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Low complication rate of elastic stable intramedullary nailing (ESIN) of pediatric forearm fractures

A retrospective study of 202 cases

Christiane Kruppa, MD[a,*], Pamela Bunge, MD[a], Thomas A. Schildhauer, MD[a], Marcel Dudda, MD[a,b]

Abstract

Elastic stable intramedullary nailing (ESIN) has been established as state of the art treatment for forearm fractures in children, if operative stabilization is required. Their use has been expanded to single bone shaft fractures, and also more complex injuries such as Monteggia fractures or Monteggia-like lesions. A wide range of complications has been reported in the literature, up to 70% in certain investigations. The purpose of this study was to assess the complication rate after ESIN treatment of forearm fractures in children and adolescents in a representative cohort of patients from a level 1 trauma center in Germany.

Between 2000 and 2015, we retrospectively analyzed all patients, up to the age of 16 years, with forearm fractures, who were operatively treated using ESIN in our department of general and trauma surgery. The main outcome measurements were the rates of postoperative complications after ESIN such as re-fracture, malunion, nonunion, tendon lesion, wound infection, and limited range of motion.

In all, 201 consecutive patients with 202 forearm fractures were included in this study. Age averaged 9.7 years (range 3–16 years). Fifteen (7.4%) fractures were open. Fractures were 82.2% diaphyseal both-bone forearm fractures. Follow-up averaged 10.2 months (range 0.7–176.3 months). Complications were 10 re-fractures, 2 malunions, 3 extensor pollicis longus tendon ruptures, 1 superficial wound infection, and 2 limited range of motions. Fourteen (6.9%) children required a secondary operative intervention for their complication. Time to implant removal averaged 3.8 months (range 0.4–16.3 months).

Elastic stable intramedullary nailing is a minimally invasive and reliable technique with a low complication rate. Both-bone forearm fractures and single bone fractures, and also Monteggia and Monteggia-equivalent fractures can be successfully treated with this method. As a major complication, re-fractures are frequently seen, even with ESIN in situ.

Abbreviations: EPL = extensor pollicis longus, ESIN = elastic stable intramedullary nailing, ICD-Code = International Statistical Classification of Diseases and Related Health Problems, ROM = range of motion.

Keywords: elastic stable intramedullary nailing, ESIN, forearm fracture, pediatric

1. Introduction

Since reports of intramedullary fixation of forearm fractures in children by many authors[1–5] were published in the late 1970s, more invasive operative techniques were replaced during the 1990s. Nowadays, closed reduction and intramedullary nailing is the preferred method for pediatric shaft fractures, if operative treatment is required. Intramedullary Kirschner-wires, rush rods, Steinmann pins, or elastic stable intramedullary nailing (ESIN) may be used.

A both-bone forearm shaft fracture is the most common reason for surgery of the forearm in children.[6] In general, controversy about surgical stabilization of pediatric fractures exists.[7] A German group observed an increasing rate from 1.8% to 22% of intramedullary nailing for forearm shaft fractures within 10 years.[8] Nonoperative treatment can be performed in most pediatric nondisplaced or minimally displaced radial and ulnar shaft fractures due to the correction potential of the pediatric bones.[9] However, for open fractures, fractures associated with compartment syndromes, additional elbow injuries, combined injuries such as Monteggia fractures, and Monteggia-equivalents, significant comminution or further displacement with nonoperative treatment, operative treatment is required. Even though the primary domain of ESIN in the forearm is both-bone shaft fracture, application can be widened for some other fracture

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[a] Department of General and Trauma Surgery, BG-University Hospital Bergmannsheil Bochum, Ruhr-University Bochum, [b] Department of Orthopaedics and Trauma Surgery, University Hospital Essen, Germany.

[*] Correspondence: Christiane Kruppa, Department of General and Trauma Surgery, BG-University Hospital Bergmannsheil Bochum, Ruhr-University Bochum, Bürkle-de-la-camp Platz 1, 44789 Bochum, Germany (e-mail: Christiane.Kruppa@ruhr-uni-bochum.de).

