

Long-term results of elastic-stable intramedullary nailing (ESIN) of diaphyseal forearm fractures in children

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Abstract

Since its introduction by Metaizeau and Prevot, elastic-stable intramedullary nailing (ESIN) has been used for almost all diaphyseal fractures in children. Here, we present a retrospective study analyzing the long-term results of ESIN of forearm fractures in children.

A total of 122 patients with diaphyseal forearm fractures and single subtypes in childhood were treated from 2000 to 2007 at our University Hospital by ESIN. At follow-up, the current conditions of the patients were evaluated using the Disabilities of Arm, Shoulder, and Hand (DASH) Score, and the Mayo Wrist score. Moreover, an individual questionnaire with 16 items was used to collect further information about the patient's condition and limitations as adults.

The evaluation was performed at 12.4 years (average) after surgery. In our study population (n=90), the average DASH scores for sports, performing arts, and work were 0.4 (standard deviation: 1.45), 0.9 (standard deviation: 5.68), and 0.3 (standard deviation: 7.39), respectively. Furthermore, 77% of our patients achieved a DASH Score of 0 (optimum outcome). The average Mayo Wrist Score was 97.64 (standard deviation: 7.39), and 82% of the study population achieved a score of 100 (optimum outcome). A correlation between the DASH and Mayo Wrist Scores was found in few patients. Overall, the DASH Score, Mayo Wrist Score, and results of our individual questionnaire demonstrated convincing point values.

This study demonstrated favorable long-term results achieved by ESIN of forearm fractures in children. It seems that good outcomes, reported by various studies with short- to mid-term follow-up beforehand, do not deteriorate over time.

Level of Evidence: Level III; retrospective study; therapeutic study.

Abbreviations: DASH = disabilities of arm, shoulder and hand, ESIN = elastic-stable intramedullary nailing.

Keywords: ESIN, forearm fracture, long-term results, study

1. Introduction

With an annual incidence of 0.7 per 1000 children,^[1] forearm fractures are among the most common fractures in children.^[2] The standard therapy for stable and only slightly displaced forearm fractures in children is conservative treatment.^[3,4] However, certain types of forearm fractures require operative treatments such as plate osteosynthesis, pinning by K-wires, or elastic-stable intramedullary nailing (ESIN).^[5,6] Based on Küntscher's intramedullary nailing, Jean Prevot and Jean-Paul Metaizeau introduced the ESIN in Nancy (France) in the late

1970s.^[7] Hereby, a nail is inserted in the medullary cavity of the ulna and radius in opposite directions and positioned in the bone under tension to create an arch shape (Fig. 1). The fracture is stabilized additionally by the membrana interossea antebrachii. This type of stabilization allows for micro movements at the site of fracture, which induces the formation of callus.^[8,9] The major benefit of the ESIN treatment compared with conservative treatments is early mobilization of the forearm and lower invasiveness of the procedure compared to plate osteosynthesis.^[10] An immobilization of the arm is not necessary, and usually only a simple bandage or sling is required.^[6,9,11] After 3 weeks, the amount of callus is comparable to callus formation after conservative treatment.^[9]

Meanwhile, ESIN is used for almost all diaphyseal fractures in children aged 4 to 16 years.^[11,12] Follow-up results after operative treatment by ESIN were obtained after 1 to 4 years by various authors.^[9,10,13–18] In the current literature, there is a lack of studies that have evaluated the long-term outcomes of ESIN in pediatric diaphyseal forearm fractures. Apart from that, a final assessment of ESIN can only be conducted in adult patients, as interactions between treatment procedures and growth are otherwise not considered.

The rationale of this study was to evaluate the long-term results of ESIN.

2. Patients and methods

This study was conducted in accordance with the principles laid down in the Declaration of Helsinki. Prior to the investigations, an approval was secured by the local board of ethics.

Editor: Johannes Mayr.

The authors have no funding and no conflicts of interest to disclose.

