

Elastic Stable Intramedullary Nail Fixation for Pediatric Forearm Bone Fractures: Outcomes and Complications Rate

Embrochage Elastique Stable Intramédullaire Pour Les Fractures De Deux Os De l'Avant-bras Chez l'Enfant : Résultats et Complications

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ABSTRACT

Background: Forearm shaft fractures are common among children. Elastic stable intramedullary nailing (ESIN) is generally considered the gold standard operative procedure. This study aimed to assess functional outcomes, axial alignment, bone healing, and complication rates in pediatric population.

Methods: This retrospective cohort study reviewed pediatric forearm fracture cases from January 2016 to December 2020 at Mouwasat Dammam Hospital, Saudi Arabia. The study included children aged 16 years and younger who were treated with elastic intramedullary nailing. Both clinical and radiological outcomes were assessed, along with the occurrence of complications.

Results: The study included 64 patients with a mean age of 8.3 years. In 60.93% of cases, both forearm bones were fractured, and in 60.09%, the fractures were located in the distal third of the forearm. Open reduction was needed in 20.03% of cases. None of the cases showed mean axial alignment values greater than 10°. The mean healing delay was 56.4 days, with a range of 38-73 days. The average time for nail removal was 4.5 months. From a clinical perspective, 92.18% of the cases (59 patients) had favorable outcomes. The complication rate was 23.43%.

Conclusion: ESIN has proven to be an effective method for stabilizing forearm fractures, ensuring proper alignment, promoting high union rates, and delivering satisfactory functional results. Although complications are relatively common, serious complications remain rare.

Keywords: Elastic, Nail, Forearm, Fracture, Outcomes, Complications

RÉSUMÉ

Introduction : Les fractures diaphysaires de l'avant-bras sont fréquentes chez les enfants. L'embrochage élastique stable intramédullaire (ESIN) est considérée comme le gold standard. Cette étude visait à évaluer les résultats fonctionnels, l'alignement axial, la consolidation osseuse et le taux de complications.

Méthodes : Cette étude rétrospective a examiné les fractures de l'avant-bras chez l'enfant entre Janvier 2016 et Décembre 2020 à Mouwasat Hospital Dammam, en Arabie Saoudite. L'étude incluait des enfants âgés de 16 ans ou moins ayant été traités par enclouage intramédullaire élastique. Les résultats cliniques et radiologiques ont été évalués, ainsi que le taux de complications.

Résultats : L'étude comprenait 64 patients avec un âge moyen de 8,3 ans. Dans 60,93 % des cas, les deux os de l'avant-bras étaient fracturés, et dans 60,09 %, les fractures étaient situées au tiers distal de l'avant-bras. La réduction ouverte a été nécessaire dans 20,03 % des cas. Aucun cas ne présentait un alignement axial moyen supérieur à 10°. Le délai moyen de consolidation était de 56,4 jours, avec une plage allant de 38 à 73 jours. Le délai moyen d'ablation du matériel était de 4,5 mois. D'un point de vue clinique, 92,18 % des cas (59 patients) ont présenté des résultats favorables. Le taux de complications était de 23,43 %.

Conclusion : L'embrochage élastique s'est révélée être une méthode efficace pour fixer les fractures de l'avant-bras, assurant un bon alignement, favorisant un taux élevé de consolidation osseuse et offrant des résultats fonctionnels satisfaisants. Bien que les complications soient relativement fréquentes, les complications graves restent rares.

Mots-clés : Broche, Élastique, Avant-bras, Fracture, Résultats, Complications

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INTRODUCTION

Diaphyseal forearm fractures are among the most frequent fractures in children, accounting for 13–40% of all pediatric fractures. These injuries predominantly affect boys aged 10–14 years and are often caused by falls, sports activities, or play.^{1,2} Management of these fractures depends on factors such as the child's age, fracture type, and degree of displacement.³ While many fractures are successfully treated with conservative methods like closed reduction and casting, surgery may be required for fractures that are unstable, open, combined, or at a higher risk of malunion or malreduction.⁴ Despite various treatment options, including K-wires, plates, or external fixators, the best nonoperative treatment approach remains uncertain. One of the most widely used surgical techniques, developed in the 1970s by Jean Prevot and Jean Paul-Metaizeau, is the closed reduction and insertion of elastic stable intramedullary nailing (ESIN).⁵ Although alternatives are available, ESIN remains the most common surgical option due to its minimally invasive nature, potential for early mobilization, and satisfactory functional outcomes.^{6,7} However, ESIN is not without risks, as it can lead to complications such as wound infection, skin perforation, bursitis, nonunion, tendon rupture, or compartment syndrome.^{7,8} The complication rates associated with ESIN range from 10 to 67%, with varying results across studies.^{8,9,10} These complications can arise either during the implantation procedure, post-surgery, or after the nail removal. This study aims to evaluate the functional outcomes of pediatric forearm fractures, focusing on axial alignment, bone healing, and complication rates.

