Original Article

HEALTH SCIENCES
MEDICINE

DOI: 10.32322/jhsm.1354354
J Health Sci Med. 2023;6(6):1366-1372

Pediatric forearm fractures: evaluating implant removal timing and complications with exposed titanium-elastic nail tips

Fatih Gölgelioğlu, Mustafa Yalın

Department of Orthopedics and Traumatology, Elazığ Fethi Sekin City Hospital, Elazığ, Turkey

Cite this article as: Gölgelioğlu F, Yalın M. Pediatric forearm fractures: evaluating implant removal timing and complications with exposed titanium-elastic nail tips. *J Health Sci Med.* 2023;6(6):1366-1372.

Received: 02.09.2023 ◆ **Accepted**: 18.10.2023 ◆ **Published**: 29.10.2023

ABSTRACT

Aims: The current study investigates complication rates, timing of implant removal, and correlations between removal timing and complications/refractures in pediatric forearm fracture patients who had exposed titanium-elastic nail (TEN) tips.

Methods: This retrospective single-center study analyzed pediatric forearm fractures in patients who underwent TEN with exposed tips. Inclusion criteria covered cases between August 2018 and January 2022, focusing on children with both-bone forearm fractures and unsuccessful conservative treatment. Data included demographics, fracture details, reduction type, implant removal timing, complications, and refracture rates.

Results: Between August 2018 and August 2022, the study involved 65 children (54 boys, 11 girls), aged 4 to 15 years. Implant removal occurred at 4 to 11 weeks, on average at 7.17±1.52 weeks. Fracture location was distal 1/3 (9.2%), middle 1/3 (78.5%), proximal 1/3 (12.3%). The predominant causes of fractures were falls (89.2%). Fracture types consisted of open fractures (6.2%) and closed fractures (93.8%). Reduction methods included mini-open reduction (9.2%) and closed reduction (90.8%). Implant removal occurred at or before 6 weeks for 43.1% of cases, while it exceeded 6 weeks for 56.9% of cases. Complications were noted in 21.5% of cases, encompassing delayed union (14.3%), hypertrophic granuloma (7.1%), infection (21.4%), skin irritation (42.9%), and refracture (14.3%). Clinical outcomes were classified as excellent in 83.1% of cases and good in 16.9% of cases. No statistically significant differences were observed in complications (p=0.351) or clinical outcomes (p=0.441) based on implant removal timing.

Conclusion: Contrary to belief, exposing nail tips, not burying them, is safe, cost-effective, and leads to minimal complications with positive clinical outcomes. Implant removal timing did not significantly impact clinical outcomes or complications. TENs used in forearm fractures can be removed before 6 weeks when adequate union is observed.

Keywords: Pediatric forearm fractures, titanium elastic nail, exposed tips, implant removal

INTRODUCTION

Forearm fractures are frequently observed in the paediatric population, ranking high in terms of prevalence.[1-3] While the treatment for most of these fractures involves reduction and casting, unstable fractures frequently necessitate fixation in order to ensure proper alignment during the course of recovery.[4,5] The prevalence of surgical procedures has grown in recent years.[6] Titanium-elastic intramedullary nails (TENs) have been employed in clinical practice since the beginning of the 1980s. Superior outcomes have been documented with TENs in comparison to open reduction internal fixation (ORIF) due to its inherent benefits, including reduced soft tissue trauma and shorter surgical duration.[7,8] Fixation of forearm fractures in individuals with immature skeletons has mostly shifted towards the use of TENs.[6,9,10]

There is significant variation between institutions and physicians in their adherents regarding the removal of these implants, and a consensus has not been reached regarding the optimal timing for removal.[11-15] While proponents of leaving exposed tips argue for their removal within an average timeframe of 6 weeks, advocates of burying subcutaneous tips recommend elective removal within an average timeframe of 6 months.[16,17] Exposing the tips of the implants during a surgical procedure offers the advantage of facilitating a simplified and effective operative process as well as reducing the extent of anaesthesia required.[17] Supporters of early implant removal argue that keeping the exposed tips of implants may offer the advantage of enabling implant removal to be performed in an office setting, thereby eliminating the necessity for a subsequent

