ESIN in Forearm Fractures

Clear Indications, Often Used, but Some Avoidable Complications

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Abstract

Background and Purpose: Elastic stable intramedullary nailing (ESIN) is well established for stabilizing pediatric forearm fractures. To prevent uncritical use, it is necessary to evaluate the problems and complications of this common technique.

Patients and Methods: Four pediatric surgical departments participated in a retrospective study analyzing the last 400 fractures treated with ESIN. Continuous documentation of treatment, postoperative course and follow-up formed the basis of evaluation. In this article forearm fractures (n = 163, 40.7%) are discussed, and epidemiology, indication, fracture types, intraoperative technique, postoperative management and problems, as well as complications and results are compared to those described in the literature.

Results: Complete, transverse fractures of the midshaft (73%) were mainly seen. Indication for intervention was an intolerable axial deviation (85.9%). Intraoperative technique (operating and transillumination time, site of approach, material choice) and postoperative management (hospital stay, number of X-ray controls, and follow-up) differed highly depending on the hospital's circumstances. Postoperatively, 3.0% of patients showed soft-tissue irritation due to sharp nail ends or wound infections. Complications (10.4%) included secondary rupture of a tendon in 3.7%, refracture with nails in situ in 2.5%, axial deviations > 10° or instability of osteosynthesis in 1.8%, delayed healing in 1.2%, migration of nails in 0.6%, and technical failure in 0.6%. Overall, a significant functional restriction (limitation of movement > 10°) was found in three cases only (1.8%) following radial neck fracture.

Conclusion: ESIN in pediatric forearm fractures is an often used technique with clear indications and excellent results to be expected. Numerically, complications have not altered considerably, but they rather show a shifting of problems with optimization and refinement of technique and improvement of equipment. Thus, continuous evaluation of technical principles and procedural recommendations constitutes the mainstay in the prevention of problems and complications.

Key Words

Fracture · Forearm · Children · Elastic stable intramedullary nailing (ESIN) · Complications

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Introduction

Elastic stable intramedullary nailing (ESIN) constitutes a well-established procedure in children's forearm fractures which is mainly used to stabilize unstable diaphyseal fractures of the forearm. Significantly displaced fractures of the radial neck and special metaphyseal

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fractures represent further indications [1]. Detailed descriptions of the well-known technique can be found in the literature [2].

To prevent uncritical use, it is necessary to evaluate the problems and complications of ESIN and point out mistakes and pitfalls. This has first been done by four pediatric surgical departments in a retrospective study including 937 patients treated by ESIN between 1990 and 1998 [3]. The same departments again retrospectively evaluated the data of 400 actual patients treated by ESIN to compare changing indications, problems, and complications.

Patients and Methods

The four pediatric surgical departments from Regensburg, Germany, Munich, Germany, Bern, Switzerland, and Graz, Austria, having great experience in ESIN, participated in the retrospective study. Each department reviewed the charts of the last 100 patients treated with ESIN based on continuous documentation of fractures, treatment and postoperative course until nail extraction. In this article all forearm fractures treated by ESIN are analyzed.

We collected data concerning epidemiology (accident course) and indication for ESIN (dislocation, stability), fracture type, operative technique, postoperative management, complications, and short-term results.

The term "fracture type" implies whether ulna or radius fractures were isolated or combined, describes the lesion's location (metaphyseal or diaphyseal), type (complete or greenstick) and course (transverse, oblique, with wedge or multifragmentary). Open fractures and refractures were analyzed in detail.

The term "operative technique" covers open or closed reduction, implanted material, the site of implantation, as well as operating time and X-ray time compared between the departments.

"Postoperative managment" includes the length of hospital stay, additional immobilization, postoperative X-rays, and reoperations within the same hospital stay.

The term "complications" includes iatrogenic nerve and tendon lesions, remaining axial deviations, nail displacement, refractures, delayed healing and pseudarthrosis, as well as "postoperative problems" like wound infection, soft-tissue irritation and skin perforation by nail ends.

"Results" only cover the short-term clinical course until nail extraction. Functional and cosmetic results are discussed. Questions concerning the long-term clinical course, e.g., growth disturbances, persistent limitation of joint movement, and loss of forearm rotation, were not part of this study and require further evaluation.

Results

Out of the 400 patients, 163 fractures (40.7%) were found at the forearm. There was a preponderance of the left side (n = 98 [60%]) over the right side (n = 65 [40%]) not only in the entire group but also in every single department. The patients' age ranged between 2 and 17 years (mean age 9.5 years). Male to female ratio was 101 : 62 (1.6 : 1).