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types such as single-bone forearm fractures, or even some types of Monteggia fractures and Monteggia-equivalents, if stable fixation can be achieved. However, surgical alternatives such as k-wires, plate fixations, and external fixators still have their indications, and the combination with intramedullary nailing might be a helpful tool for special indications. Complications after ESIN treatment, such as re-fracture, malunion, nonunion, infection, compartment syndrome, cross-union, tendon ruptures, or forearm stiffness, occur.[10–14] A wide range of complication rates have been reported in the literature. Salonen et al[15] reported in 2012 a complication rate of 67% in patients over 10 years and 33% in patients under 10 years. A complication rate of 15% was reported in a large cohort by Fernandez et al[16] in 2010.

The purpose of this study was to demonstrate our experience and assess the complication rate after ESIN treatment of forearm fractures in a representative cohort of 201 children with 202 fractures over the past 15 years to underline the safeness and efficiency of this technique.

2. Methods

The study was a retrospective exploratory review at a Department of General and Trauma Surgery at a Level One trauma center. Between May 2000 and May 2015, patients with forearm fractures (up to the age of 16 years) were identified using the ICD-Code (International Statistical Classification of Diseases and Related Health Problems). Patients with nonoperatively treated fractures, and also patients with no intramedullary fixation were excluded. Therefore, 201 patients with 202 forearm fractures, operatively treated using at least 1 ESIN, were included. The study was approved by the institutional ethical committee.

A chart review and review of all available radiographic data were performed. Open fractures were classified according to Gustilo and Anderson system.[17] Fracture patterns were analyzed on plain anterior posterior and lateral radiographic imaging. Monteggia fractures, and also Monteggia-like lesions, which were fractures of the proximal ulna and radial neck, such as type II equivalents described by Bado,[18,19] were included in the study. Isolated radial head or neck fractures were excluded from the study. The majority of fractures were diaphyseal both-bone forearm fractures (82.2%) treated in 95.2% with ESIN of the radius and ulna (Fig. 1A–D). Open fracture reduction was performed in 10 (5.0%) fractures.

Five children were referred to our institution from another Department of Surgery because of early secondary fracture dislocation after nonoperative treatment, after an average time of 8.6 days (range 6–17 days). They were operatively treated using ESIN at the radius and ulna (3) or only at the radius (2).

Indications for operative treatment at our Department of General and Trauma Surgery were unstable, open, comminuted, combined, or failed nonoperatively treated fractures, and also fractures requiring closed reduction under anesthesia.

2.1. Operative technique

Titanium Elastic Nail System from Synthes (West Chester, PA) with ESIN of 2.0 to 3.0 mm in diameter, appearing to be 1/3 of the diameter of the central bony canal,[20] are usually used in our Department of General and Trauma Surgery. We prebend the ESIN to achieve an intramedullary 3-point fixation. The radial ESIN is inserted through a 1 to 2-cm mini incision, to protect the superficial radial nerve, at the distal lateral radius, proximal the growth line. A more dorsal insertion point, near the Lister tubercle, is chosen for fractures, which are located more distally at the radius. If closed reduction fails, we percutaneously insert a 2.0 to 2.5-mm k-wire at the fracture site to elevate and reduce the fragments, if both fail open reduction through a mini incision at the fracture site is performed. The ulna is stabilized through a minimal incision at the olecranon distal the growth plate. ESINs are shortened at the subcutaneous level. The wounds are either primarily sutured or closed with steri-strips. For plastic deformation of the ulna or radius closed reduction with continuous pressure on the forearm is performed. In the case of Monteggia fractures and Monteggia-eqivalent fractures, decision between plate fixation, k-wire fixation, or intramedullary nailing for stabilization of the ulna depends on the level of the ulna fracture and the age of the child. For more proximal ulna fractures in younger children, we use k-wires, and for adolescents, we usually use plate fixation. Radial neck fractures in Monteggia-like lesions are stabilized with an anterograde ESIN (Fig. 2A–D). If radial head dislocation does not spontaneously reduce with ulna fixation, an open approach is performed.