METHODS

Study population

This retrospective cohort study examined a series of children aged 16 years or younger who underwent elastic stable intramedullary nailing (ESIN) for forearm fractures at Mouwasat Dammam Hospital, Saudi Arabia, between January 2016 and December 2020. The inclusion criteria consisted of children with diaphyseal forearm fractures who had at least six months of follow-up and completed antero-posterior (AP) and lateral (LAT) X-ray views. Exclusion criteria included epiphyseal or metaphyseal fractures and incomplete documentation. All surgical procedures used a titanium pediatric elastic nail system. The upper age limit of 16 years was chosen in accordance with guidelines set by the Nancy group, the pioneers of ESIN, which defines children with open growth plates as having growth potential.¹¹

Data was gathered from a prospectively maintained pediatric trauma database, including patient demographics, comorbidities, injury mechanisms, surgical details, and specifics of the implants used. Radiographs taken preoperatively, postoperatively, and during follow-up visits at two weeks, six weeks, three months, and six months or more were analyzed to assess

fracture alignment and healing.

Surgical procedure

Surgical procedures were performed by orthopedic surgeons with varying levels of experience. Challenges, such as the need for open reduction, were carefully recorded. All surgeries were done under general anesthesia, with the assistance of an image intensifier for precision. In cases requiring open reduction, a pneumatic tourniquet was applied to control bleeding. Closed manipulation was used to adjust the fracture's length, rotation, and angulation.

A standard distal approach to the radius and a proximal approach to the ulna, as outlined by Lascombes et al.¹² was employed. The ulna was accessed just distal and lateral to the olecranon apophysis, while the radius was approached radially, slightly above the distal growth plate, with careful attention to protect the superficial radial nerve. A 45° oblique hole was drilled into the lateral cortex of the radius' metaphysis for nail insertion. Titanium nails, with diameters ranging from 1.5 to 2.5 mm and blunt ends, were used for fixation. These nails were slightly curved to achieve a three-point fixation, and the tips were bent at 30–40° to facilitate manipulation within the medullary canal. The bent portion of the tip did not exceed 5 mm in length.

The nail was maneuvered across the fracture site and advanced into the cancellous bone of the metaphysis. Rotating the curved nail helped correct any angulation and restored the radial bow. After confirming the range of motion and stability of the fixation, the nails were bent at the insertion site and trimmed to avoid irritation of the skin. Above-elbow immobilization was applied, and all patients were monitored overnight in the hospital to assess postoperative pain and swelling.

Postoperative assessment

Patients were regularly reviewed in the clinic for wound inspections and to ensure proper alignment of the nails and adequate fracture healing. The splint was removed once callus formation was visible on radiographs. Normal activities were permitted, but sports were restricted for three months until fracture union was confirmed. Removal of the flexible nail was performed under general anesthesia.

The primary outcome of the study was postoperative fracture reduction, based on the assessment of axial alignment. Secondary outcomes included bone union, defined as the presence of callus bridging at least three out of four cortices within 90 days for upper limb fractures. Functional outcomes, particularly forearm rotation, were assessed at the final follow-up using the criteria by Price et al.¹³, which are widely used to evaluate the functional recovery of forearm fractures in children. The complication rates were also reported. The study adhered to the principles outlined in the Declaration of Helsinki and relevant ethical guidelines. Declarations regarding human ethics and consent to participate were not applicable.

Statistical analysis

Descriptive statistics were used to analyze demographics, clinical outcomes, and measurements. Continuous variables were summarized with means, standard deviations, medians, and ranges, while categorical variables were reported as frequencies and percentages. SPSS Version 26 was used for statistical analysis.

