closed	9,38±2,61		7,41±3,02	

a ; ANOVA b ; t test w; week sd; standard deviation

Figure 1. X-rays of femur fracture with TEN applied, A) preoperative B) postoperative and C) final polyclinic control

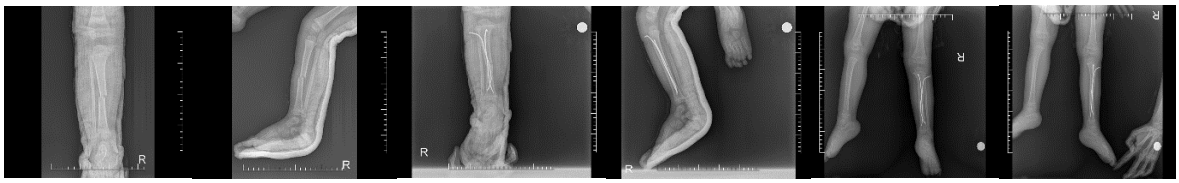

Figure 2. X-rays of tibia fracture with TEN applied, A) preoperative B) postoperative and C) final polyclinic control

Figure 3. X-rays of forearm fracture with TEN applied, A) preoperative B) postoperative and C) final polyclinic control

Full weight-bearing time was 10.28 ± 2.89 and 10.71 ± 3.12 weeks in femur and tibia fractures, respectively ($p>0.05$). The hospital stay was 3.50 ± 0.79 / 4.29 ± 1.54 / 3.33 ± 0.49 days for femur/tibia/forearm fractures, respectively, and it was the highest for tibia fractures ($p<0.05$).

DISCUSSION

To treat long bone diaphyseal fractures in children, the most appropriate implant should be a load-sharing internal splint that preserves length and rotation until the callus tissue is formed, does not harm the physis, and allows early movement (11). TENs are the implants with these features. Since most of them are applied with closed methods, the fracture hematoma and periosteum remain unharmed, thus reducing the possibility of infection and increasing the chance of union of the bone (10, 12, 13). In a study conducted on 30 patients, 14% poor, 30% acceptable, and 56% excellent results were reported according to Flynn Criteria in tibial shaft fractures in which TEN was applied (14). In a study on 48 children with femur fractures, 83% excellent and 17% sufficient results were obtained (7). In another study evaluating patients with forearm fractures who underwent TEN, data with predominantly excellent results were obtained (13). Most of the results were excellent in all broken bones in this study, poor results were not observed. The fact that we obtained similar results in most of the patients who had to have a plaster cast first and then TEN treatment is appropriate with the literature and shows that TEN is a suitable method for treating children's long bone diaphyseal fractures.

Over time, TEN has started to be applied in some open fractures. In a study conducted on 16 tibias, 13 of which were open fractures except for grades 3b and 3c, 15 of the patients were excellent and one was satisfactory, according to the Flynn Criteria (15) . In another study on 11 patients, poor result was obtained in one of three patients with grade 1, 2, 3a open femur fractures, and satisfactory results were obtained in two (16). On the other hand, it was emphasized that the union time was prolonged in the TEN results applied to open fractures (17). In this study, open fractures were seen in the femur and tibia as grade 1, and the excellent results may contribute to the literature on the safe use of TEN in open fractures. We attribute our lack of difference in union time in open fractures to the low grade of the fractures, and to the postoperative cast and antibiotherapy we applied.

The development of length discrepancy in the healing process of bones has often been associated with the femur. For this, a minimum overlap of 1.5 cm between the fracture ends is recommended in the treatment. End-to-end alignment can be a problem in terms of excessive growth in TEN use (18). In a study on femoral shaft fractures in which 29 patients were evaluated after three years, a mean shortening of 11.7 mm was observed in three patients, and a mean increase in length of 2.7 mm in nine patients. No length difference was observed in ten patients. Fifteen patients were 8.7 mm long at the end of the first postoperative year. It has been emphasized that leg length discrepancy is frequently observed, but it does not pose a problem over time (19). Leg length discrepancy has also been reported after tibial diaphyseal fractures. In a study in which 54 patients with tibial fractures were evaluated, it was reported that a length difference of 15 mm-20 mm developed in two patients with comminuted fractures. This was healed by performing epiphysiodesis on the opposite side (20). Disruption of fracture alignment has been attributed to unstable fracture patterns, advanced age, unsuitable nail size and curve, and insufficient postoperative immobilization (18). In this study, the bone with the greatest length difference was the femur, and there have not been any difficulties created by this problem in patient follow-ups.

Angulation can be seen during union at a higher rate in TENs compared to open reduction and fixation of the fracture with a plate, which may cause false unions (8). In a study conducted on 47 femur fractures, malalignment was observed in six patients with spiral fractures. Revision surgery was performed on two patients because there was greater angulation than 10 degrees in the sagittal and coronal planes (3). In a study with 19 tibial fractures in which the mean follow-up period was 15.7 months, an angulation of 5-10 degrees was reported in the coronal plane in three patients (18.9%) and the sagittal plane in

one patient (6.3%) (21). In forearm fractures, malalignment may affect especially pronation and supination movements. Injuries in the proximal region have a greater negative impact on movement; spontaneous recovery can be observed in fractures approaching the wrist region (22). In this study, we attribute the angulation in femur and tibia fractures due to the incompatibility of the patients and their relatives, not using a cast for enough time in the postoperative period, and weight-bearing in the early period.