Corresponding Author: Mustafa Yalın, mustiyalin1988@gmail.com

surgical procedure and exposure to anaesthesia. This approach could potentially result in a secondary benefit of decreased financial burden.18 The migration of implants in TENs with buried tips can present challenges due to the complexities associated with monitoring, which are influenced by external variables. Previous research in the field of literature has demonstrated that the clinical and radiological outcomes of burying or exposing the tips of TENs were found to be similar in cases of forearm fractures in paediatric patients.[19] Nevertheless, the existing body of literature on the complications associated with the removal of TEN nails is limited in terms of studies that specifically investigate the timing of removal. Early removal of TEN carries a significant risk of refracture. The primary aim of the current study was to investigate the complication rates in paediatric patients who underwent TEN with exposed tips for forearm fractures. The secondary aim of the present study was to investigate the relationship between the timing of TEN removal and the occurrence of complications and refracture.

METHODS

The current study was carried out with the permission of the Fırat University Non-interventional Researches Ethics Committee (Date: 10.08.2023, Decision No: 2023/11-16). All procedures were carried out in accordance with the ethical rules and principles of the Declaration of Helsinki.

The present investigation included a retrospective analysis of a database from a single centre, focusing on forearm fractures in children who underwent TEN with an exposed tip. The consecutive patients who underwent TEN with an exposed tip at our hospital between August 2018 and January 2022 were considered for inclusion in the cohort. The study enrolled children who had both-bone forearm fractures and received unsuccessful closed reduction and long-arm splint treatment, as well as those with type 1 open fractures and patients who experienced unacceptable angulation (for mid and distal shaft fractures: >15° angulation, >30° malrotation, and 100% displacement for children under 8 years old; >10° angulation, >30° malrotation, and 100% displacement for children over 8 years old; for proximal shaft fractures: >10° angulation, >30° malrotation, and 100% displacement for children under 8 years old; anatomic reduction with internal fixation recommended for children over 8 years old) during the post-reduction follow-up period.[20] After conducting a comprehensive review of hospital records, the study retrospectively analysed data including age, gender, fracture type, fracture location, cause of injury, whether the fracture was open or closed, type of reduction performed, timing of implant removal (≤ 6 weeks or >6 weeks), complications encountered, and rates of refracture development during the follow-up period. The information was gathered at the time of admission as well as at each subsequent appointment until the treatment was over. Excluded from the study were patients with fractures in close proximity to the epiphyseal plate, individuals with isolated fractures of the radius and ulna, individuals who had Monteggia or Galeazzi injuries, individuals with additional fractures in that specific extremity, individuals with multiple injuries, patients who discontinued follow-up or were unreachable, patients with type II-III open fractures, as well as those with pathological fractures.

Surgical Procedure and Follow-up

In each instance, one single nail was employed for each bone, with the use of a TEN (TST Istanbul Medical Devices) across all cases. All surgeries were conducted with the patient supine on the operating table, and either a closed or open reduction was performed via fluoroscopic assistance by the same team of five surgeons with a combined five years of expertise in orthopaedic trauma. Following appropriate preparation, the initial insertion was made into the radial metaphysis through the extensor carpi radialis brevis and extensor carpi radialis longus tendons, specifically targeting the radius lateral to the Lister tubercle. The antegrade technique was employed to treat the ulna by positioning its insertion point on the posterior side of the olecranon. The potential risk of developing olecranon epiphyseal injury was explained to the family and informed consent forms were obtained. After three unsuccessful attempts at closed reduction and nail penetration to the proximal fragment, the reduction of fracture in radial fractures was achieved through a dorsal approach using a mini-Thompson incision, while for ulna shaft fractures, reduction was performed from the lateral side using a transcutaneous mini-incision. The determination of nail diameter was conducted with the aid of fluoroscopic control, ensuring that it was not less than 40% of the total width of the medullary canal.[21] To avoid harming the skin, the tips of all applied nails were curved and exposed. Following surgery, the patient was given intravenous pain medication, had their arm immobilized in a long-arm splint, and began rapid finger and elbow exercises. The long-arm splint was taken off after two weeks. All cases underwent follow-up visits at biweekly intervals starting from week 2 until the completion of 3 months. Subsequently, follow-up visits were conducted at six months as well as one year. The presence of callus in three out of four cortexes observed in the images, along with the absence of tenderness upon palpation at the location of the fracture during clinical examination,