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Medicine (2019) 98:11(e14743)

Received: 2 November 2018 / Received in final form: 7 February 2019 /

Accepted: 8 February 2019

<http://dx.doi.org/10.1097/MD.0000000000014743>

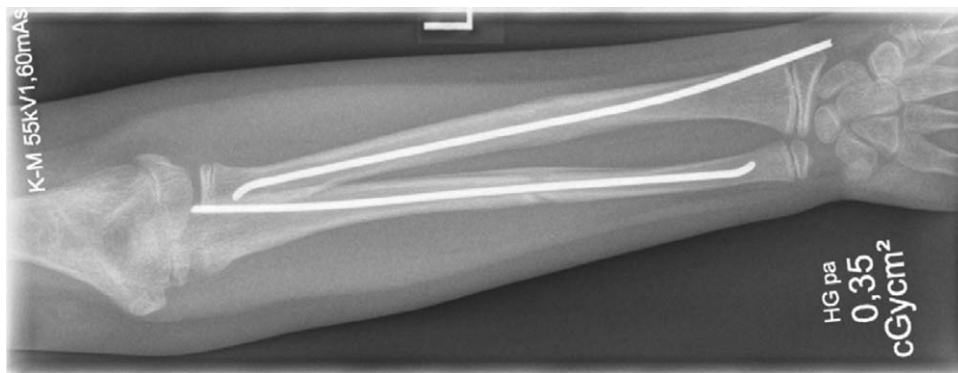


Figure 1. Elastic-stable intramedullary nailing ESIN in a 9-year-old girl with retrograde and antegrade nailing of the radius and antegrade nailing of the ulna, respectively. , ESIN=elastic-stable intramedullary nailing.

Between February 2000 to June 2007, 127 operations for forearm fractures with ESIN were performed at our Trauma Department on 122 individual pediatric patients. In 2016, this study population (then adults) was asked for a clinical and functional re-evaluation of their arm. To obtain a satisfactory number of participants, a standardized interview by phone was considered to be the most convenient method. Ninety patients gave their consent to take part in our study. Pain as well as clinical and functional outcomes of the patients were evaluated using the Disabilities of Arm, Shoulder, and Hand (DASH) questionnaire of the Canadian Institute of Work and Health and the Mayo Wrist Score. Both scores have been well established and validated to evaluate the conditions of the hands, arms, and shoulders after surgery.^[19–22] The first part of the DASH questionnaire evaluated the potential limitations of the patient while performing various daily life tasks, whereas the second part covers limitations while working. The third part considers limitations while participating in sports and playing music. The Mayo Wrist Score evaluates pain, satisfaction, rotation, and grip strength of the arm after surgery. The DASH questionnaire was used in the long form with 30 questions, and the Mayo Wrist Score consisted of 4 questions. Both questionnaires were answered by the patient on the phone, and the interview was performed by a physician. A DASH score of 0 indicated no limitations or discomfort, and a score of 100 indicated maximum limitation. The adjusted values were correlated with clinical outcome (Table 1).^[22] A Mayo Wrist Score of 100 indicated no complaints, and a score of 0 indicated maximum pain. Moreover, an individually designed questionnaire with 16 items and focus on functional outcome, implant removal, and scar development was used for the evaluation.

Table 1
Classification of DASH score according to Lee et al^[22].

| DASH Score | Classification |
|------------|----------------|
| 0 | Excellent |
| >0–5 | Good |
| >5–10.1 | Satisfying |
| >10.1 | Unsatisfying |

DASH=disabilities of arm, shoulder and hand.

2.1. Statistics

The evaluation of the data was carried out independently in a descriptive manner with the computer program SPSS (IBM, Armonk) for statistical correlations.