TENs may cause irritation and infection at entry points. In a study, it was shown that 13.6% of patients with tibial fractures had entry site-related irritation and 4.4% of patients had a superficial infection (23). It was reported that 8.5% of painful nail tips and 3.4% of superficial infections were observed in femur fractures (5). The most common complication related to TEN applied in pediatric long bone fractures followed for seven years was irritation and pain due to the entry site (3). It has been shown that causes such as shortening or angulation of unstable fractures, long nail tips left at a sharp angle, and entrances close to the distal physis predispose to this complication (12). It has been emphasized that the nail tips should remain under the skin to reduce the risk of infection, and the remaining nail tip outside the bone should be less than 2 cm (3, 10). Although we leave the nail tips under the skin in patients, we attribute our nail prominence and superficial infection to our early joint movements and leaving the nail tips under the skin long. These complications were resolved with oral antibiotic therapy and nail removal after the bone union.

TEN applications may not always be performed with the closed method. If the surgeon cannot advance the nail ends from the fracture site within 10 minutes, it is stated that open surgery should be performed, because unsuccessful attempts prolong the duration of the surgery and may increase the incidence of risks, such as compartment syndrome (24, 25). Conversion to open surgery brings risks to the union (26). In addition, in a study conducted on 50 tibial fractures, it was stated that the duration of union prolongs with age (27). In this study, it was observed that the duration of bone union was prolonged in patients aged 10 years and over and in three bone types that were switched to open surgery, and all fractures were unionized in the patient follow-ups.

It was shown that the only bone that developed non-union or malunion as a result of TEN application among all pediatric fractures was the tibia (28). The incidence of malunion in tibia fractures as a result of TEN application varies between 0-11% (27). It has been shown that this is due to the triangular cross-section of the tibia and the difficulty in maintaining the reduction (12). The incidence of non-union in tibial fractures is between 0-8%, and no non-union cases were observed in a study in which

many fractures were closed, and the nail was applied (17). Healing was achieved within 12 weeks without delay in the union in all 31 femoral fractures in which TEN was applied (6). In a study conducted on 30 diaphyseal non-unions, it was stated that most non-unions were in the tibia and femur, and severe traumas, open surgery, and infections might cause this (29). It has been reported in some publications that the ulna can fuse later in forearm fractures. Non-union is most often seen in the middle section, this area can be called the watershed zone. Inappropriate nail diameter, the development of distraction at the fracture line during retrograde nailing of the ulna, and the opening of the fracture line for reduction are among the accused theories (30, 31). Although we did not find any difference regarding union time in three types of bone fracture in this study, longer union time of the ulna compared to forearm fractures makes this bone special and shows us that more care should be taken during surgery and in patient follow-up.

Minimally fragmented, transverse, short oblique fractures are suitable fracture patterns for TEN applications. Experienced surgeons can also apply it successfully in long oblique spiral fractures. However, there may be a loss of stability in this type of unstable fracture type, and immobilization may be required after the operation (32). In the study conducted on femur fractures, union time was shorter in the transverse fracture type compared to oblique-spiral fractures. It has been shown that the fracture location and fracture mechanism are not related to the duration of bone union (5). This study is compatible with the literature regarding these parameters. Given that it has been examined in different bones from this point of view adds a special perspective to pediatric fractures.

With using TEN, the time to stay in the hospital, and so the financial burden on the health system, has also decreased. In a study on pediatric long bone fractures, the mean hospital stays of patients treated with TEN was 3.5 days. In all fractures, the union was achieved in an average of 9.6 weeks (33). In a prospective study evaluating femur and tibia fractures, the average hospital stay was 5.7 days, and most fractures healed within three months (34). In this study, we attribute the most frequent hospital stay in tibia fractures to the frequent encounters with compartment syndrome in our clinic and the necessity of following the patient closely.

Positive effects on bone healing without damaging the epiphysis blood circulation, low complication rates, early return to school, short hospital stay, and high family satisfaction rate are the main benefits of TEN treatments (35). Given that the time to attend school was longer in patients with tibial fractures, open fractures, and open surgery in this study may be due to psychological factors caused by the time of bone union and the long follow-up period in the

hospital. Despite this, family satisfaction was high in this research.

The limitations of this study are the absence of a control group in which other methods of treatment are used, the fact that the study was carried out in a single center, the short follow-up time, and the small sample size with widely distributed age groups

CONCLUSION

The findings obtained in this study suggest that using TEN is an effective and safe method in children aged 5-15 years with long bone diaphysis fractures, and its effects on the patient and the health system are positive with low complication rates. Rigid fixation can be considered in femoral diaphyseal fractures of elderly and overweight patients. We believe that multicenter studies with large patient participation and research in which treatment diversity is discussed comparatively will continue to guide surgeons in the approach to pediatric fractures.

Ethics Committee Approval: This study was approved by İstinye University Clinical Research Ethics Committee (Date: 25.02.2022; Decision No: 3/2022.K-18
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