were deemed indicators of union.[22] The patients who were deemed to have achieved union underwent the removal of their implants in an outpatient clinic setting, followed by the acquisition of control images. The durations for the removal of implants in the patients were assessed and documented as follows: ≤6 weeks or >6 weeks. The patients were monitored for a minimum of one year, regardless of the timing of implant removal. The rates of complications and refractures were documented. The pain and supination/pronation range of motion of patients were measured using a scale proposed by Price CT et al.[23] and Daruwalla et al.[24] The clinical assessment of Price CT, as used by Daruwalla, is based on daily activity and loss of range of motion. It involves categorising range of motion into 10 degrees, 11-30 degrees and 31-90 degrees. The clinical results were evaluated using the Price and Flynn criteria.[25]

Statistical Analysis

The IBM SPSS Statistics 22 (IBM SPSS, Turkey) programme was used for statistical analyses while evaluating the findings obtained in the study. The conformity of the parameters to the normal distribution was evaluated by the Shapiro-Wilks test. In addition to descriptive statistical methods (mean, standard deviation, and frequency), Fisher's exact test and continuity (Yates) correction were used to compare qualitative data. Significance was evaluated at $p<0.05$ level.

RESULTS

The study was conducted between August 2018 and August 2022 with a total of 65 children, 54 (83.1%) boys and 11 (16.9%) girls, aged between 6 and 15 years. The mean age of the children was 10.34±2.44 years (Table 1). All 65 eligible patients were assessed and none of them were unreachable.

Table 1. Distribution of demographics

	Min-Max	Mean±SD
Age	6-15	10.34±2.44
Gender	**n**	**%**
Male	54	83.1
Female	11	16.9

The timing of implant removal ranged between 4 and 11 weeks, with a mean of 7.17±1.52 and a median of 7 weeks. The duration of follow-up ranged between 12 and 16 months, with a mean of 13.51±1.21 and a median of 13 months (Table 2).

The location of the fracture was observed to be distal 1/3 in 9.2% of the children, middle 1/3 in 78.5% of the children, and proximal 1/3 in 12.3% of the children. The primary cause of injury was attributed to falls in 89.2% of cases, while direct strikes accounted for 4.6% and traffic accidents accounted for 6.2%. The open fracture type accounted for 6.2% of cases, while the closed fracture type accounted for 93.8% of cases. The mini-open reduction type was observed in 9.2% of cases, while the closed reduction type was observed in 90.8% of cases (Table 2).

Table 2. Distribution of the operating parameters

	Min-Max	Mean±SD (Median)
Timing of implant removal (weeks)	4-11	7.17±1.52 (7)
Duration of follow-up (months)	12-16	13.51±1.21 (13)
	n	%
Fracture location		
Distal 1/3	6	9.2
Middle 1/3	51	78.5
Proximal 1/3	8	12.3
Cause of injury		
Fall	58	89.2
Direct Strike	3	4.6
Traffic accident	4	6.2
Fracture Type		
Open	4	6.2
Closed	61	93.8
Reduction type		
Mini-Open	6	9.2
Closed	59	90.8
Timing of implant removal (weeks) group		
≤6	28	43.1
>6	37	56.9
Complications		
None	51	78.5
Delayed union	2	3.1
Hypertrophic granüloma	1	1.5
Infection	3	4.6
Refracture	2	3.1
Skin irritation	6	9.2
Complications Group		
No	51	78.5
Yes	14	21.5
Complications (n=14)		
Delayed union	2	14.3
Hypertrophic granüloma	1	7.1
Infection	3	21.4
Skin irritation	6	42.9
Refracture	2	14.3
Clinical outcomes		
Good	11	16.9
Excellent	54	83.1

