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ARAŞTIRMA / RESEARCH

Closed reduction and titanium elastic nailing in diaphyseal femoral and tibial fractures in children

Çocuk femur ve tibia şaft kırıklarında kapalı redüksiyon ve titanyum elastik çivileme

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Abstract

Purpose: The aim of this study was to evaluate clinical and radiological results of children who were treated using titanium elastic nail (TEN) for femoral and tibial diaphyseal fractures.
Materials and Methods: A total of 49 (15 female, 34 male) femur shaft fractures (FF group) and 35 (12 female, 23 male) tibial shaft fractures (TF group) were retrospectively analyzed. Time until the operation (in days), duration of hospital stays (in days), time to union (in weeks), and the time to implant removal (in months) were recorded. In the final follow up; limb length discrepancy (mm), angulation, restrictions in the range of hip and knee joint motion were measured. Flynn Score was used for clinical results.
Results: The mean age was 7.96 in the FF group and 9.34 in the TF group. The mean follow-up time was 51.3 months in the FF Group and 58.3 months in the TF group. The mean duration of hospital stay was 1.4 days in both groups. The mean time for bony union was 9.7 weeks and 10.7 weeks for the FF and the TF groups, respectively. The mean time to implant removal was 7.1 months and 6.22 months for the FF and the TF groups, respectively. Flynn scores were poor in 3 patients, successful in 6 patients and excellent in 40 patients in the FF group; whereas it was poor in 1 patient, successful in 2 patients and excellent in 32 patients in the TF group. None of the patients had major complications. Bony union was achieved in all patients.
Conclusion: Intramedullary fixation using TEN is a successful treatment method with satisfactory clinical results and low complication rates for pediatric femoral and tibial diaphyseal fractures.
Keywords:. Pediatric fractures, titanium elastic nailing, closed reduction

Öz

Amaç: Bu çalışmada femur ve tibia diyafiz kırıklarında titanyum elastik çivileme (TEÇ) ile tedavi edilen çocuk hastaların klinik ve radyolojik sonuçlarının değerlendirilmesi amaçlanmıştır.
Gereç ve Yöntem: TEÇ uygulanan 49 (15 kız, 34 erkek) femur diyafiz kırığı (FK grubu) ve 35 (12 kız, 23 erkek) tibia diyafiz kırığı (TK grubu) geriye dönük olarak incelendi. Ameliyata kadar geçen süre (gün), hastanede kalış süresi (gün), kemik kaynama süresi (ay) ve implant çıkarma süresi (ay) kayıt altına alındı. Son kontrolde, bacak uzunluk farkı (mm), açılanma, kalça ve diz eklemi hareket açıklıkları ölçüldü. Klinik skorlama için Flynn skorlaması kullanıldı.
Bulgular: Yaş ortalaması FK grubunda 7,96, TK grubunda ise 9,34 yıl idi. Ortalama takip süresi FK grubunda 51,3 ay, TK grubunda ise 58,3 ay idi. Ortalama hastanede yatış süresi her iki grup için 1,4 gün olarak bulundu. Ortalama kırık kaynama süreleri FK ve TK grubunda sırasıyla 9,7 hafta ve 10,7 haftaydı. Ortalama implant çıkarma süreleri ise FK ve TK grubunda sırasıyla 7,1 ay ve 6,22 ay idi. Flynn skorları FK grubunda 3 hastada kötü, 6 hastada başarılı ve 40 hastada mükemmel; TK grubunda ise 1 hastada kötü, 2 hastada başarılı ve 32 hastada mükemmel olarak hesaplandı. Tüm hastalarda kemik kaynaması sağlandı.
Sonuç: Titanyum elastik çivi ile kanal içi sabitleme yüksek tatmin edici klinik sonuçları ve düşük komplikasyon oranı ile birlikte çocuk femur ve tibia şaft kırıklarında başarılı bir tedavi yöntemidir.
Anahtar kelimeler: Çocuk kırıkları, titanyum elastik çivileme, kapalı redüksiyon

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INTRODUCTION

Bone fractures in children are frequently encountered by all orthopedists. Fractures in children generally differ from the fractures in adults. Diaphyseal tibial and femoral shaft fractures are common injuries in the childhood. The treatment options for these fractures depend on both fracture and patient characteristics. Most of the pediatric fractures have been traditionally treated conservatively[1, 2] Surgical treatment is indicated for fractures that do not meet initial acceptable radiographic criteria for closed reduction (Table 1). Other indications are open fractures, failed non-operative treatment, compartment syndrome, and multiple trauma.