Most of the accidents happened in the spare time followed by club sports and accidents at home (Figure 1). Less than presumed accidents happened at school. In high-velocity accidents the lower extremities were predominantly concerned.

In 118 cases (73%) a midshaft forearm fracture had to be treated, including four at the distal meta-diaphyseal transition. Isolated fractures of the ulna were registered in twelve cases (7%), including four Monteggia lesions. 33 fractures of the radius (20%) were stabilized by ESIN; of those 13 were isolated radial shaft fractures (8%) and 20 were fractures of the radial neck (12%). In most of the cases we had to deal with complete fractures (83.4%). Greenstick fractures were stabilized in 9.8% (n = 16). The fracture line was transverse in 73.6%, oblique fractures, thus more likely to displace delayed, occurred in nearly one fourth. Other fractures only presented as individual cases (Figure 2). Eleven refractures (6.7%) were reported; of those six had initially been treated by plaster immobilization (refracture after 4.5 months on average),

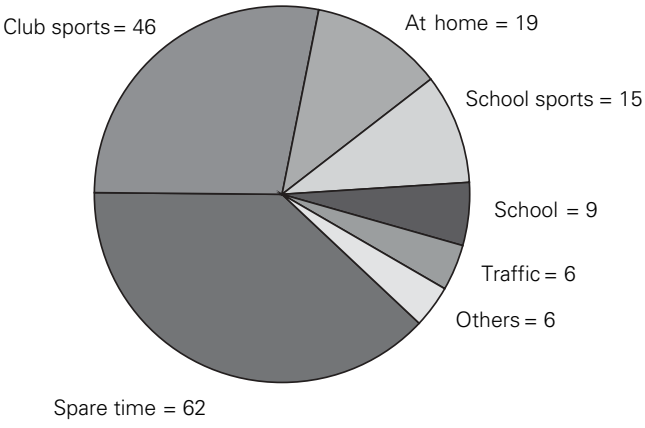


Figure 1. Cause of accident.

Figure 2. ESIN in a multifragmentary fracture.

four had been stabilized by ESIN (hardware in situ for 4.8 months, refracture 6.7 months after metal removal), and one patient had an external fixator before (Table 1).

The main indication for intervention was an intolerable initial axial deviation (n = 140). In 23 cases a closed reduction was initially meant to be satisfactory, but intraoperatively proven instability led to treatment by ESIN. The eleven refractures resulted in an indication for ESIN because of an otherwise long consolidation time with conservative treatment.

Table 1. Affected bones, types and course of fracture.

Affected bone	**(n = 163)**	
Forearm, both bones	118	73%
· Distal meta-diaphyseal junction	4	
Ulna	12	7%
· Shaft	8	
· Monteggia	4	
Radius	33	20%
· Shaft	13	
· Radial head	20	
Type of fracture	**(n = 163)**	
Complete fracture	136	83.4%
Greenstick fracture	16	9.8%
Mixed	10	6.2%
No declaration	1	0.6%
Course of fracture	**(n = 163)**	
Transverse	120	73.6%
Oblique	37	22.7%
Wedge	2	1.2%
Multifragmentary	1	0.6%
Bowing	1	0.6%
No declaration	2	1.2%
Type of fracture (B)	**(n = 163)**	
Refracture	11	6.7%
Open fracture	11	6.7%

Figure 3. Splinting of the ulna from a proximal or distal approach.

In 58% of the cases operation was performed on the day of admission, 21% were held off until the next morning, and in 2.5% the operating interval was up to 3 days. In 18.5% a conservative treatment with cast was started initially, but operation was performed when secondary displacement was seen (10th day after accident on average). In this group patients were also admitted from peripheral hospitals.

In 59% (n = 96) titanium nails and in 32% (n = 52) stainless steel implants were used (not documented in 9% [n = 15]). We found a preferential use of a distal dorsal radial approach in 105 cases, and a distal lateral radial implantation in 46 patients. An ascending splinting of the ulna was registered in only six cases, but a descending approach was used in 124 (Figure 3). The mean operating time was 43 min (minimum 10, maximum 143 min). Intraoperative X-ray time averaged 2.36 min (minimum 0.06, maximum 21.59 min). Postoperatively, the children stayed on the ward for 3.32 days. In two thirds a postoperative X-ray documentation was performed. These parameters differed depending on the departments' circumstances (Table 2). 19 patients got an additional immobilization because of nondisplaced additional fracture of the other forearm bone (n = 6) and for analgesia (n = 7). No reason for immobilization was mentioned in six cases.

