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# Pediatric Forearm Fractures: Investigating the Functional Outcomes of Titanium Elastic Nailing for Unstable Both-Bone Fractures

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**Learning Point of the Article:**

Flexible intramedullary nailing shows mostly successful outcomes; following basic surgical principles is required to avoid complications.

## Abstract

**Introduction:** Diaphyseal forearm fractures pose a common challenge in children and adolescents, impacting forearm function due to rotational deformities and angulation. The landscape of pediatric forearm fracture treatment has seen limited progression, with increased surgical intervention adoption driven by factors such as functional implications, technological advancements, societal expectations, and legal concerns.

**Materials and Methods:** This study enrolled consecutive children aged 5–16 years with forearm fractures presenting between August 2018 and January 2020, requiring surgical intervention. The study assessed functional outcomes and complications in children treated with titanium elastic nailing.

**Results:** Sixteen patients underwent surgery for both-bone forearm fractures. Elastic nailing was the primary intervention, with 75% undergoing closed nailing. Patients' ages ranged from 5 to 15 years, with 87.5% being male. The study evaluated fracture characteristics, surgical procedures, post-operative care, and complications.

**Conclusion:** The study demonstrates promising outcomes for flexible intramedullary nailing in pediatric forearm fractures. Despite the observed complications, the majority of cases achieved excellent results in fracture union and patient recovery, supporting the efficacy of this technique. Larger cohorts are needed for a comprehensive understanding of its applicability and outcomes in pediatric forearm fracture management.

**Keywords:** Pediatric forearm fractures, flexible intramedullary nailing, titanium elastic nailing, functional outcomes, surgical intervention.

## Introduction

Diaphyseal forearm fractures are prevalent among children [1-3] and adolescents [4-6], causing rotational deformities and angulation that impede forearm function [4, 5]. Anatomical reduction is crucial, particularly for older children with limited remodeling potential [4, 6]. Despite these concerns, the treatment landscape for pediatric forearm fractures has seen minimal progression.

Factors such as functional implications of malunion, technological advancements, societal expectations, and legal concerns have driven the increased adoption of surgical intervention [7-9]. Open reduction and internal fixation (ORIF) methods involving stainless steel Kirschner wires, Steinmann's pins, plates, screws, and intramedullary nails are

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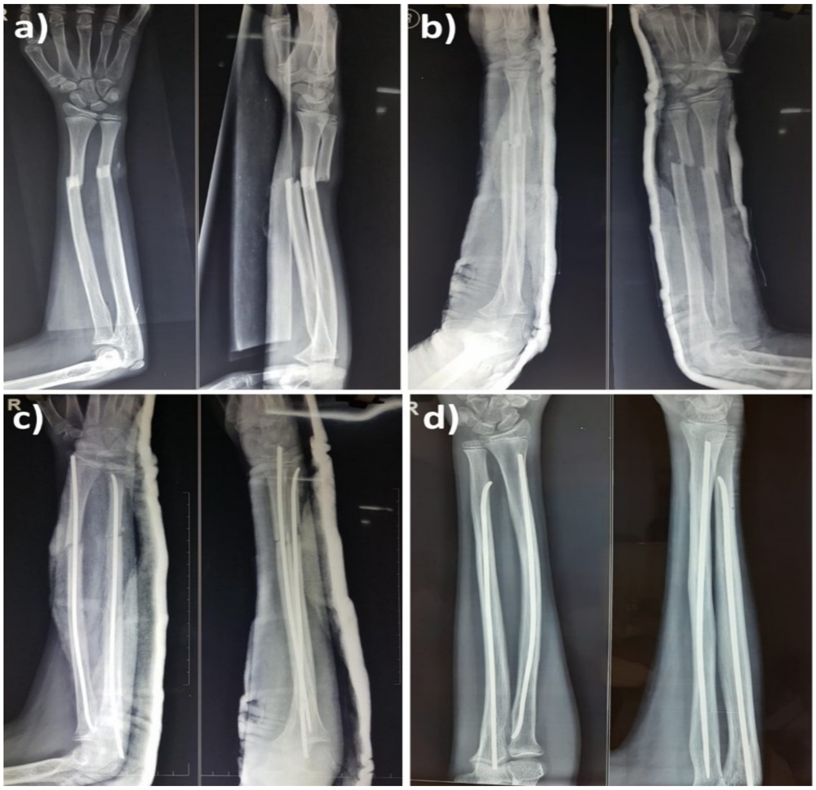