Table 1. Acceptable radiological criteria for pediatric tibial and femoral diaphyseal fractures.

Diaphyseal Tibial Fracture	Diaphyseal Femoral Fracture
♦ 50% of translation ♦ less than 1 cm of shortening ♦ less than 5-10 degrees of angulation in the sagittal and coronal planes ♦ Non-acceptable rotational deformity in the sagittal and coronal planes	♦ less than 2 cm of shortening ♦ less than 10 degrees of angulation in the coronal plane and 20 degrees of angulation in sagittal plane ♦Non-acceptable rotational deformity in the sagittal and coronal planes

There are many surgical treatment options for treating pediatric lower extremity long bone fractures. External fixation, percutaneous pinning, plate fixation, rigid intramedullary fixation and flexible intramedullary fixation can be considered as the surgical options [2,3,4].

Improvements in the intramedullary nails used in children and development of titanium elastic nails (TEN) have opened a new page, particularly in the treatment of long bone fractures in children[5,6]. TEN is the most commonly used implant for flexible intramedullary nailing. Considering its historical development, elastic nails were based on the model described by Rush[7]. After 1980s, nails similar to those we use today were developed. The most important reasons titanium elastic nails are so well adopted can be listed as follows: they allow mild movement along the fracture line, they allow secondary bone union without damage to the growth plate, being a minimally invasive procedure they leave a small and aesthetic scar tissue, early joint movement and return to normal physical activity, low infection rate, reduce the psychologic effects caused by immobility, and reduce the duration of hospital stay[8].

Use of TEN allows indirect reduction and bone healing with less soft tissue dissection[9,10]. The main important difference from the other fixation methods is that TEN prevents displacement, rotation and angulation with its own elastic nature[11]. Our hypothesis is that TEN application in tibia and femoral shaft fractures provides good clinical and radiological results with low complications.

In the present study, long term clinical and radiological results of the patients who were treated with titanium elastic nail due to femoral and tibial diaphyseal fracture and our clinical experience are reported.

MATERIALS AND METHODS

Ethical committee approval was obtained before the study (Eskişehir Osmangazi University, Clinical Researches Ethical Committee, 19.08.2011, 2011/6). Patients who underwent surgical treatment after tibia or femur diaphyseal fracture between 2005-2012 were searched for in the digital archive system. 104 patients were found. The patients who underwent closed reduction and titanium elastic nailing due to tibia or femoral diaphyseal fracture were included in the study. Fractures of the distal and proximal ends, patients with simultaneous fractures of the femur and tibia, open fractures, and patients who underwent open reduction were excluded from the study. A total of 49 (15 girls, 34 boys) femur shaft fracture (FF group) and 35 (12 girls, 23 boys) tibial shaft fracture (TF group) cases who met the inclusion and exclusion criteria were retrospectively analyzed and called for a final follow up. Informed consent was obtained from the parents of all patients. Tibial and femur shaft regions were divided into 3 main sections for defining fracture localization. These sections are called 1/3 proximal, middle, and 1/3 distal of the shaft. By scanning files and old radiographic data, time to the operation (in days), duration of hospital stays (in days), time to union (in weeks), and the time to implant removal (in months) were recorded. In the final follow up; limb length discrepancy (LLD, mm), angulation (degrees), restrictions in the range of hip and knee joint motion were recorded. Leg lengths were calculated by measuring the distance between the medial malleolus and anterior superior iliac spine at both sides. A difference of more than 10 mm was considered significant. When evaluating the final position of the bone, angulation more than 10 degrees detected at the anteroposterior or lateral radiography, was considered significant and accepted as angulated union. In addition, cases were clinically scored based on the scoring system defined by Flynn et al.[12], (Table 2). Union of at least three cortexes and clinical absence of tenderness along the fracture line were accepted as the signs of bone union[13].