Free range of motion (ROM) of the elbow and wrist was tested for all fractures at the end of the operation by the surgeon, and intraoperative radiographs were taken. Postoperatively, children are placed in a long arm cast until wound healing, and, depending on the intraoperative fracture stability and individual surgeon's decision, in a short arm cast for 2 to 4 weeks. If no associated injuries are present, children were discharged the day after surgery. Clinical and radiographic follow-up is performed 2, 4, and 12 weeks after surgery. ESIN removal was scheduled when radiographic 4-cortices healing was ensured.

Complications such as neuropraxia, re-fracture, nonunion, malunion, tendon rupture, compartment syndrome, cross-union, wound infection, and forearm stiffness were recorded. Complications were further analyzed regarding fracture type, initial treatment, treatment for complication, and final outcome. Follow-up averaged 10.2 months (range 0.7–176.3 months). Thirty-six (17.9%) children were lost to follow-up.

Descriptive statistics were completed including percent, mean, and range using Microsoft Excel, 2010. The numbers of 202 fractures were used for calculations.

3. Results

The average age of our subjects was 9.7 years (range 3–16 years). Demographics, fracture types, and the treatments are shown in Tables 1 and 2.

In all, 18 (8.9%) complications occurred in the study population (Table 3). Sixteen complications occurred in both-bone forearm fractures, which represents a complication rate of 9.6% (16/166). One occurred in a Monteggia lesion (9.1%, 1/11) and 1 in a distal dia-metaphyseal fracture 12.5% (1/8). Fourteen (6.9%) children required further operative treatment. Seven re-fractures occurred due to a new trauma. This occurred at average 3.7 months (range 1.5–9.5 months) after ESIN removal. The time to implant removal in these patients averaged 2.6 months (range 1.1–3.8 months). Two children showed limited ROM $\geq 20^\circ$ of at least 1 direction, 1 after treatment for a Monteggia fracture at final follow-up of 2 months, and the other 8 months after re-osteosynthesis, because of a loss of reduction in a distal dia-metaphyseal fracture. No nonunion occurred. Two malunions were observed, both of which required the operative intervention. Three extensor pollicis longus tendon ruptures were observed and required operative treatment. One superficial wound

Figures 1. (A–D) Anterior posterior (AP) and lateral views of a 11-year-old girl with an I° open diaphyseal both-bone forearm fracture treated with closed reduction and ESIN of radius and ulna. The ulnar ESIN nail was inserted via a posteromedial approach, to prevent damage to the ulnar nerve; in general a posterolateral approach is recommendable. ESIN = elastic stable intramedullary nailing.

infection, but no deep wound infection, was observed; no compartment syndrome occurred due to the fracture or after surgery. In 103 (51.2%) children, ROM was documented to be free for all directions on final follow-up, in 23 (11.4%) children, ROM was intraoperatively documented to be free and in 33 (16.4%) children no information about elbow ROM was documented, but no complaints were documented in these reports, either (Table 4, supplemental digital content, http://links.lww.com/MD/B661).

In 2 (1.0%) children, a second fracture occurred in the same arm due to an adequate trauma, 39.5 and 60.4 months after ESIN removal. The ESIN in these children were removed 3.1 and 6.2 months after initial treatment. Implant removal was performed in 166 (82.2%) fractures, after an average time of 3.8 months (range 0.4–16.3 months), in our Department of Surgery. In 137/166 (82.5%) patients, no further consultation for disorders after implant removal followed.