**Figure 1:** Anteroposterior and lateral radiographs of the right forearm of a 14-year-old boy (a) at presentation. (b) After closed reduction (reduction was attempted considering his age), (c) following titanium elastic nailing, and (d) at 7-month follow-up showing good alignment and fracture union with maintenance of radial bow.

common [4, 5, 8, 10]. Among these, intramedullary nailing has gained traction due to the benefits it offers, including elasticity and stability from three-point fixation [11, 12].

Intramedullary flexible nails, popularized by Metaizeau, provide good stability in long bone fractures in children [13, 14], and in the forearm, they can adequately recreate the interosseous space [11, 12]. Though they are not without complications [15], Titanium (Ti 6A114V) nails, favored over stainless steel, afford easier insertion, fixation, and fracture stability [5]. Although elastic nailing is established in the Western context, evidence remains scarce in the Indian population. Therefore, our study aims to address this gap by assessing the functional outcomes and complications in children with diaphyseal fractures of both forearm bones treated using titanium elastic nailing (TEN).

## Materials and Methods

The study enrolled consecutive children aged 5–16 years with forearm fractures presenting between August 2018 and January 2020 and having unstable or unacceptable reduction. Institute Ethics Committee approval was obtained before initiating the study.

Inclusion criteria encompassed children aged 5–16 years with forearm fractures displaying displacement, rotation, or reduction loss during conservative management. Type 3 compound fractures, pathological fractures, fractures associated with neurovascular injuries, and isolated fractures of either the radius or ulna were excluded from the study. The study proceeded with systematic data collection, encompassing pre-operative preparation, surgical procedures, and subsequent follow-up assessments.

### Brief procedure

First, the fractures were assessed using digital radiographs and classified according to the AO classification system. Eligible patients underwent clinical and radiological evaluation before surgery, including routine blood tests and an assessment of their fitness for anesthesia.

Next, the size of the nail needed was calculated based on the width of the forearm isthmus from the radiographs. Elastic nailing principles were used to ensure that the nail did not penetrate the physis.

One nail per forearm bone was inserted, either retrograde for the radius or antegrade or retrograde for the ulna. The patient was lying on the operating table with the fractured limb on a radiolucent arm table, and a C-arm was used for imaging.

The recommended nail diameter was 2/3 to 80% of the isthmus diameter, and similar diameters were used for balanced bending forces. For the radius, a dorsal approach was used on Lister's tubercle with a perpendicular awl insertion angulated to 45° and a slightly larger opening than the nail diameter. The nail was introduced at 90°, rotated 180° to align with the medullary canal, and advanced with rocking motions to the fracture site.

For the ulna, either an anterograde approach 2 cm distal to the olecranon or a retrograde approach 2 cm proximal to the joint line was used. The radius nail tip was aligned with the upper fragment medulla and advanced with reduction or open reduction, and the ulna nail advanced and docked the metaphysis with tips rotated toward the interosseous membrane.

Finally, the nails were ensured to be properly positioned and cut 5 mm to 1 cm from the bone ends. Over-inserted nails were retracted with extraction pliers or capped, and the radial nail end was extended to avoid tendon friction. Image intensification was used to ensure that the reduction was correct and the nail length was appropriate.


**Figure 2:** Anteroposterior and lateral radiographs of the left forearm in a 15-year-old boy (a) at presentation, (b) following titanium elastic nailing, (c) at 4-month post-operatively, and (d) at 10-month post-operatively demonstrating delayed union.