RESULTS

Demographic features

During assessment period, there were 72 consecutive cases involving 72 children. Of these, 8 cases were excluded for various reasons: 6 cases because surgeries were performed outside hospital, and 2 cases due to incomplete medical records. This resulted in a total of 64 children included, accounting for 64 cases. Among these, 41 were males (64.06%) and 23 were females (35.93%) with a mean age of 8.3 years (range: 3-16). The majority of cases involved both bones in 39 cases (60.93%), isolated radius in 17 cases (26.56%) and isolated ulna in 8 cases (12.5%) with 3 cases (4.68%) were Monteggia fracture dislocation. Most were on the right side (54.68%), and most occurred in distal third of the forearm (60.09%), followed by middle third (34.37%) and proximal third (4.68%). Fractures were open Gustillo Anderson grade 1 in 6 cases (9.37%). The injuries resulted from various mechanisms: 41 cases (64.06%) involved falls from standing, 20 cases (31.25%) were sports-related, and 3 cases (4.68%) was from a road traffic accident (RTA). Open reduction was required in 13 cases (20.03%): both bones in 10 cases (15.62%) and isolated radius in 3 cases (4.68%). Postoperatively, plaster cast back slab above elbow was indicated in all cases. Postoperative immobilization mean duration was 6.2 weeks (range: 4-12). Mean hospital stay was 1.3 day (range: 0-5). Mean surgery duration was 42.17 minutes (range: 20-68 minutes) (Table 1).

Table 1. Demographic features of patients

	Number/% Mean / Range
Age	8.3 years (range 3-16)
Gender	
Male	41 (64.06%)
Female	23 (35.93%)
Side	
Right	35 (54.68%)
Left	29 (45.31%)
Bone involvement	
Both Radius and Ulna	39 (60.93%)
Isolated Radius	17 (26.56%)
Isolated ulna	5 (7.81%)
Monteggia type fracture	3 (4.68%)
Level of fracture	
Proximal third	3 (4.68%)
Middle third	22 (34.37%)
Distal third	39 (60.09%)
Open fracture (Gustillo Anderson Grade 1)	6 (9.37%)
Refracture	2 (3.12%)

Radiological outcomes

Postoperative reduction was successfully achieved in all cases according to axial alignment. Patient were divided into three groups to assess mean axial alignment values: -Group A (1 to 6 years): on AP views: radius 2.1° (range: -2,18°), ulna 1.4° (range: -1,8°), on lateral views: radius 1.7° (range: 0,14°), ulna 1.1° (range: -1, -16°). -Group B (7 to 12 years): on AP views: radius 2.6° (range: -1,17°), ulna 1.2° (range: -0,11°); on lateral views radius 2.3° (range: 0,12°), ulna 1.6° (range: 0,13°). -Group C (13 to 16 years): on AP views: radius 2.2° (range: -2,16°), ulna 1.1° (range: 0,10°); lateral views radius 1.1° (range: -2,8°), ulna 0.9° (range: 2,7°). None of the obtained mean axial alignment values exceeded 10 degrees and were hence appropriate. Any differences can be attributed to anatomical variations in bone shape resulting from different ages of the patients. The dependence of axial alignment value on age group was also analyzed. None of these results were statistically significant. Although values for both AP and lateral views of ulna are lower than LAT and AP values of radius; this is due to natural curvature of radius. Concerning nail diameter, diameter of 2.0 mm was used in 81.25% and was not found to be dependent on axial alignment for the ulna in AP ($p=0.142$; $r=0.153$) or in LAT ($p=0.52$; $r=0.078$). Nor was it dependent for the radius in AP ($p=0.089$; $r=0.411$) or LAT ($p=0.128$; $r=0.572$). None of these results were statistically significant. The mean bone healing delay was 56.4 days (range 38-73 days). Fracture healing was achieved in all cases. Removal of nails was done in all cases with mean delay of 4.5 months (range: 1-10) (Table 2).

Table 2. Intraoperative characters of the patients

	Mean/Numbers/%/Range
Surgery delay	
<24 hrs	53 (82.81%)
>24 hrs	11 (17.18%)
Overall incidence of open Reduction	13 cases (20.03%)
Both bone fracture	10 cases (15.62%)
Isolated radius	3 cases (4.68%)
Isolated ulna	0
Surgery duration (minutes)	42.17 minutes (20-68 minutes)
Hospital stays	1.3 day (range 0-5)
Immobilization duration	6.2 weeks (range 4-12)
Fracture healing delay	56.4 days (range 38-73 days)
Removal nails delay	4.5 months (range 1-10)

Functional outcomes

At mean follow up of 7.21 months (range: 6-12 months), 92.18% of cases (59 cases) had satisfactory results whereas 5 cases (7.81%) had unsatisfactory outcomes: three cases related to metalwork failure caused by surgical technique errors, such as malorientation of nail tips and undersized nails, leading to early re-displacement of both fractures and requiring revision surgery. The 2 others unsatisfactory outcome involved infection with cheloid scar at the last follow up (Table.3).