4. Discussion

Since the 1980s, many authors reported good results with ESIN at different locations.[1,13,21–23] A wide range of complication rates between 15% and even 67% for intramedullary fixation is reported in the literature.[15,16] Flynn and Waters[24] reported a rate of 14.6%, Smith et al reported a rate of 42%,[25] whereas Shah et al[26] reported no complications after intramedullary

Figures 2. (A–D) Anterior posterior (AP) and lateral views of a 14-year-old boy with a Monteggia-like lesion, treated with ESIN of the radius and plate fixation of the ulna.

Table 1

Demographics, mechanism of injury, associated injuries.

	n (%)	
Demographics		
Boys	148 (73.6%)	
Girls	53 (26.4%)	
Left forearm fracture	123 (60.9%)	
Right forearm fracture	79 (39.1%)	
Children treated at the day of injury	192 (95.5%)	
Children referred from another Department of Surgery with fracture dislocation after non-operative treatment	5 (2.5%)	
Children with fracture dislocation after nonoperative treatment at our Department of Surgery	2 (1.0%)	
Children referred after failed operative treatment at another Department of Surgery	2 (1.0%)	
Open fractures	15 (7.4%)	14 (I); 1 (II)[11]
Mechanism of injury		
Fall on the arm (playing, jumping, skating, etc)	197 (98.0%)	
Polytraumatized (motor vehicle accident; fall from 3-m height)	2 (1.0%)	
No adequate trauma (osteogenesis imperfecta; juvenile bony cyst)	2 (1.0%)	
Associated injuries*		
Ipsilateral supracondylar fracture	2 (1.0%)	
L2 body fracture	1 (0.5%)	
Femoral + tibial shaft fracture	1 (0.5%)	
Acetabular + sacral + superior pubic ramus fracture	1 (0.5%)	

* Multiple values were present.

Table 2

Included fractures, treatment, and implant removal.

Fracture	Average age, y	Treatment, n (%)	Open reduction	Average time to IPR, mos
Both bone fracture (166)	9.7 (4–16)	158 (95.2%) ESIN "r" + "u"	4	4.0 (0.4–16)
		1 (0.6%) ESIN "u" + k-wire "r"	—	(135 fx)
		1 (0.6%) ESIN "r" + IM k-wire "u"	—	
		1 (0.6%) ESIN "u"	—	
		5 (3.0%) ESIN "r"	—	
Radial fracture + ulnar bowing (12)	11.3 (5–15)	12 (100.0%) ESIN "r"	1	3.6 (1.4–6.9) (11 fx)
Ulnar fracture + radial bowing (3)	7.6 (6–10)	3 (100.0%) ESIN "u"	—	2.7 (1.7–3.7) (2 fx)
Diaphyseal radial fx + distal metaphyseal ulnar fx (2)	8.6 (6–11)	1 (50.0%) ESIN "r" (2 ESIN)	—	2.2 (1 fx)
		1 (50.0%) ESIN "r" + k-wire "u"	—	
Monteggia/-equivalent fracture (11)	8.3 (3–14)	6 (54.5%) ESIN "r" + k-wire "u"	1	2.1 (0.7–5.1) (10 fx)
		1 (9.1%) ESIN "r" + plate "u"	1	
		4 (36.4%) ESIN "u"	—	
Distal dia-/metaphyseal forearm fracture (8)	10.9 (7–14)	6 (75.0%) ESIN "u" + k-wire "r"	—	4.1 (1.4–8.1) (6 fx)
		2 (25.0%) ESIN "u" + plate "r"	2	

fx = fracture, IPR = implant removal, "r" = radius, "u" = ulna.

nailing and Antabak et al[27] a rate of 25% in 88 children. In the present study population with a large cohort of 202 fractures, we observed a low total complication rate of 8.9%, of which only 6.9% required a second operative intervention.