Table 2. Demographic and clinical findings

	FF Group (n=49)	**TF Group (n=35)**	**Total (n=84)**	**P Value**
Age (mean ± Sd)	7.96 ± 2.39	9.34 ± 2.13	8.53 ± 2.34	**0.018**
	Median (Min./Max.)	Median (Min./Max.)	Median (Min./Max.)	
Follow-up Time (Month)	46 (24/102)	54 (27/116)	50 (24/116)	0.142
Union Time (Week)	9 (7/15)	11 (8/16)	7 (7/16)	**0.001**
Duration of Hospital Stay (Day)	1 (1/5)	1 (1/5)	1 (1/5)	0.415
Limb Length Discrepancy (mm)	0 (-11/17)	0 (-9/0)	0 (-11/17)	0.111
Malunion with varus-valgus (degree)	0 (0/17)	0 (0/12)	0 (0/17)	0.644
Malunion with flexion-extension (degree)	0 (0/21)	0 (0/10)	0 (0/21)	1
Implant removal time (month)	7(4/18)	6 (3/8)	6 (3/18)	**0.017**

FF: Femur fracture, TF: Tibia fracture, n: Number of patients, Sd: Standard deviation, Min.: Minimum, Max: Maximum, Independent T Test (Bootstrap)

Surgical technique and postoperative follow-up

All surgeries were performed under general anesthesia, while the patient was in supine position, and C-arm flouroscopy was used. Prophylactically, in all cases, 25 mg/kg cefazolin was administered intravenously 30 minutes prior to the surgery. In femur shaft fractures, distal entry was preferred in all cases. In tibial shaft fractures, proximal entry was preferred in all cases. In the metaphyseal region, 2 cm away from the growth plate, using drill or initial entry awl equipment, point of entry was prepared. The nails were chosen so that their width would fill 40% of the bone medulla and before placing the nails, they were bent so that the bowing was maximum along the fracture line. The nail was inserted through the bony cortex at a 30-45 degrees angle and then advanced to the fracture site by rotating 180 degrees in paying attention not to penetrate the opposite cortex. Then, the fracture was reduced using C-arm flouroscopy control. Following the reduction of the fracture, the nails were sequentially advanced to the opposite fracture site. To avoid damage to the greater trochanteric apophysis in femur fractures, and damage to distal epiphysis in tibial fractures, this procedure was performed carefully. After the final control using C-arm fluoroscopy, the nails were cut in such a way that the parts of the nails outside the bone did not create pressure on the skin, end-cup or tip protector was not used. The wound sites were sutured, sterile dressing was performed.

All patients were immobilized with splint after surgery. In femur fractures, long leg splinting was done whereas in tibial fractures, short leg splinting was done. Entry sites of the nails were followed up with wound dressing change in every three days. For post-operative infection prophylaxis, 25 mg/kg *Cefazolin* was administered intravenously 3 times a day for 2 days. Patients were called for control radiographic examination on the postoperative days 7, 15, 30 and 45. Non weight bearing mobilization was started at the first postoperative week. After complete bony union, full-weight bearing was allowed.

Statistical analysis

SPSS 22.0 (IBM Corporation, Armonk, New York, United States) was used for data analysis. Normality distribution of the data was evaluated using Shapiro-Wilk test, and homogeneity of variance was evaluated using Levene's test. The Independent-Samples T test was used for comparing two independent groups. Quantitative variables were expressed as mean ± SD (standard deviation) and median Range (Maximum-Minimum), and categorical variables as n (%) in tables. The variables were examined with 95% confidence level and a p value less than 0.05 was considered significant.

The power analysis was performed using G*Power version 3.1.9.2 (Heinrich-Heine-Universität, Dusseldorf, Germany). 49 patients for the FF group and 35 patients for the TF group were assessed and the power value was found to be 95% and the number of the patients was sufficient (effect size=0.8, α=0.05).

RESULTS

The mean age was 7.96 (3-14) years in the FF group, and 9.34 (5-12) years in the TF group. Two of the patients (4.08%) in the FF group had distal shaft fracture, 44 (89.8%) had middle shaft fracture, and 3 (6.12%) had proximal shaft fracture. In TF group, these numbers were 4 (11.43%), 30 (85.71%), and 1 (2.86%), respectively. The fracture types in the FF group were segmental multi-part in 2 (4.08%) patients, long oblique in 3 (6.12%) and short oblique or transverse in 44 (89.8%), whereas in the TF group, 2 (5.71%) were long spiral oblique and 33 (94.29%) were short oblique.

The mean duration of postoperative hospital stays for both groups were 1.4 (1-5) days. The mean follow-up time was 51.3 (24-102) months in the FF Group and 58.3 (27-116) months in the TF group. The mean time to fracture union was 9.7 (7-15) weeks in the FF group and 10.7 (8-16) in the TF group. The mean time to implant removal was 7.1 (4-18) months for the FF group, and 6.22 (3-8) months for the TF group.