3. Results

Overall, 127 treatments of pediatric forearm fractures by ESIN in 122 children were documented at our University Hospital. All 122 patients were asked to take part in our study for a follow-up. Of these patients, 4 suffered from refractures and needed revision surgery. Among the 90 patients who responded to our request, the average age at surgery was 8.3 years (min, 1 year; max, 18 years). Thirty-three (36.7%) and 57 patients (63.3%) had fractures on the left and right arms, respectively. Diaphyseal forearm fractures were the most common fracture type (Table 2). Additional implants, such as K-wires or plates, were used in 11 patients (Table 3). The average interval between primary surgical care and metal removal was 78.4 days (min, 14 days; max,

Table 2
Distribution of the different fractures.

| Fracture type | Quantity | Percentage (%) |
|-------------------------------|----------|----------------|
| Diaphyseal forearm fractures | 71 | 78.9 |
| Distal forearm fracture | 9 | 10 |
| Radius fracture | 3 | 3.3 |
| Monteggia fracture | 2 | 2.2 |
| Ulna fracture | 2 | 2.2 |
| Ulna fracture 1st degree open | 3 | 3.3 |

Table 3
Type of surgery.

| Type of surgery | Quantity | Percentage (%) |
|---------------------------------------|----------|----------------|
| Prevot nail in ulna and radius | 71 | 78.9 |
| Prevot nail in ulna | 4 | 4.4 |
| Prevot nail in radius | 4 | 4.4 |
| Prevot nail in ulna, K-wire in radius | 4 | 4.4 |
| Prevot nail in ulna, plate in radius | 6 | 6.7 |
| Reduction with K-wire | 1 | 1.1 |
| Plate in ulna, prevot nail in radius | 0 | 0 |

Table 4
Results of the DASH score.

| DASH module | Arithmetic average | Standard deviation | Maximum | Minimum | Frequency | |
|--------------------------------------|--------------------|--------------------|---------|---------|-----------|-----------|
| | | | | | Score = 0 | Score ≠ 0 |
| Disability of arm, shoulder and hand | 0.4 | 1.45 | 9.2 | 0 | 71 | 19 |
| Sport/performing arts | 0.9 | 5.68 | 37.5 | 0 | 84 | 3 |
| Work module | 0.3 | 2.14 | 18.8 | 0 | 83 | 2 |

DASH = disabilities of arm, shoulder and hand.

207 days). In 5 patients (5.6%), an open reduction was necessary, whereas in 85 patients (94.4%), a closed reduction was possible. The average stay in the hospital after surgery was 2.4 days (min, 1 day; max, 5 days).

3.1. DASH score

With respect to the main module of the DASH score, 70 patients had no complaints at all, 17 patients had good results, and 3 patients had satisfactory results (Table 4). In the work module, 83 patients did not have complaints, one patient had a satisfactory result, and 1 patient had an unsatisfactory result. For the sports/performing arts module, 84 patients had no complaints, 1 patient had a satisfactory result, and 2 patients were unsatisfied. Overall, 8 patients reported an impaired sensitivity, and 12 patients had problems with the scars.

Three patients of our study population experienced refractures. They were treated with ESIN of the radius and ulna at the first surgery as well as in the revision. All 3 patients achieved a DASH score of 0 after the 2nd intramedullary nailing, and therefore had no complaints as adults. The extraction of the nails was performed in these patients on average after 68 days.

One patient displayed substantially elevated scores for all 3 DASH modules. He achieved a score of 7.25 for the DASH main module, 18.75 for the work module, and 6.25 the sports/performing arts module. This patient had sustained a fracture of the forearm in childhood while playing. Surgery was performed with Prevot nails in the ulna and radius, and the surgery was conducted on the day of the accident. The age of this patient was 17 years on the day of the accident. He was the oldest participant in this study.

3.2. Mayo wrist score

This Mayo Wrist Score was obtained in all of the patients (Table 5). Overall, 74 patients achieved a Mayo Wrist Score of 100, which corresponded to no complaints, while 8 patients scored 80 to 99 points. Four patients achieved a score of 80–89, which were good results. Only 3 patients achieved a score of 70 to 79, which corresponded to satisfactory results. The above-mentioned patient achieved a satisfactory result for the Mayo Wrist Score.

Table 5
Results of the Mayo wrist score.

| Category | Arithmetic average | Standard deviation | Median |
|-----------------|--------------------|--------------------|--------|
| Pain | 24.55 | 1.43 | 25 |
| Satisfaction | 24.44 | 2.05 | 25 |
| Range of motion | 24.16 | 3.55 | 25 |
| Grip strength | 24.49 | 2.96 | 25 |
| Total score | 97.64 | 7.39 | 100 |

Both the Mayo Wrist Score and the questionnaire on an individual basis (Table 6) demonstrated overall very good results.