### Post-operative care

Immobilization was generally unnecessary post-operatively, allowing for the early initiation of active motion. In some cases, above-elbow plaster immobilization was preferred. Nail removal was done after complete fracture union and remodeling, typically occurring 6-month postoperatively, with the exact timing dependent on the patient's age.

### Post-operative assessment

All patients underwent a minimum of clinical and radiological assessments at 4, 8, 12, and 24 weeks post-surgery, followed by as needed thereafter. Clinical and radiological data were recorded using a pro forma and checklist. The results were evaluated using Daruwalla grading and Price et al. criteria. A Student's t-test was used to compare the means of the nail-to-canal ratio in relation to the presence or absence of major and/or minor complications.

## Results

Sixteen patients underwent surgery for two-bone fractures of the forearm. Twelve patients received elastic nailing for both bones, while four patients had the ulna nailed, while the radius was fixed with K-wires or plating due to their distal location.

Patients' ages ranged from 5 to 15 years, with a mean of 10 years. Seven were <10 years old and nine were >10 years old. Of the 16 patients, 14 (87.5%) were male and 2 (12.5%) were female (male: female ratio 7:1).

Falling on an outstretched hand when playing was the primary causes (13 patients, 81.25%), while road-traffic accidents caused injuries in 3 patients (18.75%). The right forearm was affected in 9 patients (56.3%), and the left in 7 (43.8%). Most patients presented immediately after trauma, except one who presented 10 days later.

### Fracture characteristics

All fractures were closed fractures (16 patients, 100%). Fracture distribution: middle one-third (8 patients, 50%), proximal one-third (5 patients, 31.3%), and distal one-third (3 patients, 18.8%). The most common pattern was transverse (9, 56.3%), followed by short-oblique (6, 37.5%), and partially comminuted (1, 6.3%). Overriding ranged from 6 mm to 18 mm (median = 13 mm).

No major associated injuries or polytrauma were reported. Two patients (12.5%) had been treated by traditional bone setters before seeking orthopedic care.

### Reduction and surgery

Most patients (11, 68.8%) had one reduction attempt, while 5 patients (31.3%) had two reduction attempts. Closed nailing of both bones was performed in 12 patients (75%), and open reduction in 4 (25%). Surgery was performed within 1–3 days (median = 1 day) from presentation, with surgical duration ranging from 60 to 180 min (median = 1.5 h). Hospital stays varied from 3 to 10 days (median = 5 days). The last follow-up ranged from 12 to 17-month postoperatively (mean = 15 months). C-arm images intraoperatively ranged from 8 to 40 (median = 22).

In evaluating forearm fractures, the radius canal ranged from 3 mm to 5 mm (mean = 3.81), while the ulna canal measured 2 mm to 3 mm (mean = 2.4). The chosen diameter for titanium elastic nails was 2 mm to 3 mm, with 2.5 mm being the common choice for both the radius and ulna. The nail-to-canal ratio was

**Figure 3:** Deep infection at ulnar nail entry site, also showing the prominent elastic nail. The wound healed after early implant removal at 2 months.

determined as the bone isthmus diameter divided by the nail diameter. For the radius, the ratio ranged from 60.00 to 66.67 (mean = 64.81), and for the ulna, it ranged from 50.00 to 66.67 (mean = 60.39), revealing no significant relationship with complications ($P > 0.05$). During surgery, inserting nails into the distal fragment presented a common challenge, resulting in 25% of cases requiring open reduction. In post-surgery, below-elbow plaster support was provided for 2–4 weeks to ensure additional stability.

Soft-tissue irritation manifested as nail extrusion in 18.75% of cases and skin irritation/bursitis in 12.5%; yet, these complications did not necessitate revision procedures. Most patients achieved full forearm rotations, elbows, and wrist movements by 12 weeks, except for one patient (6.25%) who experienced delayed union and 45° forearm pronation. Regarding angular and rotational malalignment, angular malalignment (>15° sagittal, >10° coronal) was observed in two patients (12.5%), with no significant movement restriction noted. Limb-length discrepancy was absent in all patients.