Table 3. Functional outcomes and complications rates

	Mean / Number (%)
Follow-up	7.21 months (6-12 months)
Functional outcome	
Satisfactory	59 cases (92.18%)
Unsatisfactory	5 cases (7.81%)
Complications	23.43%
Infection	2 cases (3.12%)
Nerve injury	1 case (1.56%)
Re fracture	2 cases (3.12%)
Exposure and prominent hardware	6 cases (9.37%)
Metalwork failure	3 cases (4.68%)
Extensor pollicis longus entrapment	1 case (1.56%)

Complications

Overall complications rate was 23.43%: 6 cases (9.37%) of exposure and prominent hardware requiring early metalwork removal, 3 cases (4.68%) related to metalwork failure caused by surgical technique errors, 2 cases (3.12%) of superficial infection without osteomyelitis, 2 cases (3.12%) of re-fracture after removal of nails, and one case (1.56%) of extensor pollicis longus entrapment requiring early metalwork removal and one case (1.56%) of superficial radial nerve palsy. There were no cases of compartment syndrome which is known as first complication of ESIN technique. Importantly, no cases of implant breakage or difficulties with metalwork removal occurred. There was no significant difference in complications rates between children discharged on the same day as their surgery or those who stayed as inpatients [Table 3].

DISCUSSION

ESIN has been proven to be a reliable method for managing a variety of long bone fractures, including those of the humeral shaft, both bones of the forearm, radial neck fractures (using the Metaizeau technique), Monteggia fractures of the proximal ulna, as well as tibial and femoral shaft fractures.^{13,14} The mean age of our study cohort was 8.3 years (ranging from 3 to 16 years), which aligns with findings from other research on pediatric flexible nailing.^{13,14,15} Notably, the average hospital stay was 1.3 days (ranging from 0 to 5 days), a significantly shorter duration compared to typical hospital stays reported in the literature.¹⁵ This reduction offers both financial and patient experience benefits and warrants further investigation.^{15,16}

Technique and indications

Surgical intervention for diaphyseal forearm fractures in children is typically indicated for unstable fractures, dislocations, open fractures, irreducible or unsuccessful reductions, refractures, and fractures associated with neurovascular complications.¹⁷ The decision to proceed with surgery often hinges on the degree of rotation

and angulation, as these factors play a significant role in determining the treatment approach and functional outcomes.¹⁸ Proper alignment and restoration of axial rotation are essential in minimizing potential functional deficits, though there is ongoing debate regarding the acceptable limits of malalignment, leaving the final decision to the surgeon's judgment.¹⁹ In our study cohort, ESIN was successfully used to treat open fractures in 6 cases (9.37%), with all cases undergoing formal debridement of the open fracture site followed by stabilization with elastic nails. This approach led to complete union without any infections. It is generally acknowledged that open fractures in children, especially those classified as Gustilo and Anderson grade I, do not require as aggressive management as in adults, and internal fixation often yields favorable results.²⁰

When surgical treatment is necessary, the surgeon must determine whether closed or open reduction is more appropriate. Elastic stable intramedullary nailing (ESIN) is a commonly preferred technique for managing such cases. Our findings also indicate that ESIN can be safely applied to open fractures without an increased risk of complications, particularly infections. Additionally, ESIN can be successfully performed as a day-case procedure for forearm fractures, providing benefits in terms of patient experience and cost-effectiveness. Although the complication rate is not insignificant, it is consistent with what has been reported in the literature.^{19,20,21,22}

Axial alignment

Regarding anatomical outcomes, our study demonstrated an improvement in the mean axial alignment values following ESIN implantation across three different age groups, measured for both the ulna and radius in both AP and LAT views. However, there remains considerable debate over the exact thresholds for acceptable axial alignment or angulation.^{23,24,25} Papermanikou et al.²⁶ suggest that alignment should be within 15° for fractures in the distal and middle thirds of the diaphysis, and under 10° for the proximal diaphysis. Flynn et al.¹⁴ proposed that a 10–20° angulation is acceptable for patients younger than 10 years, while those older than 10 should maintain an angulation of less than 10°. Other studies have set the threshold at less than 15° for the distal diaphysis.^{27,28}