Based on the comparison of Flynn scores, the results were poor in 3 (6.12%) patients, successful in 6 (12.24%), and excellent in 40 (81.63%) in the FF group. The results were poor in 1 (2.86%) patient, successful in 2 (5.71%), and excellent in 32 (91.43%) in the TF group. The number of patients with significant angulation in the anteroposterior and lateral radiographs in the FF and TF groups were 3 (6.12%) and 3 (8.57%), respectively. LLD was found in 4 patients (8.3%) in the FF and 2 patients (5.71%) in the TF group.

Of the patients with a length discrepancy in the FF group, 2 had a length difference greater than 10 mm and the fractured limb was lengthened in both. Of the 2 patients in the TF group with a length difference had less than 10 mm. None of the patients had any intraoperative complications but skin irritation was seen in 1 (2%) patient in the FF group and 4 (11.4%) in the TF group. None of the patients included in the study had any restriction for hip and knee joint range of motions. All patients had full bony union at the last follow-up. It was found that the time to bony union and implant removal was significantly different between the groups. (p:0.001 and p:0.017, respectively). (Table 3).

Table 3. Flynn's scoring criteria with Titanium Elastic Nails

	Excellent	Successful	Poor
Limb Length Discrepancy	< 1 cm	< 2 cm	> 2 cm
Sequence Disorder	5 degrees	10 degrees	> 10 degrees
Pain	Absent	Absent	Present
Complication	Absent	Mild	Major complication and/or extended period for resolvable morbidity

DISCUSSION

Elastic intramedullary nailing is preferred in children's long bone shaft fractures as it allows mild movement along the fracture line, it allows secondary bone union without damage to the growth plate, being a minimally invasive procedure, it leaves a small and aesthetic scar tissue[14,15]. In the present study, titanium elastic intramedullary nails were used. TENs are implants which function based on three points principle, particularly biomechanically. Paying attention to the technical specifications during application contribute to the good results. Lascombes et al. reported that the best results were obtained with maximal curves in the fracture line and by filling 40% of the bone medullas[16]. We adhered to these principles during TEN application. (Figure 1).

Figure 1. Postoperative radiographic views of a patient who underwent TEN due to tibial shaft fracture.

Figure 2. 7-years-old girl, femoral shaft fracture. Radiographic images at (a) pre-operative, (b) early post-operative, and (c) postoperative 5 months.

The range of age in TEN application is a controversial issue. Donati et al. applied TEN on 27 femur shaft fractures with an average age of 3.2 and all under 6 years of age. None of the patients had problems of union and none of the patients had a length discrepancy more than 2 cm. The study strongly supports that surgical treatment can be performed in femoral shaft fractures even in the younger age[17]. In the other studies with wide range of age, TEN application was proven to be effective in femoral shaft fractures[18,19]. In the present study, the mean age for femur fractures was 7.96 (3-14) years and TEN was performed even in the young ages. For pediatric tibia shaft fractures, TEN application is recommended around the age of 10[20,21]. In the present study, the mean age for tibia shaft fractures was 9,34 (5-12) years.

The limb length discrepancy that can occur after elastic nailing is often compensated by the high remodeling capacity of the child's bone structure. In a study by Narayan et al. it was reported that only 6 of the 78 patients with titanium elastic nailing for femoral shaft fractures developed LLD[22]. Gicquel et al. reported that 2 of the 45 patients with titanium elastic nailing for tibial shaft fractures developed limb length differences[23]. In the present study, only two patients in the FF group had limb length difference greater than 10 mm.

The incidence of "malunion" is rare in pediatric fractures. Chen et al. reported that 4 of the 40 patients with titanium elastic nailing for femoral shaft fractures had malunion due to malalignment[8]. In a study conducted in 2016, 16 patients with tibial shaft fractures who underwent TEN were examined and none had angulation more than 10 degrees detected in any plane[24]. In our study, it was found that 3 patients in each group (TF and FF groups) had angulation.

"Nonunion" is a rare condition like "malunion" in pediatric fractures. Saseendar et al. reported titanium elastic nailing for femoral shaft fractures and none of the 16 patients had nonunion[25]. Similarly, O'Brein et al. reported that bony union was achieved in all 14 patients with tibial fractures who underwent titanium elastic nailing[26]. In another study published in 2016, elastic nailing was performed in 45 patients for tibial shaft fracture and while 4 patients had delayed union, nonunion was not detected in any[27]. In the present study, nonunion was not detected in any of the patients in both the FF and TF groups (Figure 2). We found that the mean time to union in the FF and TF groups were 9.7 and 10.7 weeks, respectively. After statistical analysis, it was proven that union occurred significantly earlier in the FF group than the TF group.