The mean extraosseous nail lengths were 10.38 mm for the radius and 11.13 mm for the ulna, with nail end protrusion linked to lengths exceeding 10 mm. Fracture union, defined by bridging callus in ≥3 cortices, was achieved with varying times ranging from 8 weeks to 8 months (median = 12 weeks) (Fig. 1). Three patients had major complications (18.75%): a 15-year-old boy who needed open reduction for the radius had delayed union (Fig. 2); two patients (12.5%) developed malunion with loss of radial bow, one of them being the patient with delayed union; and one patient developed a deep infection in the ulnar nail entry site (Fig. 3), necessitating early removal of the nail at 2 months. Minor complications, including nail extrusion, prominences, and ulnar bursitis, were present in 37.5% of patients without necessitating unplanned revisions.

The final outcome was graded based on the price outcome score described by Price et al. as excellent, good, or poor. The outcome was "excellent" in 15 (93.8%), "good" in 1 (6.3%), and "poor" in 0 (0.0%). Similarly, the Daruwallah outcome score was "excellent" in 15 (93.8%) and "good" in 1 (6.3%). Nail removal was done post-fracture consolidation, occurring 6-month to 1-year post-surgery. None of the patients needed pre-union nail removal.

## Discussion

The epidemiology of forearm fractures in childhood reveals a prevalence of 18% by age 9, with a peak incidence occurring between 5 and 14 years, pre-dominantly affecting boys [16, 17]. Forearm fractures constitute 40% of childhood fractures, with incidence peaks noted at 5–9 and 10–14 years with shaft fractures, accounting for 3–5% of pediatric fractures [17, 18].

Forearm fracture treatment has shifted from common closed reduction, which had poor outcomes, to ORIF, associated with high infection and non-union rates [19]. While Sarmiento's functional bracing approach exhibited superior results [20], Blount stressed the uniqueness of fractures in children due to their growth potential [21]. However, little is still known regarding the correction of rotational malalignment through remodeling [3]. Gandhi et al. pointed out that angular deformities persist in older children, prompting the emergence of alternative methods such as titanium elastic nails [22]. Surgical interventions are thus usually reserved for candidates who are generally non-responders to conservative management [2, 22].

The remodeling potential of pediatric bones facilitates malunion correction, with effectiveness peaking below 10 years and declining thereafter [23-26]. Severe malunion correction is feasible in children below 8 years but diminishes in efficacy after 10 years [27]. The impact of age and fracture site on the remodeling of angular malalignment is evident, with sagittal malalignments showing better outcomes. Thus, Flynn's acceptance of 15–20° angulation varies with age [28].

In contrast to angular malalignment, rotational malalignment lacks self-correction and is often associated with angulation [29, 30]. Muscles play a crucial role in causing rotational deformity, impairing functionality, and leading to compensatory shoulder use, which can result in complications [31]. The primary goal of treatment should be restoring normal alignment, especially in complete shaft fractures [32, 33]. While closed reduction with an above-elbow cast is common, malunion can compromise function [31, 34, 35]. Studies by Asadollahi identified a re-displacement rate of 11% due to poor reduction and increased angulation [36]. Price recommends angulations of ≤15° for children below 8 years and ≤10° for older children [37].

Non-operative approaches such as closed manipulation and casting have shown more favorable outcomes in age <10 years [38, 39]. There is an increasing trend in surgical intervention, primarily for open fractures, instability, irreducibility, deformity, and post-manipulation re-displacement [12]. While elastic stable intramedullary nailing (ESIN) and plate-and-screw fixation offer similar outcomes [40], ESIN, being less invasive and tailored to pediatric anatomy, presents a more easily removable option [34, 41]. Although plate fixation supports anatomic alignment and radial bow, allowing early motion [42], it may entail longer incisions and complications such as malunion and synostosis [42].