17 complications (10.4%) were reported (Table 3), with tendon injury being the most frequent. In four cas-

Table 2. Demographics, intra- and postoperative data.

Hospital	I	II	III	IV
Demographics				
Fractures (n)	52	30	27	54
Mean age (years)	8.8	9.3	9.3	10.3
L/R ratio (n)	34/18	18/12	17/10	29/25
Intraoperative times				
Operating time (min)	47	43	41	44
Minimum/maximum (min)	12–143	10–115	14–93	20–145
X-ray time (min)	2.36	4.54	0.48	3.38
Minimum/maximum (min)	0.18–10.54	0.43–21.59	0.06–4.24	0.37–12.42
Postoperative management				
Hospital stay (days)	3.29	4.57	2.72	2.85
Minimum/maximum (days)	2–6	2–8	2–7	1–4
Postoperative X-ray (yes/no, n)	52/0	21/7 (2)[a]	5/22	28/24 (2)[a]
X-ray controls (n)	3.12	1.63	2.81	2.22
Minimum/maximum (n)	1–7	1—6	2–6	1–5
Metal removal (days)	98	133	172	163

[a] no data (n)

es the tendon of extensor pollicis longus and in two the tendon of extensor carpi radialis brevis were affected during dorsal distal radial nail implantation or by continuous tendon friction over sharp nail ends. A reconstruction was performed at the time of nail extraction or later, once with a tendoplasty using one extensor tendon for the index finger. There were no iatrogenic nerve injuries registered.

Four patients (2.45%) sustained refractures with nails in situ. All of them underwent simple closed reduction without change of nails (see Figure 7). Three children (1.8%) presented with relevant axial deviations (> 10°) due to secondary postoperative displacement, prompting corrective surgery (plate osteosynthesis in one case, closed reduction after early metal removal and plaster immobilization in the second case). Both fractures were in the transition from diaphysis to metaphysis. In the third case displacement did not impair movement after healing, and was therefore tolerated. In two children with an open fracture (1.2%), healing was delayed because of an infection but complete after hardware removal (see Figure 8). One more patient required early revision of osteosynthesis because of severe failure of technique.

Five postoperative problems (3.1%) were registered (Table 3). In three children, insufficiently shortened nail ends induced soft-tissue irritation with swelling and pain during motion and at least perforation of the skin. Seroma and wound infection occurred in another two patients.

On average 2.63 clinical controls were performed in the surgical departments depending on the complexity of the injury. Besides, 2.96 X-ray controls (n = 156) were done. We registered four cases (2.4%) with bad cosmetic results following nail perforation and infection. Apart from a slight temporary limitation of movement (≤ 10°) in 15 cases (9.2%), a significantly restricted range of motion (> 10°) was found in only three cases (1.8%) following radial neck fracture.

Table 3. Complications and postoperative problems in elastic stable intramedullary nailing.

Complications	**17**	**10.4%**
Rupture of tendon	6	3.7%
Refracture with hardware in situ	4	2.5%
Axial deviations > 10°	3	1.8%
Delayed healing	2	1.2%
Technical failure	1	0.6%
Migration of nails	1	0.6%
Postoperative problems	**5**	**3.0%**
Nail end perforation	3	1.8%
Wound infection	2	1.2%

Discussion

ESIN is the first-choice surgical technique for stabilizing pediatric diaphyseal and special metaphyseal forearm fractures. Without special emphasis, complications were only mentioned in reports reflecting the use of ESIN in a special indication or single institution. Lascombes et al. [4] and Cullen et al. [5] were the first to use the term "complications" in articles dealing with intramedullary nailing of children's fractures. Recently, Schmittenbecher et al. [3] have evaluated problems and complications in a multicenter study and pointed out mistakes and pitfalls which they judged as being preventable by adequate technique. Detailed knowledge of technical principles and procedural recommendations constitute the mainstay in prevention. However, changes in terms of indication, sorts of problems and complications as well as operating techniques have to be reevaluated continuously to optimize this technique for fracture treatment in children to a maximum.