With regard to the major fracture type in our population, which was diapyhseal both-bone forearm fractures, we observed a complication rate of 9.6% in this group. One hundred fifty-eight cases of both-bone forearm fractures were treated with ESIN fixation of both bones. A total of 6 fractures were treated using a single ESIN of either the radius (5) or ulna (1). In one 16-year-old patient, treated with radial ESIN only for a both-bone forearm fracture, loss of reduction with malunion and radial shortening was observed. Consequent osteotomy and plate fixation of the radius followed. All other single-bone treated both-bone fractures healed without complication. Single-bone fixation of the ulna has been reported to be safe and effective for unstable diaphyseal both-bone forearm fractures by Dietz et al[28] and Flynn et al,[24] whereas other authors suggested loss of reduction of the unfixed radius.[11,29] If adequate remodeling fails and significant malunion with loss of motion is present, osteotomy and plate fixation may be necessary.[6,30] A second malunion with limited supination was observed in a 13-year-old child after ESIN stabilization of both bones and was treated with an osteotomy and plate fixation.

Re-fracture represented our main complication (10/18), either with the ESIN in situ or after implant removal. This is not unexpected, as forearm fractures are known to have a higher rate of re-fractures in children than other fractures,[14] and they have been frequently reported after removal of intramedullary forearm fixation in the literature.[4,11,16,31] Our total re-fracture rate was 5.0%, which is similar to the reported rates in the literature of 4% to 8%.[32,33] Three re-fractures occurred with the ESIN in situ in this study population. Two children underwent an exchange of the ESIN and in 1 child, the ESIN was preserved. In a literature review of 11 studies performed by van Egmond et al,[34] they recorded an average incidence of 2.3% for re-fractures with ESINs in situ due to a second trauma. Seven re-fractures occurred after implant removal in our study population. In all patients, an adequate re-trauma was present. Three of them occurred after premature removal of the ESIN, 1.1, 2.0, and after 2.4 months after insertion. We usually remove the ESIN after the third month and only if 4-cortices healing is radiographically established. The average time to implant removal for both-bone forearm fractures in our patients was 3.8 months. It is recommended in the literature that nail removal before should not be performed before 4 to 6 months after insertion and not before complete consolidation of the fracture occurred.[6,35] Further, Lascombes et al[4] suggest no nail removal until 1 year after surgery. If re-fracture occurred, internal fixation is recommended by some authors.[13,36] In our study population, all of the 7 children presenting a re-fracture after implant removal were also treated with ESIN of the radius and ulna the second time.

Table 3

Complications.

Complication	n (%)
Re-fracture with ESIN in situ	3 (1.5%)
Re-fracture after ESIN removal	7 (3.5%)
Malunion	2 (1.0%)
EPL rupture	3 (1.5%)
Infection	1 (0.5%)
Limited ROM	2 (1.0%)
Total	18 (8.9%)

EPL = extensor pollicis longus tendon, ESIN = elastic stable intramedullary nailing, ROM = range of motion.

Extensor tendon injuries due to direct trauma during nail insertion or removal, and also slow erosion caused by the end of the nail, have been reported previously in the literature.[4,37,38] This was the second most common complication in our study population with 1.5%. Either pin shortening over the tendon level[11] or through the skin[37] is suggested to prevent these injuries. In our patients, the nails were shortened at the subcutaneous level and we avoided tendon damage through a mini incision at nail insertion. Nevertheless, 3 ruptures of the EPL tendon occurred. Flynn et al[39] reported rupture of the EPL tendon due to an injury from the ESIN in 2 of 103 patients (1.9%), which is close to our rate of 1.5%. Gibbon et al[40] recently published an investigation recommending bending of the ESIN tip and suggested tip bending of 180° before burying to prevent skin irritations and additional procedures. Only 1 superficial wound infection at the radial insertion point occurred after implant removal and was locally treated; no deep infection was observed even after open fractures. We observed 1 limited ROM 2.2 months after treatment for both-bone forearm fracture in a 10-year-old child. Because the child was lost to follow-up, no

further assessment of the ROM followed. As all fractures were intraoperatively tested for free ROM, it is likely that the ROM improved over time in this child.