Skin irritation caused by prominent nail tips is a common complication in the literature[28]. Particularly after tibial shaft fractures, the reported frequency of nail tip irritation is 7 to 40%[10,11]. In the present study, nail tip irritation was detected in one patient in the FF and 4 patients in the TF group.

In terms of implant removal for TEN, 6 months is the recommended time for both femoral and tibial shaft fractures[9,12]. In the present study, the mean time to implant removal was 7.1 months in the FF group and 6.2 months in the TF group. Although the time to union was shorter in the FF group, it was found that the time to implant removal was longer. This is due to the possibility of nail tip irritation after tibial TEN application.

The necessity of splint after titanium elastic nailing in long bones is controversial[6,9,12]. In the present study, splinting was used until a callus tissue was observed along the fracture line. Regarding the use of splinting, we think that the choice of the surgeon who applied the elastic nail is important.

One of the major concerns regarding the application of TEN in pediatric long bone fractures is the lack of stability. Unstable fracture pattern, overweight and higher age were associated with instability. Andreacchio et al. reported that higher weight (> 50 kg) as a potential risk factor associated with poor clinical outcomes[29]. Shieh et al. defined that unstable fracture pattern as fracture length greater than twice the cortical width[30]. In the present study, we could not reach the weight information of the patients at the time of surgery. Almost all patients had simple fractures in our study groups (except for 2 segmental multi-part fractures in the FF group). Therefore, we cannot comment on this issue.

The main limitations of the present study are that it was planned retrospectively and there was no control group with conservative treatment. Secondly, the weight of the patients at the time of surgery and the instability patterns of the initial fractures were not included in the analysis.

In conclusion, closed reduction with titanium elastic nailing provides favorable results and low complication rates in the treatment of pediatric lower limb fractures. A more comprehensive study including patient characteristics and preoperative instability pattern of the fractures would make a good contribution to the literature in the future.

Yazar Katkıları: Çalışma konsepti/Tasarımı: AK, NK; Veri toplama: AK, ZMA; Veri analizi ve yorumlama: AK, ZMA, NK; Yazı taslağı: AK, ZMA; İçeriğin eleştirel incelenmesi: NK; Son onay ve sorumluluk: AK, ZMA, NK; Teknik ve malzeme desteği: -; Süpervizyon: NK; Fon sağlama (mevcut ise): yok.
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REFERENCES

1. Larsen P, Elsoe R, Hansen SH, Graven-Nielsen T, Laessoe U, Rasmussen S. Incidence and epidemiology of tibial shaft fractures. Injury. 2015;46:746-50.
2. Hunter JB. Femoral shaft fractures in children. Injury. 2005;36:86-93.
3. Raducha JE, Swarup I, Schachne JM, Cruz AI Jr, Fabricant PD. Tibial shaft fractures in children and adolescents. JBJS Rev. 2019;7:e4.
4. Ramseier LE, Janicki JA, Weir S, Narayanan UG . Femoral fractures in adolescents: a comparison of four methods of fixation. J Bone Joint Surg Am 2010;92:1122–9.
5. Slongo TF, Audige L, Group AOPC. Fracture and dislocation classification compendium for children: the AO pediatric comprehensive classification of long bone fractures (PCCF). J Orthop Trauma. 2007;21:135-60.
6. Ligier JN, Metaizeau JP, Prevot J, Lascombes P. Elastic stable intramedullary nailing of femoral shaft fractures in children. J Bone Joint Surg Br. 1988;70:74-7.
7. Rush LV. Dynamic factors in medullary pinning of fractures. Am Surg. 1951;17:803-8.
8. Chen YN, Lee PY, Chang CW, Ho YH, Peng YT, Chang CH, et al. Biomechanical investigation of titanium elastic nail prebending for treating diaphyseal long bone fractures. Australas Phys Eng Sci Med. 2017;40:115-26.
9. Sankar WN, Jones KJ, David Horn B, Wells L. Titanium elastic nails for pediatric tibial shaft fractures. J Child Orthop. 2007;1:281-6.
10. Khoriati AA, Jones C, Gelfer Y, Trompeter A. The management of paediatric diaphyseal femoral

