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RESEARCH

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Elastic stable intramedullary nailing in paediatric diaphyseal forearm fractures – a retrospective analysis of 201 cases

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Abstract

Background Forearm shaft fractures are common injuries, often caused by falling from a fully-upright position or falling off a bike. They can be treated nonoperatively or surgically with intramedullary nailing or plates. The method of choice for treating pediatric forearm shaft fractures is the application of elastic stable intramedullary nailing (ESIN)|. The aim of the study was to evaluate ESIN in pediatric patients with forearm shaft fractures based on radiological images, and determine the etiology and complication rate associated with the injury.

Methods The study included 201 patients, 30.5% female 69.5% male, aged 1 to 17 years (mean 9.1 years; SD = 3.2), all had been diagnosed with a fracture of the forearm shaft and had been treated surgically with ESIN. In addition, all possessed a complete set of X-ray images and had attended a minimum six-month follow-up examination of the forearm. Axial alignment was evaluated retrospectively in the anatomical (AP) and lateral (LAT) positions. In total, 402 radiographs were examined. Of the injuries, 68% occurred during sports activity and 75% involved both the radius and the ulna.

Results Union was observed in all cases. Mean axial alignment values in AP and LAT X-ray or both the ulna and radius were satisfactory. Axial alignment values were not influenced significantly by age, type of surgery, type of fracture or etiology. Plaster cast application (9.8% of cases) significantly influenced radius axial alignment. The complication rate was 11.4% ($n = 23$). Significantly more complications were observed in patients receiving open reduction internal fixation (ORIF) ($p = 0.0025$).

Conclusion The ESIN technique is an effective treatment for forearm diaphyseal fractures in children, with good results regarding reduction and bone healing, indicated by x-ray.

Keywords Adolescent, Bone nail, Child, Forearm fracture, Fracture fixation, Intramedullary nailing, Postoperative complications, Upper extremity

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Introduction

Diaphyseal forearm fractures are the third most common pediatric fracture: it constitutes 13–40% of all childhood fractures, with most cases occurring in boys aged 10–14 [1, 2],. They are typically caused by falls, sports or play. Their management is based on a range of factors such as age, fracture type, and displacement [1, 2]. While conservative treatment, involving closed reduction and plaster cast immobilization, is successful for many diaphyseal forearm fractures, surgical intervention may be necessary for unstable, open, or combined fractures, or those at high risk of malunion or malreduction [2]. However, the optimal nonconservative treatment remains unclear.

One commonly-used surgical technique, established in the late 1970s by Jean Prevot and Jean Paul-Metaizeau, involves closed reduction and the implantation of elastic stable intramedullary nailing (ESIN). While alternatives exist, including the use of K-wires, plates, or external fixators [1], ESIN remains the most common primary choice for surgical treatment in diaphyseal forearm fractures due to its minimally invasive application, the potential for early mobilization, and satisfactory postsurgical functional outcomes [1–3]. Nevertheless, the use of ESIN is associated with multiple complications, such as wound infection, skin perforation, bursitis, nonunion, tendon rupture, or compartment syndrome. The general complication rate ranges from 10 to 67%, with varied results reported in different studies [4–6]. Complications may occur after ESIN implantation, during the procedure, or after nail removal.

The aim of this study is to evaluate the axial alignment and bone union in pediatric forearm fracture treated surgically with elastic stable intramedullary nailing (ESIN). The study also examines the etiology of the injury and the complications rate associated with surgery.

It is hypothesized that elastic intramedullary nailing gives acceptable axial alignment values and a low rate of complications.

Materials and methods

Materials

A retrospective analysis was conducted on 201 pediatric patients who had received surgery for diaphyseal forearm fractures. The inclusion criteria comprised age 1–17 years, admission to the clinic between 01.2018 and 01.2022, a minimum six-month follow-up, diaphyseal forearm fracture, ESIN surgery, and completed anterior-posterior (AP) and lateral (LAT) X-ray views. The exclusion criteria comprised epiphyseal or metaphyseal fractures or insufficient documentation.