Even though diaphyseal both-bone forearm fractures comprised the majority of our study population, 17.8% fractures were of another configuration and were successfully treated with at least 1 ESIN. Of the remaining 2 complications, 1 occurred in a Monteggia lesion (9.1%) and 1 in a distal dia-metaphyseal fracture (12.53%). We observed a limited ROM in 1 child with a Monteggia fracture, especially for pronation/supination. The remaining 10 fractures healed without further intervention. Treatment of Monteggia fractures and their equivalents is usually dictated by the type of ulnar fracture rather than the radial head injury.[41,42] Schmidt et al reported about 4 children with Monteggia-like lesions. Two were successfully treated with ESIN of the ulna, 1 ulna required re-osteosynthesis and plate fixation, because of loss of reduction after intramedullary nailing, and 1 was primarily stabilized with a plate. They stated that if ESIN is used, a minimum of 2 ESIN within the ulna will able to hold the fracture aligned.[43] In our population, 4 fractures were treated with a single ESIN of the ulna after closed reduction. The ulna fracture in these children was located at the middle shaft. Six were fixed using ESIN for the radius and k-wire fixation for the ulna, and no loss of reduction was observed. Time to implant removal averaged 2.0 months, because most of them were treated with k-wire fixation of the ulna, which are supposed to be removed after 6 to 8weeks.

Further, 1 in 8 fractures at the distal dia-metaphyseal junction developed a complication. A child primarily treated with ESIN of the radius and ulna was referred for further treatment to our department of surgery after loss of reduction. Removal of the radial ESIN and plate fixation followed. Because fractures at this junction are difficult to treat, loss of reduction with intramedullary nailing, especially of the radius, is likely. For children treated primarily at our department of surgery, intramedullary nailing was only used for the ulna in combination with k-wire or plate fixation of the radius to avoid fracture dislocation, such as seen in the referred patient. Lieber et al showed successful treatment with transepiphyseal intramedullary k-wire fixation in 10 patients, and in 5 patients with additional antegrade ESIN of the ulna. They suggested advantages of this technique over other treatment options such as plate fixation, external fixators, or ESIN.[44]

For radial/ulnar fracture plus bowing of the second forearm bone, and also diaphyseal radial fracture plus metaphyseal ulnar fracture, we did not observe any complications. In these injuries, fixation of the shaft fracture was performed according to the principles in diaphyseal both-bone forearm fractures. No loss of reduction or other complications were observed. In 15 children, a bowing injury occurred, which is most commonly reported to be at the ulna, in addition with a radius fracture.[45] In our population, this was present in 12 fractures in children with an average age of 11 years. Fracture and bowing were reduced closed and an ESIN inserted into the broken bone to maintain the reduction. For fractures with a metaphyseal component of the ulna, either no fixation or additional k-wire fixation of the ulna showed successful treatment.

For the majority of patients in our study population (82.2%), no further consultation, because of disorders after implant removal, followed.

A number of limitations apply to the present study. First, it is a retrospective study with its inherent problems. Even though the relatively short-term clinical data suggest no major limited forearm ROM, no conclusions can be made regarding longer-term outcomes. Further, the study population consisted of different types of forearm injuries, which are not directly comparable to each other.

In conclusion, ESIN of forearm fractures in children is safe and reliable. Apart from both-bone diaphyseal forearm fractures, some special cases such as Monteggia-like fracture dislocations or single-bone forearm fractures can be successfully treated. Complication rates are low, and a nondeficit functional outcome can be achieved in most cases. Re-fractures are an ongoing problem in pediatric forearm fractures. Late implant removal may lessen the risk, but probably not completely extinguish their occurrence. We suggest ESIN removal after 4 to 6 months and not before 4-cortices healing is demonstrated. Care should be taken during nail insertion and removal to prevent damage to the EPL tendon, and mini incisions might be preferable. The risk to fracture malunion might be increased with single-bone fixation in both-bone forearm fractures.

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