Complete displaced forearm shaft fractures and unstable greenstick fractures of the shaft still represent the main indication for ESIN, because conservative therapy results in a significant number of functional restrictions

with limitation of pronation/supination [1, 2, 6, 8]. Even radial neck fractures are stabilized by ESIN with great success [15]. Multifragmentary and wedge fractures appear to be rarities in the forearm, but both fracture types also represent an indication for ESIN (see Figure 9). In most multifragmentary fractures the external fixator has to be kept in mind. Fractures around the transition from metaphysis to diaphysis present a difficulty in terms of the optimal method of stabilization. Transepiphyseal intramedullary Kirschner wiring [10, 12, 13], external fixation and ESIN are suitable methods, all of them having certain disadvantages: need for additional plaster immobilization, difficulty in perforating the opposite cortical bone with the K-wire due to its very steep progression and risk of pin-tract infection with external fixator, and adequate stabilization difficult to achieve as well as risk of secondary displacement with ESIN (see Figure 5).

Regardless of fracture type and localization, initial axial deviation and given instability with fracture of both bones on the same level and/or oblique fracture planes are the most frequent indications for operative intervention. In only 23 cases (14%), an instability was proven intraoperatively before the indication for stabilization was given. It remains unclear whether reduction and plaster retention would have given different results in these cases, because randomized studies are lacking. Intramedullary nailing of children's forearm factures without long-term immobilization, with quick return to daily activities and reliable prevention of functional restrictions is widely accepted as positive in the patients' and parents' view. But even in well-established and extensively used methods, one should not forget about detriments and complications.

As long as no neurovascular impairment is described, no emergency case exists and intervention can be delayed until the next morning for elective surgery. However, in times of cost reduction in the medical system and discussion about diagnosis-related groups (DGRs), e.g., in Germany, the authors have to consider intramedullary nailing of forearm fractures in children to be possible in day-surgery circumstances. Hospitalization time in our collective was 3.32 days on average. Realistically, only additional injuries or preexistent diseases (e.g., coagulation disorders, incompatibility of anaesthesia) justify hospitalization. On the other hand, numerous accidents happen in the evening hours and discharge from hospital after midnight cannot be referred to as "suitable for children". Therefore, a hospital stay of around 1.5 days will be expected in future.

A detailed description of intramedullary nailing can be found in the literature [1, 7, 8, 18]. Previously, an ascending splinting technique of the radius from lateral and a descending technique of the ulna from the proximal radial side were most frequently described. The ascending splinting technique of the radius from dorsal is discussed below including its advantages and problems. However, approaching both bones from distal offers, on the one hand, a more comfortable position for the surgeon and, on the other hand, simplifies X-ray transillumination. Therefore, distal ulnar implantation receives more acceptance (Figure 3). This technique prevents soft-tissue irritation and nail-tip perforations at the elbow when the patient leans up, e.g., on the table. Splinting the ulna from a distal approach is technically easy without any anatomic risk of nerve or tendon injury, even if the medullary canal is smaller distally [11].

In terms of material choice there are no definitive established recommendations. To achieve reduction of a displaced radial head, titanium nails are preferably used because of their higher flexibility. On the other hand, stainless steel provides better stabilization in midshaft fractures because of its higher rigidity. Allergic reactions are described neither for titanium nor for steel in detail [16]. Overall, the material choice often conforms to the surgeon's preferences and hospital's circumstances. Independent of the material in either case identical and adequate diameters for the certain implants should be considered, in radius and ulna two thirds each of the smallest diameter of the medullary cavity.

As a basic principle both bones should be splinted, even if only one bone shows displacement to make an additional cast dispensable. In Monteggia lesions or fractures of the radial neck isolated splinting of the fractured bone is sufficient. An additional plaster immobilization is redundant in all cases. An indication for additional immobilization only exists in additional forearm fractures without any stabilization, e.g., olecranon or distal metaphyseal fractures. A proper postoperative analgesia is easy to achieve by suppositories or other peripheral painkillers and pain should not require application of a cast.

Operating and transillumination times differ considerably, depending on the complexity of fracture and dimension of displacement on the one hand and on the surgeon's experience on the other (Table 3). In this re-

gard closed reduction sometimes proves impossible, especially in completely displaced forearm fractures as observed in 7.4% of our cases. Open reduction with the fingertip, hook or a pliers has to be kept in mind to shorten transillumination and radiation times. Additionally, special technical radiologic assistants are already available in some operating rooms making transillumination more effective.