In pediatric patients, angulation can often improve through natural remodeling. Research indicates that children under the age of eight can remodel up to 50% of an angulation less than 20°, while older children can remodel angulations of less than 10°.²⁸ However, rotational deformities are more difficult to correct naturally and are harder to assess. Acceptable rotational values tend to vary across studies, but are generally considered to be under 30° for both younger and older children, where manipulation may not be necessary.²⁹ In our study, the mean axial alignment values ranged from 0.9° to 2.6°, all within these accepted limits, indicating good axial alignment. Similar findings were reported by Du et al.²⁷, where mean angulation values

for the ulna in both AP and LAT views ranged from 2.20° to 2.80° for double ESIN implantation, and from 5.50° to 6.04° for single ESIN implantation. Korhonen et al.²³ also reported comparable results, with a mean postoperative displacement of 7.6° for the radius and 1.8° for the ulna. Slightly higher angulations, around 10° to 12°, were observed by Papamerkouriou et al.²⁶ These variations could be due to differences in surgical techniques, radiological assessment methods, and anatomical variations, such as differences in the curvature of the radius, which can make assessing angulation more complex and deviate from standard reference values. Despite these findings, the literature on the effectiveness of ESIN in maintaining axial alignment for forearm fractures is still limited, highlighting the need for further research to define optimal and universally accepted thresholds for alignment.

Functional outcomes

Regarding functional outcomes, 92.18% of cases (59 cases) achieved satisfactory results, which is consistent with other studies.^{28,29,30} However, five cases (7.81%) had unsatisfactory outcomes. Three cases related to metalwork failure caused by surgical technique errors, such as malorientation of nail tips and undersized nails, leading to early re-displacement of both fractures and requiring revision surgery. The 2 others unsatisfactory outcome involved infection with cheloid scar at the last follow up. Our mean union delay was 56.4 days (range 38-73 days) are similar to those reported in other series.^{29,30,31}

Complications and nail removal

The overall complication rate in our study was 23.43%, which is consistent with the range of 14-42% reported in the literature.^{29,30,31,32,33} Most complications were related to metalwork prominence, which led to the early removal of hardware before full fracture consolidation. The nail end at the ulna near the olecranon presented more challenges compared to the radial nail, likely due to the limited soft tissue coverage and the mobility of the elbow joint. This raises the question of whether the metalwork should be implanted deeper, balancing the risk of hardware failure or the inability to remove the implants as seen in some studies.^{30,31} One possible solution might be to assess nail prominence more carefully during surgery, particularly when the elbow is hyper-flexed.

Major complications were primarily due to hardware prominence and exposure, occurring in 6 cases (9.37%), necessitating early hardware removal. Additionally, 3 cases (4.68%) were related to metalwork failure caused by misalignment of nail bends during surgery, resulting in the loss of fracture stabilization. These issues are attributed to surgical technique errors rather than problems with the implants themselves. Greater awareness of surgical techniques could help improve success rates in managing pediatric fractures with ESIN. Furthermore, there were 2 cases (3.12%) of refracture after nail removal, all at the

same site as the original fractures. Forearm refractures are known to occur, particularly in cases with incomplete union, with reported rates of 6-10%.^{34,35}

Rare complications included transient anterior interosseous nerve palsy and entrapment of the extensor pollicis longus tendon by the radial nail. These issues typically arise when using the Lister's tubercle entry point, but in our cases, they were due to an excessively sharp nail orientation.³⁶ Notably, there were no instances of compartment syndrome, which is a known complication of the ESIN technique.³⁷

Regarding nail removal, there is limited guidance in the literature about the timing of ESIN removal. While the procedure is generally considered straightforward with a low complication rate, specific timelines and potential complications are often not well-documented.^{36,37,38} For example, Pogorelić et al.²² reported a median removal time of five months (ranging from four to nine months), with all patients regaining full limb function. They also noted that complications during hospitalization were resolved once the nails were removed. In cases of ulnar fractures, patients regained full function with a mean removal time of four months, and the study found a low complication rate of 3.4%, including temporary sensation loss, tendon rupture, refracture, and superficial wound infection.³⁹ Furlan et al.⁴⁰ reported a median removal time of six months. In contrast, in our study, the nails were removed in all cases with a mean delay of 4.5 months (ranging from 1 to 10 months), without increasing the risk of refracture, as both cases of refracture occurred 4 and 9 months after nail removal, respectively.

The study's limitations include its retrospective nature and challenges in standardizing clinical outcome data, such as functional scores. Additionally, the study focused on pediatric patients, most of whom were otherwise healthy, limiting our ability to attribute complications directly to specific causes. This study provides descriptive epidemiological data from a level one trauma center in Saudi Arabia and is representative of daily clinical practice. Our outcomes are consistent with published series, making these findings likely applicable to other clinical settings.

CONCLUSION

This study has demonstrated that ESIN technique is an effective method for maintaining fracture reduction in pediatric forearm fractures when used appropriately and with respect to surgical procedure steps. The technique leads to successful restoration of bone alignment, good union rates, and a return to normal function.

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