Flexible intramedullary nailing, introduced by Metaizeau, is a viable alternative using titanium alloy (Ti6Al14V) nails, known for their osseointegration, biocompatibility, and magnetic resonance imaging compatibility [43]. Curved nails enhance stability and radial bow [11, 41]. Biomechanically, these curved nails boost interosseous membrane tension, providing rotational stability and radial bow [11, 41]. Although complications such as extensor pollicis longus and extensor pollicis brevis ruptures, superficial radial nerve injury, and pin tract infections have been reported with elastic nailing, various studies report good functional outcomes [44-48]. Complication rates range from 14% to 21%, covering hardware issues, non-union, neurodeficits, infections, and compartment syndrome [25, 34, 41, 49, 50].

The management of pediatric forearm fractures has evolved from accepting deformity post-closed reduction to stringent alignment criteria [8, 22]. Precision in angulation and rotation, aligned with the child's age, is now demanded [3]. Internal fixation suits unstable fractures, malreduction, and older children [31, 51, 52]. In our study, patients specifically met these criteria, with 50–90% of internal fixations driven by instability and malreduction and no open fractures observed. Transverse fractures were pre-dominant, followed by short oblique fractures [27, 37]. Although all patients underwent closed reduction, satisfactory alignment was not universally achieved [3]. The median age of patients was 11 years, with fracture union occurring within 8–12 weeks, except for one delayed union case. Healing rates after open reduction and internal fixation with plating have been shown to be slower than with elastic nailing [53]. Titanium nails' elasticity allows up to 2° of movement, while their thicker periosteum offers stability and aids healing [31].

Nail selection is critical, with a nail-to-canal ratio ≥60–80% of the canal diameter required for stability [54]. The most common nail size used in our study was 2.5 mm for both the radius and the ulna. Immobilization post-TEN remains debatable, with patients commonly opting for plaster immobilization due to titanium nails' relative flexibility and the risk of post-operative alignment loss [55]. No significant correlation was found between the nail-canal ratio and complications [56, 57]. Surgery, ideally within 24–72 h, occurred on the nearest elective list [51], with a median hospital stay of 5 days for post-operative monitoring.

Our series did not encounter any cases of non-union. Non-union has been reported primarily in open fractures [58]. Patient outcomes, evaluated using Price and Daruwallah scores, were pre-dominantly excellent or good [31, 52, 59]. However, the absence of open fractures may impact these outcomes.

While TEN is not without complications, including nail extrusion, soft tissue irritation, and delayed union, our study indicates that flexible intramedullary nailing is a promising method for stabilizing unstable pediatric forearm diaphyseal fractures. Adhering to TEN principles and avoiding basic errors could prevent complications [41, 49, 60]. Neurovascular damage was absent in our study.

## Limitations

Our study has certain limitations. The sample size, although reflective of our institute's patient load over 2 years, is small due to COVID-19 constraints. No open fractures were encountered, possibly due to regional trauma center distribution. This may account for our series' favorable outcomes compared to the literature. A comparison with other treatments like conservative or plate osteosynthesis could yield stronger evidence, yet this was not our research aim [3].

## Conclusion

Our study on flexible intramedullary nailing for pediatric forearm both-bone fractures revealed promising outcomes. The majority of cases underwent successful closed nailing, demonstrating overall excellent results in fracture union and patient recovery. Despite the observed complications, the study supports the efficacy of flexible intramedullary nailing in the management of pediatric forearm fractures. Further research with larger cohorts is warranted for a comprehensive understanding of this technique's applicability and outcomes.

**Clinical Message**

Flexible intramedullary nailing shows promise in pediatric forearm fractures, with mostly successful outcomes despite complications, emphasizing the need for further research with larger cohorts for a comprehensive understanding of its efficacy and applicability.

**Declaration of patient consent:** The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

**Conflict of interest:** Nil **Source of support:** None

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