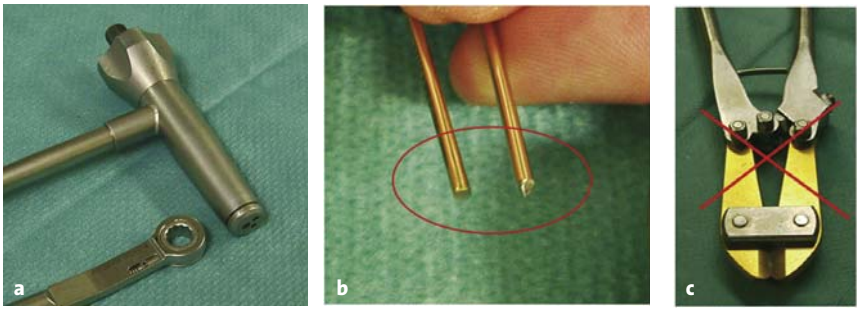
Besides an intra- or postoperative documentation a first X-ray control is necessary 4 weeks postoperatively to demonstrate consolidation and to allow the child full weight bearing. The second X-ray control before metal removal normally shows complete remodeling. Depending on complexity of the injury and incidence of complications and problems, the number of X-rays and clinical controls diversify highly.

Numerically, complications have not altered considerably, but they rather show a shifting. Affection of the superficial radial nerve was the former main problem with lateral radial nail insertion reported in detail by Hahn et al. [6], Lascombes et al. [4] (1.2%), and Schmittenbecher et al. [3] (1.4%). By visualizing the nerve before placing the awl, we could completely avoid this complication in our collective. A slightly longer incision, required for a proper implantation and especially metal removal anyway, saves the surgeon wordy explanations to the child and parents until the nerve has recovered spontaneously and sensibility of the thumb is reestablished.

When inserting the intramedullary nail into the distal radius using a dorsal approach through Lister's tubercle, the extensor pollicis longus tendon is highly vulnerable. This is not so much a matter of intraoperative problems but rather a secondary damaging of the tendon rubbing over sharp nail ends. Using an inappropriate instrument for cutting the nails resulting in sharp tip ends represents the main reason for tendon injuries (Figure 4). Therefore, cutting the nail with an adequate instrument avoids this dangerous friction. Additionally, placing the end of the nails outside the tendon compartment does not impair wrist movement, and concurrently, the nail is easily palpable. This enables a simple and trouble-free removal without a serious risk of structural damage.

Axial deviation > 10° or instability with loosening of the nails, both leading to malalignment as reported by Schmittenbecher et al. [3] in 5.3% and Lacombes et al. [4] in 4.7%, were significantly lower in our collective (1.8% [n = 3]). In these cases we were dealing with technical faults on the one hand: nails require a sufficient diameter, correct implantation, and rigid proximal impaction. On the other hand, there must be a correct indication for ESIN, especially in fractures around the transition from metaphysis to diaphysis. Often, a sufficient three-point support cannot be achieved because of the short distal fragment. Consequently, secondary displacement occurs. In these cases an insertion as far as possible away from the fracture line should exactly be realized, and the nail must be prebent to achieve the opposite cortex before the fracture plane is crossed (Figure 5). Additionally, the nail should be advanced into the medullary cavity of the radius carefully. Brusque hammer blows should be avoided, because the nail tip might burst out a fragment from the opposite cortical bone which may preclude further ESIN, because the distal fragment cannot be sufficiently fixed resulting in ulnar deviation of the distal radius. The ratio "length of distal fragment of the radius/total length of radius" (Figure 6) might be a helpful parameter for preoperative evaluation whether ESIN is practicable or not [20]. However, if no stable fixation is obtainable by ESIN, the external fixator has to be kept in mind. Plate osteosynthesis is more invasive, brings higher risk of nerve damage, more extensive scarring, and mostly needs additional immobilization [14].

When talking about the performance of intramedullary nailing, emphasis should be placed on stability testing by bending and torsional stress at the end of surgery. This exclusively minimizes the risk of secondary hardware migration and meets the demands of definite treatment using single anesthesia and the optimal technique according to the child's fracture type.



Figures 4a to 4c. The use of inappropriate instruments for cutting the nails resulting in sharp tip ends represents a reason for tendon injuries or skin perforations.

Figure 5. ESIN in a fracture at the transition from diaphysis to metaphysis. A sufficient three-point support has to be achieved by special prebending.