fractures: a modern approach. Strategies Trauma Limb Reconstr. 2016;11:87-97.
11. Kuntia S, Swaroop S, Patro BP, Sahu S. Paediatric Long Bone Fractures Managed with Elastic Intramedullary Nails: A Retrospective Study of 30 Patients. Cureus. 2020;12:e7847.
12. Flynn JM, Hresko T, Reynolds RA, Blasier RD, Davidson R, Kasser J. Titanium elastic nails for pediatric femur fractures: a multicenter study of early results with analysis of complications. J Pediatr Orthop. 2001;21:4-8.
13. Fisher JS, Kazam JJ, Fufa D, Bartolotta RJ. Radiologic evaluation of fracture healing. Skeletal Radiol. 2019;48:349-61.
14. Hedstrom EM, Svensson O, Bergstrom U, Michno P. Epidemiology of fractures in children and adolescents. Acta Orthop. 2010;81:148-53.
15. Nisar A, Bhosale A, Madan SS, Flowers MJ, Fernandes JA, Jones S. Complications of Elastic Stable Intramedullary Nailing for treating paediatric long bone fractures. J Orthop. 2013;10:17-24.
16. Lascombes P, Haumont T, Journeau P. Use and abuse of flexible intramedullary nailing in children and adolescents. J Pediatr Orthop. 2006;26:827-34.
17. Donati F, Mazzitelli G, Lillo M, Menghi A, Conti C, Valassina A, et al. Titanium elastic nailing in diaphyseal femoral fractures of children below six years of age. World J Orthop. 2017;8:156-62.
18. Bhuyan BK, Mohan Singh S. Titanium elastic nailing in pediatric femoral diaphyseal fractures in the age group of 5-16 years - A short term study. J Clin Orthop Trauma. 2014;5:203-10.
19. Rajak MK, Thakur R, Choudhary A, Bhaduri I, Kumar S. Titanium elastic nailing in femoral diaphyseal fractures in children of 6-14 years age. Acta Orthop Belg. 2016;82:883-8.
20. Setter KJ, Palomino KE. Pediatric tibia fractures: current concepts. Curr Opin Pediatr. 2006;18:30-5.
21. Mashru RP, Herman MJ, Pizzutillo PD. Tibial shaft fractures in children and adolescents. J Am Acad Orthop Surg. 2005;13:345-52.
22. Narayanan UG, Hyman JE, Wainwright AM, Rang M, Alman BA. Complications of elastic stable intramedullary nail fixation of pediatric femoral fractures, and how to avoid them. J Pediatr Orthop. 2004;24:363-9.
23. Gicquel P, Giacomelli MC, Basic B, Karger C, Clavert JM. Problems of operative and non-operative treatment and healing in tibial fractures. Injury. 2005;36:44-50.
24. Heo J, Oh CW, Park KH, Kim JW, Kim HJ, Lee JC, et al. Elastic nailing of tibia shaft fractures in young children up to 10 years of age. Injury. 2016;47:832-6.
25. Saseendar S, Menon J, Patro DK. Treatment of femoral fractures in children: is titanium elastic nailing an improvement over hip spica casting? J Child Orthop. 2010;4:245-51.
26. O'Brien T, Weisman DS, Ronchetti P, Piller CP, Maloney M. Flexible titanium nailing for the treatment of the unstable pediatric tibial fracture. J Pediatr Orthop. 2004;24:601-9.
27. Kc KM, Acharya P, Sigdel A. Titanium Elastic Nailing System (TENS) for tibia fractures in children: functional outcomes and complications. JNMA J Nepal Med Assoc. 2016;55:55-60.
28. Nisar A, Bhosale A, Madan SS, Flowers MJ, Fernandes JA, Jones S. Complications of elastic stable intramedullary nailing for treating paediatric long bone fractures. J Orthop. 2013;10:17-24.
29. Andreacchio A, Alberghina F, Marengo L, Canavese F. Pediatric tibia and femur fractures in patients weighing more than 50 kg (110 lb): mini-review on current treatment options and outcome. Musculoskeletal Surg. 2019;103:23-30.
30. Shieh AK, Saiz Jr AM, Hideshima KS, Haus BM, Leshikar HB. Defining length stability in paediatric femoral shaft fractures treated with titanium elastic nails. J Child Orthop. 2021;15:525-31.