4. Discussion

The typical characteristics of fractures in children include the ability to spontaneously remodel malaligned fractures, rapid fracture healing, and high adjacent joint tolerance to immobilization. However, these characteristics are highly dependent on the type of fracture, the location of the fracture, and the age of the child.^[11,12,23–25] With age, these skills decrease. Children up to the age of 10 years have the greatest potential to compensate for axial malalignment by increasing the length of the bone. Correspondingly, more pronounced deviations and bone displacement can be accepted in children under 10 years of age.^[17,26] There are no indications for the use of ESIN in distal metaphyseal

Table 6
Results of the questionnaire on individual basis.

| Number | Question | Number | |
|--------|---|--------|----|
| | | Yes | No |
| 1 | Do you remember the injury? | 85 | 5 |
| 2 | Do you feel restricted by the injury? | 6 | 84 |
| 3 | Does the injured arm looks different then the noninjured one? | 10 | 80 |
| 4 | Are there differences in the mobility of both arms? | 12 | 78 |
| 4a | Are there differences in mobility of the elbow joints? | 7 | 5 |
| 4b | Are there differences in the rotational movements between both arms (inside/outside)? | 9 | 3 |
| 4c | Are there differences in the mobility of the wrists? | 7 | 5 |
| 4d | Radial/ulna abduction? | 7 | 5 |
| 5 | Are there painful limitations of mobility? | 5 | 85 |
| 6 | Do you take pain medication on a regular base due to the arm injury? | 2 | 88 |
| 7 | Are there problems with sensitivity between both arms? | 15 | 75 |
| 8 | Is the sensitivity on the back of the thumbs the same on both hands? | 84 | 6 |
| 9 | Are there problems with scars? | 6 | 84 |
| 10 | Is DASH questionnaire filled out completely? | 90 | 0 |
| 11 | Was apart from implant removal another surgery needed? | 5 | 85 |

DASH = disabilities of arm, shoulder and hand.

Table 7**Time between removal of implants and evaluation of the arm.**

| Author | Time span between removal of implants and evaluation, months |
|---------------------------|--|
| Mann et al (2003) | 3 |
| Richter et al (1998) | 6 |
| Van der Reis et al (1998) | 12 |
| Verstreken et al (1988) | 14 |
| Behnke et al (2012) | 16.5 |
| Houshain and Bajaj (2005) | 20 |
| Fernandez et al (2015) | 20.6 |
| Fernandez et al (2010) | 37 |
| Jubel et al (2004) | 38 |
| Lascombes et al (1990) | 42 |

fractures, undisplaced unstable fractures, grade III open fractures, as well as stable green stick fractures below the 5th year of life. The use of ESIN is also not possible if the fracture is too proximal or distal to allow for sufficient fixation of the nail.^[17,25,26] Other contraindications include comminuted fractures, wound infections, or when the diameter of the medullary canal is <3 mm.^[11]

Refractures may occur due to premature removal of the implant or insertion of intramedullary nails with small diameters. Another typical cause for refractures is high velocity trauma.^[27] In a refracture, the bent intramedullary nails must be removed and replaced with a new nail after a reduction of the fracture.^[11,17,28] The number of refractures reported is usually low.^[29]

In literature, the time period between metal extraction and final evaluation of the functional outcome of the arm varies substantially (Table 7). Mann et al,^[15] van der Reis et al,^[10] and Fernandez et al^[6] evaluated the operated arm after 3 (15), 12 (10), and 20.6 months (6), respectively. The longest time between metal extraction and final evaluation to date was reported by Lascombes et al,^[9] who did the final evaluation after 42 months (9). In the aforementioned studies, patients were evaluated after a comparatively short time. Unlike our study, those authors did not evaluate adult patients. In this study, we intended to fill this gap and evaluate the arms of the patients being treated with ESIN at adult stage of life. The average time between metal removal and evaluation was 12.4 years. The average age of the patients at the ESIN surgery was 8.3 years, and therefore the patients were adults when the evaluation was performed.