In 43.1% of the cases, the duration for implant removal in children was 6 weeks or less, whereas in 56.9% of the cases, it exceeded 6 weeks. A total of 78.5% of individuals experienced no complications, while 21.5% encountered complications. The observed complications included delayed union in 14.3% of cases, hypertrophic granuloma

in 7.1% of cases, infection in 21.4% of cases, skin irritation in 42.9% of cases, and refracture in 14.3% of cases (Figures 1 and 2). The clinical outcomes were deemed good in 16.9% of cases and excellent in 83.1% of cases (Table 2).

Figure 1. Initial postoperative radiograph of an 8-year-old male patient.

Figure 2. The radiograph obtained at approximately six weeks after the surgical procedure and just before to the extraction of the elastic nail.

Upon comparing the complication rates based on the timing of implant removal, no statistically significant difference was observed between the groups (p=0.351, p>0.05) (Table 3).

Table 3. Evaluation of the presence of complications and clinical outcomes between implant removal time groups

	Timing of implant removal (weeks) group		p
	≤6 n (%)	>6 n (%)	
Complications Group			10.351
No	24 (85.7)	27 (73)	
Yes	4 (14.3)	10 (27)	
Complications			20.175
Delayed union	0 (0)	2 (20)	
Hypertrophic granuloma	0 (0)	1 (10)	
Infection	0 (0)	3 (30)	
Skin irritation	3 (75)	3 (30)	
Refracture	1 (25)	1 (10)	

1Continuity (Yates) Correction, 2Fisher's Exact Test

No statistically significant difference was found between the groups when comparing the clinical results based on the time of implant removal (p=0.441, p>0.05) (Table 4).

Table 4. Evaluation of clinical outcomes between implant removal time groups

Clinical outcomes	Timing of implant removal (weeks) group		p
	≤6 n (%)	>6 n (%)	
Good Excellent	4 (14.3) 24 (85.7)	7 (18.9) 30 (81.1)	0.441

Fisher's Exact Test

DISCUSSION

The primary outcome of the current study revealed a lack of association between the time of implant removal and the incidence of complications and refractures in paediatric individuals who underwent TEN with exposed tips for forearm fractures. An additional significant discovery of the research is its strong emphasis on the low occurrence of complications and the excellent clinical results associated with the use of TENs with exposed tips. These findings support the idea that exposing IM implants during the surgical treatment of paediatric forearm fractures is a feasible option.

According to a study conducted by Dinçer et al.[19] in 2019, the clinical and radiological outcomes of both-bone forearm fractures in children were found to be comparable when the tips of TENs were either buried subcutaneously or left exposed. Consistent with the aforementioned study, existing literature indicates that there are no significant disadvantages associated with leaving the tips of the elastic nails exposed.[17,26] The patients received a single administration of general anaesthesia solely for the purpose of reduction procedures. Implant removal can be efficiently conducted in an outpatient clinic setting without the requirement for anaesthesia. Moreover, drawing on the data obtained in the current study, we would like to highlight the high level of compliance shown by patients who had TENs with exposed tips in terms of adhering to follow-up appointments. This noteworthy characteristic has potential advantages for ensuring effective patient monitoring and continuity of care.

The research conducted by Kelly et al.[17] reported a complication rate of 17.2% among a sample of 128 patients who had the implant tips exposed. The findings from this study match closely with the current study, which also observed a complication rate of 21.5%. Dinçer et al.[19] found that among 74 patients with exposed implant tips, 26 (35%) experienced at least one complication, with skin irritation being the most

prevalent. The complication rates observed in the current study are comparatively lower than those reported by Dinçer et al.[19] However, it is noteworthy that both studies identified skin irritation as the most commonly observed complication.