Patient data was extracted from the hospital database, including basic demographic information, injury etiology, type of ESIN used, and post-surgical complications. In total, 402 X-ray images were analyzed.

The mean age of the patients was 9.1 years (SD=3.2), with a mean follow-up of 9.1 months (SD=2.8). Of the fractures, 92.7% had been treated with closed reduction internal fixation (CRIF), and 9.3% with open reduction internal fixation (ORIF); 90.7% of fractures were closed. In 9.8% of cases, a cast had been applied for two to four weeks in the younger children to alleviate post-surgery pain. All patients underwent ESIN (diameter 1.5 –3.0 mm) [Figure no. 1].

Surgical procedure

General anesthesia was performed in all cases. Intramedullary nailing was performed using standard metaphysial approaches under C-arm fluoroscopy. In all cases, the medullary canal of the radius was approached laterally, and no dorsal incision was performed. An anterior approach to the forearm was used if open reduction was necessary. A plaster cast was used in 19 cases due to its analgetic effect or coexisting injuries.

Statistical analysis

The patients were divided into three age groups for more detailed analysis: 1 to 7 years old, 7 to 13 years old, and 14 to 17 years old. Union and alignment of radius and ulna were assessed on X-rays using RadiAnt software (Medixant, Poznan, Poland). The Mann-Whitney U-test was used for independent data analysis, Spearman's rank correlation was used to compare nail diameter and alignment. The relationship between treatment approach (ORIF/CRIF) and complication rate was determined using Fisher's exact test. Statistical significance was assumed for $p<0.05$. Statistical analysis was performed using Statistica 13.1 (Statsoft Inc, USA).

Bioethics

Due to its retrospective nature, consent was not needed to participate in this study (Internal Review Board of the Polish Mother's Memorial Hospital in Lodz; opinion number - KB-38/2023). The study was performed in accordance with the Declaration of Helsinki and relevant guidelines. Human Ethics and Consent to Participate declarations were not applicable.

Results

Of the injuries, 23% of cases were isolated radius fractures, 2% isolated ulna fractures, and 75% involved both. Most were on the left side (54.3%), and most occurred in the distal 1/3 of the forearm (61%), followed by the middle 1/3 (36%) and the proximal 1/3 (3%) (Fig. 1). Bone union was achieved in all cases.

Age dependence of axial alignment

In the 1 to 7-year age group, the mean axial alignment values were as follows: radius in AP view 2.2° (SD 3.2°,