However, there are a few limitations to our study. We decided to make an evaluation by phone, because in a test attempt, only one patient was willing to take part in a physical evaluation for this study. This may partly be due to the long time between surgery and evaluation. Another likely reason could be that the patients were satisfied with the result of the surgery, which was visible in the results of the DASH and Mayo Wrist Scores, and therefore, had no interest in participating in the study. Accordingly, a modified Mayo Wrist Score was used since the evaluation of the condition of the patient was not performed by a physician, but by the patient himself.

5. DASH score

It is remarkable that question 21 (“sexual activity”) was not answered by 20 (22%) patients. This was probably due to the very personal nature of this question. The Institute of Work and Health also reported that typically 20% of the patients do not answer this question.^[30]

The average DASH Score of the US population is 10.1.^[27] Currently, there is no formal categorization of the DASH scores in classes. However, various authors have classified their results. Meier et al^[31] reported a DASH Score of 3.5 after surgical treatment of forearm deformations in children and classified this result as “good” to “very good.” In another study, the same author reported a DASH Score of 4 after surgery of deformed radii in children and considered it as a low level of disability.^[32] Scaglione et al^[33] achieved an average DASH score of 8.9 after treating humerus fractures of adults, which was considered “excellent.” Lerch et al^[34] considered a DASH score of 4.14 in adult patients as “acceptable,” whereas Nishiwaki et al^[24] considered a DASH score of 4.8 as a low degree of disability. Two other studies achieved a score of 6.5 in adult patients, which was considered “good.”^[35,36] Lee et al^[22] classified a DASH score between 0 and 19 as “good.” Based on these evaluations, we rated our study population. A DASH Score above the average score of the US population was considered “unsatisfactory,” since the patients were young and the score should be below the average score of the population.

Dietz et al^[37] suggested that the ESIN treatment was suitable for children from 4 to 14 years. The standard procedure for the treatment of forearm fractures in adults is plate osteosynthesis.

Aidelsburger et al^[27] achieved a QuickDASH score of 0.81 after treating distal fractures of the humerus with ESIN in children. Similarly, Khan et al^[38] treated children with fractures of the humerus with ESIN and achieved a DASH score of 2.0. Rabinovich et al^[39] achieved a DASH score of 6.0 after treating children with fractured olecranon with ESIN.

When comparing the DASH scores measured in this study with the aforementioned results, we can conclude that the results we achieved were very good. This demonstrates the efficacy of ESIN for pediatric forearm fractures in the long term.

Extraction of the nails is usually recommended after 3 months.^[13,14,37] Some authors wait 4 months^[11] or 6 to 8 months.^[28] Lascombes et al^[9] even considered that metal removal after 4 months was too early, and advised waiting for 10 to 12 months.

Two out of 3 refractures occurred more than 1 year after the initial treatment. Therefore, we conclude that there was no correlation between metal extraction and those refractures. In one case, the refracture happened 56 days after implant removal, and whether the refracture was caused by the premature metal extraction cannot be excluded. Van Egmond et al^[40] reported a refracture rate of 2.3% and Kelly et al^[29] reported a refracture rate of 1.2% after treatment with ESIN; the refracture rate observed in our study was similar (3.3%).

Chen et al^[41] evaluated the intramedullary nailing of fractures of the radius in adults and achieved an average Mayo Wrist Score of 83.8. Wakasugi et al^[42] measured a Mayo Wrist Score of 91.9 after intramedullary nailing of the radius in adult patients. Rampoldi and Marsico^[43] demonstrated “very good,” “good,” and “satisfactory” results in 63%, 26%, and 11% of their adult patient population, respectively.

Therefore, the results of the Mayo Wrist Score measured in this study were substantially better than those measured after intramedullary nailing of adult patients in other studies.

6. Conclusion

This study demonstrated convincing long-term results of pediatric forearm fractures treated with ESIN. Overall, the good

outcomes as reported by various studies beforehand did not deteriorate over time.

Author contributions

Conceptualization: Christian-Dominik Peterlein, Steffen Ruchholtz, Antonio Krüger.

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