The occurrence of nonunion and delayed union in paediatric forearm fractures is rare. The literature has shown a prevalence of nonunion in the range of 0.3% to 1% as a result of open reduction as well as other contributing factors.[27,28] Adolescents may have difficulties with delayed union after TEN, particularly after open fractures or open reduction of ulnar fractures.[19] No instances of nonunion were detected in any of the patients included in the current study. Delayed union was observed in two patients who underwent TEN with an exposed tip. Both patients underwent open reduction of their forearm bones, with union times of 11 weeks and 10 weeks, respectively.

The migration of implants in TENs with buried tips might present an obstacle due to the complexities associated with follow-up, which can be influenced by patient and external factors. With exposed TENs, a second surgery is not necessary. In one instance within the current study, a hypertrophic granuloma was debrided subsequent to the extraction of the elastic nail. The wound successfully healed without necessitating suturing. It is well known that tendons (particularly the extensor pollicis longus) and the superficial sensory branch of the radial nerve may be irritated or damaged by buried tip TEN implantation. The absence of any detected tendon or nerve injury in our patient cohort serves to further support the safety of using TENs with an exposed tip. Infections of the bone and soft tissues are another major concern for orthopaedic surgeons. Similar to the literature, in three instances, accounting for 4.6% of the cases, pintract infections occurred in patients with exposed tips. Kelly et al.[17] identified an infection incidence of 2.7% in patients with exposed TENs, whereas another investigation evaluating distal humeral fractures revealed a prevalence of 3%.[22] The infections were successfully cured within a period of one week with the administration of adequate antibiotherapy. There was no occurrence of a deep infection among any of the patients.

The duration of the extraction of intramedullary devices is a matter of concern due to the potential risk of refracture. The literature reports a refracture rate of approximately 5-10% in patients who are managed conservatively.[29,30] In contrast, cases treated with TEN have shown a rare occurrence of refracture, with a rate of 0.5%.[31,32] The current study found refracture in two individuals, accounting for 3.1% of the sample (**Figures 3** and **4**). Dinçer et al.[19] reported a surprising finding of refracture in 2.1% of exposed implants and 3.1% of buried cases following removal. Lascombes et al.[16] hypothesised that implants should be buried under the skin for 6-12 months to provide biomechanical support and reduce the risk of refracture. However, this hypothesis contradicts both the present study and the study conducted by Dinçer et al.[19] In a study conducted by Qairul et al.[33] involving 100 paediatric patients with forearm fractures, it was found that the fractures typically healed within a period of 3-6 weeks. The preservation of the periosteum during TEN applications, along with the slight movement of the fracture, contributes to the promotion of callus formation, thereby positively impacting the process of fracture healing.[34] In the current study, the likelihood of refracture following the removal of implants within 6 weeks was comparable to the likelihood of refracture following the removal of implants after 6 weeks. This similarity may be attributed to the achievement of adequate bone union before the 6-week mark. The current study did not find any statistically significant association between the timing of implant removal and the incidence of any other complications ($p>0.05$). Considering the complication rates associated with both methods, it may be reasonable to remove TENs before 6 weeks, taking into consideration the level of union.

Figure 3: The child experienced a fall approximately 8 months after the removal of the implant, resulting in a diagnosis of refracture

Figure 4: Lateral radiograph of the patient with refracture. The patient rejected the offer of surgery and discharged themselves from the hospital.

An additional significant finding of the current study was that the clinical outcomes were excellent in 83.1% of cases and good in 16.9% of cases, regardless of the timing of implant removal. The union was achieved in all patients, and the removal of implants was performed in a cost-effective manner within the outpatient clinic setting.

Limitations and Strengths

The present investigation is subject to several limitations. The research is limited to a single tertiary institution within our nation, making it a retrospective study with inevitable drawbacks. The limited patient population and low occurrence of complications restricted the possibility of conducting a statistical analysis on some data. The potential influence of patients' social and educational backgrounds on complication rates and subsequent study findings should be considered. An additional limitation is the absence of age-specific analysis for the complication rates of the patients included in the study. A primary factor contributing to this is the insufficient sample size, which rendered the statistical findings insignificant. One notable strength of the research is its comprehensive assessment of clinical outcomes and complications, suggesting that the use of TENs for the management of forearm fractures in paediatric patients with exposed tips is a viable and efficacious therapeutic approach. Another notable aspect of the current study is its attempt to partially address the existing controversy within the literature about the optimal timing for implant removal.