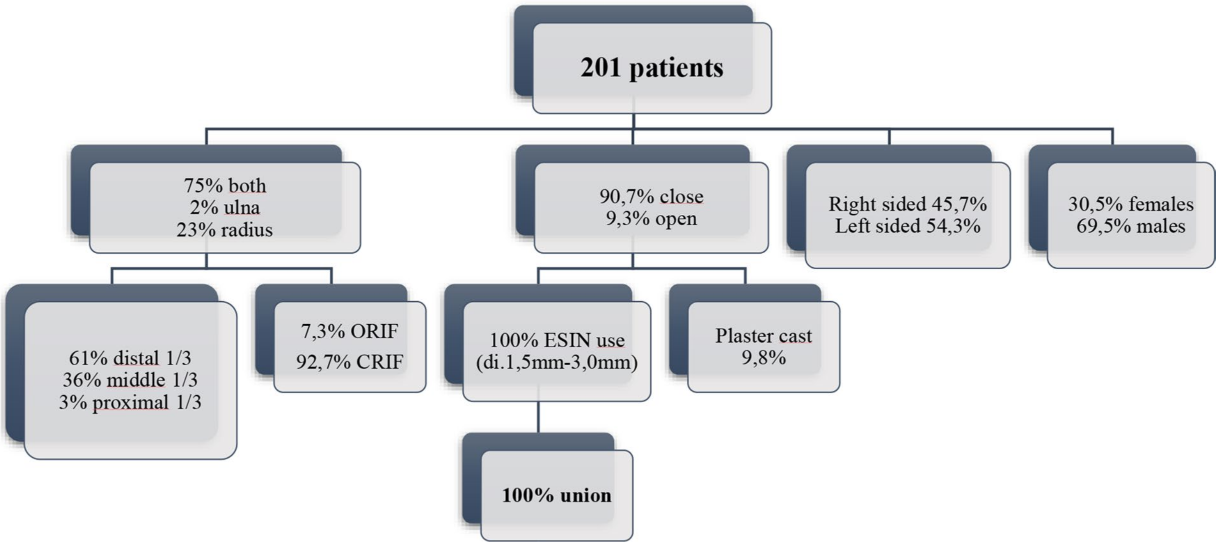

Fig. 1 Study group characteristics; ORIF – open reduction internal fixation, CRIF - close reduction internal fixation, ESIN – elastic stable intramedullary nailing

Table 1 Influence on p values and axial alignment; ORIF – open reduction internal fixation, CRIF – close reduction internal fixation, SD – standard deviation

	Ulna AP [°]	Radius AP [°]	Ulna LAT [°]	Radius LAT [°]
ORIF/ CRIF *p-value*	2.18 (SD = 2.04) 1.53 (SD = 1.87) *p* = 0.186	1.27 (SD = 1.56) 2.76 (SD = 3.31) *p* = 0.178	1.27 (SD = 1.74) 1.69 (SD = 2.22) *p* = 0.065	0.91 (SD = 1.38) 2.33 (SD = 2.68) *p* = 0.548
Open/ close fracture *p-value*	2.08 (SD = 1.75) 1.53 (SD = 1.90) *p* = 0.194	3.08 (SD = 3.59) 2.56 (SD = 3.19) *p* = 0.789	1.23 (SD = 3.35) 1.70 (SD = 2.26) *p* = 0.784	2.62 (SD = 2.50) 2.18 (2.49) *p* = 0.835
Plaster cast (*n* = 19) *p-value*	1.55 (SD = 1.88) *p* = 0.630	3.69 (SD = 2.89) *p* = 0.036	1.67 (SD = 2.30) *p* = 0.725	4.22 (SD = 2.43) *p* = 0.035

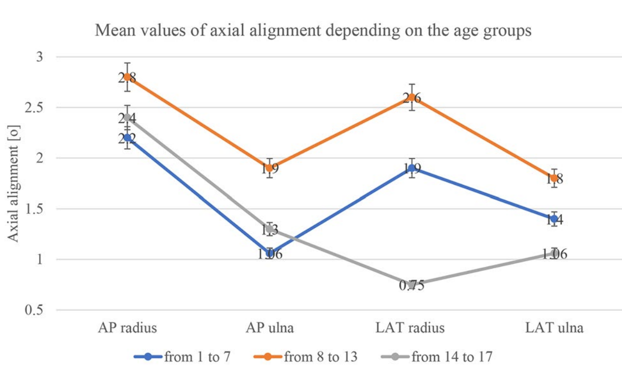

Fig. 2 Mean axial alignment according to particular age groups

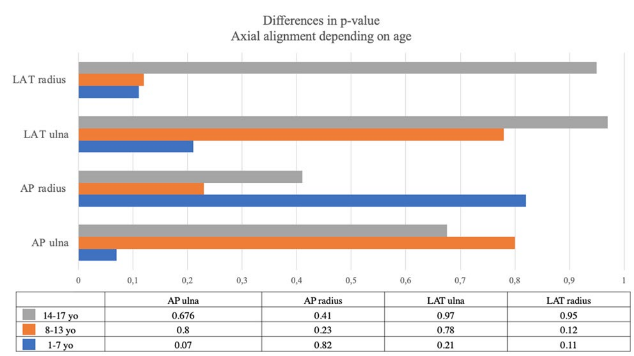

Fig. 3 Influence of age on axial alignment values

range 0-16°), ulna in AP view 1.1° (SD = 1.8°, range 0-7°), radius in lateral view 1.9° (SD 2.6°, range 0-12°), ulna.

in lateral view 1.4° (SD = 2.1°, range 0-13°). In 8 to 13-year age group: AP view - radius 2.8°, ulna 1.9°; lateral view - radius 2.6°, ulna 1.8°. In the 14 to 17-year age group: AP view - radius 2.4°, ulna 1.3°; lateral view - radius 0.75°, ulna 1.06°. None of the obtained mean axial alignment values exceeded 10 degrees and were hence appropriate. Any differences can be attributed to the anatomical variations in bone shape resulting from the different ages of the patients (Table no. 1).