CONCLUSION

Contrary to popular belief, the technique of allowing the nail tip to be exposed is a secure treatment choice that serves as an alternative to subcutaneously burying the tips. The rates of complications are minimal, clinical outcomes are highly favourable, and the process of removing the implant is both cost-effective and straightforward. Our observations indicate that the timing of implant removal did not have a significant impact on clinical outcomes and rates of complications. TENs used in forearm fractures can be removed before 6 weeks when adequate union is observed.

ETHICAL DECLARATIONS

Ethics Committee Approval: The current study was carried out with the permission of the Fırat University Non-interventional Researches Ethics Committee (Date: 10.08.2023, Decision No: 2023/11-16).

Informed Consent: Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process: Externally peer reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Author Contributions: All the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

1. Mann DC, Rajmaira S. Distribution of physeal and nonphyseal fractures in 2,650 long-bone fractures in children aged 0-16 years. *J Pediatr Orthop.* 1990;10(6):713-716.
2. Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. *J Hand Surg Am.* 2001;26(5):908-915.
3. Mehlman CT, Wall EJ. Injury to the shafts of the radius and ulna. In: Rockwood CA, Wilkins KE, Beaty JH, et al, eds. Rockwood and Wilkins' Fractures in Children. Philadelphia, PA: Lippincott Williams & Wilkins. 2006:347-404.
4. Franklin CC, Robinson J, Noonan K, Flynn JM. Evidence-based medicine: management of pediatric forearm fractures. *J Pediatr Orthop.* 2012;32 Suppl 2:S131-S134.
5. Zionts LE, Zalavras CG, Gerhardt MB. Closed treatment of displaced diaphyseal both-bone forearm fractures in older children and adolescents. *J Pediatr Orthop.* 2005;25(4):507-512.
6. Flynn JM, Jones KJ, Garner MR, Goebel J. Eleven years experience in the operative management of pediatric forearm fractures. *J Pediatr Orthop.* 2010;30(4):313-319.

7. Van der Reis WL, Otsuka NY, Moroz P, Mah J. Intramedullary nailing versus plate fixation for unstable forearm fractures in children. *J Pediatr Orthop.* 1998;18(1):9-13.
8. Myers GJ, Gibbons PJ, Glithero PR. Nancy nailing of diaphyseal forearm fractures. single bone fixation for fractures of both bones. *J Bone Joint Surg Br.* 2004;86(4):581-584.
9. Jubel A, Andermahr J, Isenberg J, Issavand A, Prokop A, Rehm KE. Outcomes and complications of elastic stable intramedullary nailing for forearm fractures in children. *J Pediatr Orthop B.* 2005;14(5):375-380.
10. Kang SN, Mangwani J, Ramachandran M, Paterson JM, Barry M. Elastic intramedullary nailing of paediatric fractures of the forearm: a decade of experience in a teaching hospital in the United Kingdom. *J Bone Joint Surg Br.* 2011;93(2):262-265.
11. Loder RT, Feinberg JR. Orthopaedic implants in children: survey results regarding routine removal by the pediatric and nonpediatric specialists. *J Pediatr Orthop.* 2006;26(4):510-519.
12. Raney EM, Freccero DM, Dolan LA, Lighter DE, Fillman RR, Chambers HG. Evidence-based analysis of removal of orthopaedic implants in the pediatric population. *J Pediatr Orthop.* 2008;28(7):701-704.
13. Simanovsky N, Tair MA, Simanovsky N, Porat S. Removal of flexible titanium nails in children. *J Pediatr Orthop.* 2006;26(2):188-192.
14. Peterson HA. Metallic implant removal in children. *J Pediatr Orthop.* 2005;25(1):107-115.
15. Kahle WK. The case against routine metal removal. *J Pediatr Orthop.* 1994;14(2):229-237.
16. Lascombes P, Prevot J, Ligier JN, Metaizeau JP, Poncelet T. Elastic stable intramedullary nailing in forearm shaft fractures in children: 85 cases. *J Pediatr Orthop.* 1990;10(2):167-171.
17. Kelly BA, Miller P, Shore BJ, Waters PM, Bae DS. Exposed versus buried intramedullary implants for pediatric forearm fractures: a comparison of complications. *J Pediatr Orthop.* 2014;34(8):749-755.
18. Das De S, Bae DS, Waters PM. Displaced humeral lateral condyle fractures in children: should we bury the pins?. *J Pediatr Orthop.* 2012;32(6):573-578.
19. Dinçer R, Köse A, Topal M, Öztürk İA, Engin MÇ. Surgical treatment of pediatric forearm fractures with intramedullary nails: is it a disadvantage to leave the tip exposed? *J Pediatr Orthop B.* 2020;29(2):158-163.
20. Price CT. Acceptable alignment of forearm fractures in children: open reduction indications. *J Pediatr Orthop.* 2010;30:S82-S84.
21. Segev E, Hemo Y, Wientroub S, et al. Intra- and interobserver reliability analysis of digital radiographic measurements for pediatric orthopedic parameters using a novel PACS integrated computer software program. *J Child Orthop.* 2010;4(4):331-341.
22. Köse A, Aydın A, Ezirmik N, Can CE, Topal M, Tipi T. Alternative treatment of forearm double fractures: new design intramedullary nail. *Arch Orthop Trauma Surg.* 2014;134(10):1387-1396.
23. Price CT, Scott DS, Kurzner ME, Flynn JC. Malunited forearm fractures in children. *J Pediatr Orthop.* 1990;10(6):705-712.
24. Daruwalla JS. A study of radioulnar movements following fractures of the forearm in children. *Clin Orthop Relat Res.* 1979;(139):114-20.
25. Demirtaş İ, Asfuroğlu ZM, Çolak M. Technical aspects that may affect the outcomes of pediatric patients with both-bone forearm diaphyseal fractures treated using elastic stable intramedullary nails [published online ahead of print, 2023 May 29]. *J Pediatr Orthop B.* 2023;10.1097/BPB.0000000000001093.
26. Chan LW, Siow HM. Exposed versus buried wires for fixation of lateral humeral condyle fractures in children: a comparison of safety and efficacy. *J Child Orthop.* 2011;5(5):329-333.
27. Adamczyk MJ, Riley PM. Delayed union and nonunion following closed treatment of diaphyseal pediatric forearm fractures. *J Pediatr Orthop.* 2005;25(1):51-55.
28. Ogonda L, Wong-Chung J, Wray R, Canavan B. Delayed union and non-union of the ulna following intramedullary nailing in children. *J Pediatr Orthop B.* 2004;13(5):330-333.
29. Bohm ER, Bubbar V, Yong Hing K, Dzus A. Above and below-the-elbow plaster casts for distal forearm fractures in children. a randomized controlled trial. *J Bone Joint Surg Am.* 2006;88(1):1-8.
30. Cullen MC, Roy DR, Giza E, Crawford AH. Complications of intramedullary fixation of pediatric forearm fractures. *J Pediatr Orthop.* 1998;18(1):14-21.
31. Sommerfeldt DW, Schmittenbecher PP. Elastic stable intramedullary nailing (ESIN) in the adolescent patient-perils, pearls, and pitfalls. *Eur J Trauma Emerg Surg.* 2014;40(1):3-13.
32. Kutsikovich JI, Hopkins CM, Gannon EW 3rd, et al. Factors that predict instability in pediatric diaphyseal both-bone forearm fractures. *J Pediatr Orthop B.* 2018;27(4):304-308.
33. Qairul IH, Kareem BA, Tan AB, Harwant S. Early remodeling in children's forearm fractures. *Med J Malaysia.* 2001;56 Suppl D:34-37.
34. Kong JS, Huang Y, Chen T, et al. Comparison of open reduction and internal fixation with plate and titanium elastic intramedullary nail in treating pediatric humeral fracture. *Orthop Surg.* 2021;13(2):434-441.