The dependence of axial alignment value on age group was also analyzed (Figs. 2 and 3). None of these results were statistically significant. Although the values for both the AP and lateral views of ulna are lower than the LAT and AP values of the radius; this is due to the natural curvature of the radius.

Influence of nail diameter on axial alignment

In 87% of cases, nails with a diameter of 2.0 mm were used. However, nail diameter was not found to be dependent on axial alignment for the ulna in AP ($p=0.123$; $r=0.160$) or in LAT ($p=0.5$; $r=0.064$). Nor was it dependent for the radius in AP ($p=0.093$; $r=0.341$) or LAT ($p=0.133$; $r=0.542$). None of these results were statistically significant (Fig. 4).

Etiology of diaphyseal forearm fractures

Regarding the etiology of forearm fractures, 32% were caused by a fall from a standing position onto an outstretched hand. In addition, 29% were caused by sport and recreation, of which 16% were accidents on a scooter and 12% on a trampoline. Otherwise, 25% occurred while cycling, 7% during PE lessons and 4% during a football game. Cycling was excluded from the list of recreational activities to emphasize the importance of these disciplines in causing fractures. The data is presented in Fig. 5. In no cases did the etiology influence axial alignment ($p>0.05$).

The relationship between mean axial alignment (radius and ulna) and the type of treatment, type of fracture and type of plaster cast used were also assessed (Table 1). It was found that the use of a plaster cast influenced axial alignment of the radius in AP ($p=0.036$) and LAT ($p=0.035$). This may result from the use of a plaster cast due to its analgetic effect, or a Monteggia fracture, a coexisting epiphyseal fracture or refracture: most patients with a plaster cast had sustained a Monteggia fracture.

Complications of the treatment

Complications occurred in 9.5% ($n=19$) of patients. The most common was oedema of the implantation site ($n=9$). Less common was refracture ($n=5$), neuropraxia of the ulnar nerve ($n=3$) and skin puncture of the nail stubs ($n=2$). Regarding the influence of possible complication-related factors (Table 2), complications were found to correlate with the type of surgery performed, type of fracture and type of plaster cast application. A significant relationship was found between the use of open reduction internal fixation (ORIF) and complications ($p=0.0025$). Neither fracture or plaster cast application significantly influenced the development of the complications ($p>0.05$).

Discussion

In all cases, elastic intramedullary nailing of the forearm (ESIN) was found to lead to bone union with satisfactory axial alignment. Complications were noted in 19 patients, of which refracture appeared in five cases, neuropraxia of the ulnar nerve in three and skin puncture of the nail stubs in two.

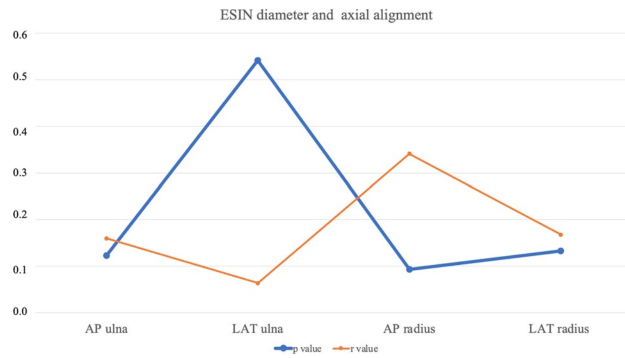

Fig. 4 Nail diameter versus axial alignment

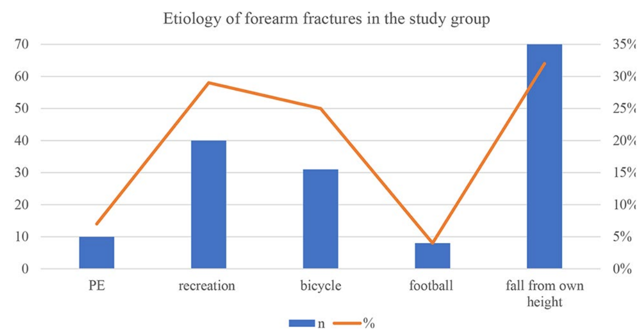

Fig. 5 Etiology of injuries in the study group; PE – physical education

Table 2 Possible complication dependence; ORIF – open reduction internal fixation

	Study group [%]	Complications	*p*-value
ORIF	7.2	Yes ($n=11$)	$\mathbf{p=0.025}$
Open fracture	9.3	Yes ($n=2$)	$p=0.571$
Plaster cast	9.8	Yes ($n=4$)	$p=0.252$

Axial alignment values

Our findings indicate the mean axial alignment values of ESIN implantation in three age groups, calculated for both ulna and radius, in AP and LAT views. However, the precise value for acceptable axial alignment or angulation remains controversial. Papermanikou et al. report it to be less than 15 degrees in the distal and middle third of the diaphyseal, and less than 10 degrees for the proximal diaphyseal [6]. Flynn et al. assert that 10–20 degrees indicates acceptable alignment in patients younger than 10 years old, and less than 10 degrees in older children [7]. Other authors report this value to be less than 15 degrees for the distal diaphyseal [8].

All the mean values obtained in the present study, i.e. from 0.75 to 2.8 degrees, are within these values, and hence indicate correct axial alignment. Similar results were achieved by Du et al. where the mean angulation of the ulna in AP and LAT views ranged from 2.20 to 2.80 degrees following double ESIN implantation and 5.50 to 6.04 degrees after single ESIN [9]. Comparable outcomes were reported by Korhonen et al. with a mean postoperative displacement at follow-up of 7.6 degrees for the radius and 1.8 degrees for the ulna [10]. Slightly different observations have been presented by Papamerkouriou et al. with the authors reporting an angulation of around 10 to 12 degrees [6,9,10]. Such outcomes may be the result of different techniques and radiological assessment programs, as well as anatomical variations in the radius curvature which prevent proper analysis of angulation and reference to normal values. Nevertheless, the literature is still insufficient regarding the effectiveness of using ESIN in forearm fractures regarding axial alignment. As such, further studies are needed to find optimal and acceptable values.

Cause of injury

Among the reviewed patients, the most common fracture etiology was a fall from an upright position (32%), followed by causes associated with sport and recreation (29%). This is consistent with available literature. Papamerkouriou et al. indicate that the most frequent mechanism of injury was a fall onto an outstretched hand from an upright standing position [6], while Lyman et al. report the most common mechanism to be a fall onto an outstretched hand, followed by sport injuries [2]. Vopat et al. also indicate the most common mechanism to be falling from an upright standing position (83%), with the injury occurring most frequently in playground areas, and less commonly, associated with bicycle, scooter and trampoline use [1]. Similarly, Papamerkouriou et al. found less frequent causes to be vehicle and playground accidents, falling from a tree and a fall from a trampoline [6]. Hence, despite slight differences, most previous studies confirm that pediatric forearm fractures are most commonly caused by falling onto an outstretched hand, which is consistent with studies on adult forearm fractures.

Complications

The incidence of complications appears to be diverse. In our study, the complication rate was 9.5%, with the most common side effect being implantation side oedema of the wound area ($n=9$), followed by refracture ($n=5$) and ulnar nerve neuropraxia ($n=3$). No complications regarding the delayed union or malunion were observed in the study. Fernandez et al. report a complication rate of 14.6%, with the most common complication being refracture, lesion of the radial nerve and delayed union [4]. Pogorelić et al. found the main complication to be superficial skin irritation, which was not observed in our study [11]. Flynn et al. report a 14.6% complication rate: the most common side effect was delayed union (6/15 cases), with other complications being compartment syndrome, tendon laceration and infection [4–9,11].

Korhonen et al. report the most frequent complication to be delayed or lacking union, and that open reduction was associated with an increased risk of ulna nonunion [10]. This finding is relevant to our present observations, as open reduction was found to correlate with a greater risk of complication. They also found ulna nonunion to result from the use of thicker nails and a more distal location of the fracture; nevertheless, the authors indicate that the ESIN implantation procedure shows satisfactory healing [10].

Peterlein et al. note a refracture rate of 3.3% and regard ESIN as achieving convincing long-term results in forearm fractures [3]; however, Lyman et al. report a 24% complication rate, with the most common being ulnar or radial nerve dysfunction, described by the author as a postoperative complication, and tendon rupture [2]. Other side effects include compartment syndrome and implant migration requiring early removal [2,3,9,12–18].

Nevertheless, despite these complications, other studies report satisfaction with the functional results of ESIN [16–20]. Furthermore, other literature has found ESIN to be associated with a lower number of refractures compared to conservative treatment [7, 22, 23].

Surgical treatment indications

Common indications for surgical treatment of diaphyseal forearm fracture in children include unstable fractures and dislocations, open fractures, fractures that failed to reduce or were irreducible, as well as refractures and fractures with neurovascular defects. However, it is important to note that the rotation and angulation of the fractures has an impact on the type of treatment and functional ability in children. While restoring correct axial alignment and rotation can diminish potential loss of function, the acceptable values of malalignments remain controversial, leaving the final decision about treatment up to the surgeon.

Even so, in the pediatric population, it is important to note that angulation may be restored by remodelling: it has been found that among children younger than eight years, 50% of correction can remodel in cases with angulation less than 20 degrees [19], and for angulation less than 10 degrees in older children. Nevertheless, rotational deformities are not expected to remodel completely and may be difficult to examine. Again, acceptable rotational values differ between studies, and range from 0 to 45 degrees; however, acceptable malrotation is generally assumed to be below 30 degrees in both younger and older children, i.e. no manipulation of the fracture is needed in such cases [2, 11, 13, 18, 19].

In other cases, the need for closed or open reduction depends on the surgeon's assessment. In cases where surgical treatment is unavoidable, the use of the ESIN as a preferred technique is one possibility.

Nail removal

Not many studies specify the time after which ESIN should be removed. Although the literature generally indicates that removing ESIN is a relatively easy procedure with a low rate of complications, no studies give any precise time or possible complications. Pogorelić et al. report that nails were removed after a median time of five months (i.e. four to nine months) and all patients were reported to have regained full limb function [11]. Moreover, all the complications that occurred during hospitalization were resolved after nail removal. Patients with ulnar injuries regained function, with a mean time to ESIN removal being four months; the study also notes a low complication rate (3.4%) including temporary loss of sensation, tendon rupture, refracture and superficial wound infection [21]. In the work of Furlan et al. found the median time of ESIN removal to be six months [11, 13–18]. Unfortunately, it was not possible to determine the period before removal in the present study as not all of the patients had undergone removal; however, in most cases, ESINs were taken out at the request of the parent after a year.

The study has two key limitations. The first is its retrospective nature, which did not allow any opportunity to obtain additional data regarding functional scales or pain assessment scales from the patients. The second is lack of comparison between surgical and non-surgical treatment results in patients with relatively small displacement.

Conclusions

Elastic stable intramedullary nailing may be considered a satisfactory method of surgical treatment of pediatric forearm fractures with acceptable axial alignment values and a low rate of complications. ESIN should be considered as the method of choice for displaced forearm fractures in the pediatric population.

Abbreviations

ESIN	Elastic stable intramedullary nailing
ORIF	Open Reduction and Internal Fixation
CRIF	Closed Reduction and Internal Fixation
AP	Anterior posterior
LAT	Lateral

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Not applicable.

Author contributions
KK. performed the study and wrote the article. KS. planned the tables and figures, wrote the article. MM. performed statistical analysis. KM. planned and supervised the study.

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Data availability
Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate
This study adhered to the principles of the most recent Declaration of Helsinki (2013). Consent was not needed to participate in this study (Internal Review Board of the Polish Mother's Memorial Hospital in Lodz; opinion number - KB-38/2023)

Consent of publication
Informed consent was received by all subjects.

Competing interests
The authors declare no competing interests.

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