A reoccurring fracture with the nails still in situ does not really represent a complication. An adequate trauma is the likely reason, but even the use of wrong hardware of too thin a diameter. A closed reduction is the appropriate procedure (Figure 7). Only individual cases require a change of hardware. Generally, the risk of refracture is known especially in forearm fractures in 3.5–6.7%, mainly observed in greenstick fractures with delayed healing [4, 8, 18, 19]. This risk is definitely lower in ESIN, but in general, it seems advisable not to extract forearm nails until full bone remodeling and restoration of the medullary canal have occurred without visible changes in cortical structure. However, the timepoint of nail extraction is questionable. Our collective demonstrates, that radiologic criteria implicate metal removal. The refracture rate does not drop with leaving the hardware intramedullarily for 6 months instead of 3. On the other hand, no disadvantages exist from later removal, apart from an eventually grueling and demanding metal removal.

Even if reported in two cases only, open fractures and open reduction procedures, respectively, result in a higher risk of pseudarthrosis-like delayed healing, because of periosteal damage and possible infection. In these cases, provided consolidation has begun and stability for exercises has been obtained, nail extraction may lead to healing (Figure 8). In none of the cases a curettage, spongiosa plasty and stabilization using an external fixator became indispensable.

According to the literature hematoma, seroma, perforation, and local infection occur in 8.6–11.8% [4, 8, 9]. Schmittenbecher et al. [3] observed lower rates of skin problems (6.4%) using better instruments and cutting off nail ends, but pointed out that further reduction still remains a future aim. Through continuous improvement of hardware and instruments, but especially choice of the optimal point for nail cutting (pro-

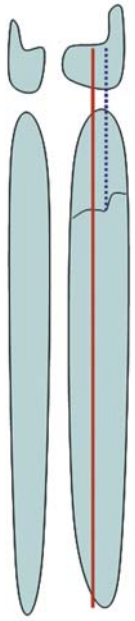


Figure 6. The ratio "length of distal fragment of the radius/total length of radius" might be a helpful parameter for preoperative evaluation.
If blue : red is < 0.3, ESIN is not supposed to be practicable.

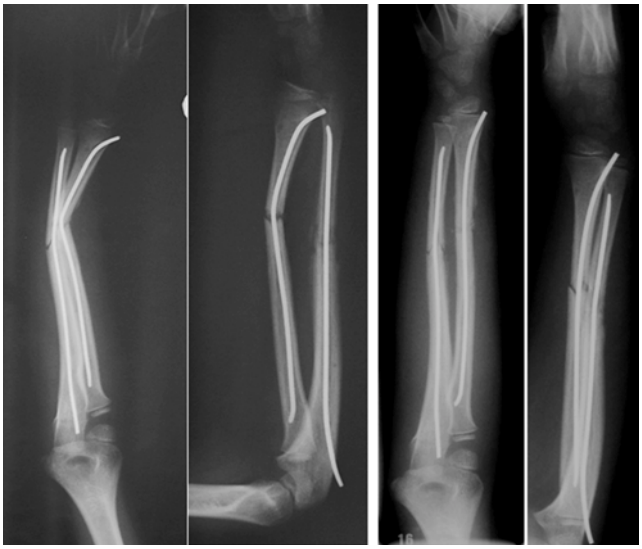


Figure 7. Refracture with hardware in situ. Closed reduction without hardware change.

truding the tendon compartment, without tension on skin, still long enough for easy removal) we have further reduced cosmetic failure to 2.4%.

Lascombes at al. [4] described incontestable functional results in 92.6%, Buch et al. [17] confirmed an excellent outcome in 85.3%, and Parsch et al. [19] saw excellent clinical results throughout. Corresponding more or less with our results, we only collected full data before metal removal. In 9.2% of cases a slightly impaired range of motion with a limitation ≤ 10° was reported, but considered to be of temporary nature (Figure 9). In fractures of the radial neck we observed the only strongly impaired range of rotational movement (1.8%).

Figures 8a to 8f. Delayed healing in a I° open fracture. Initial X-ray (a) and after ESIN (b). Delayed healing with signs of infectious pseudarthrosis 56 days (c) and 126 days (d) postoperatively. After metal removal 6.5 months later (e), consolidation (10 months, f).

Figures 9a to 9c. Bending wedges do not need special attention, if they do not impair rotation. X-ray after surgery (a), 2 months (b) and 4 months (c) postoperatively.

Conclusion

Intramedullary nailing of children's diaphyseal, special metaphyseal forearm and radial neck fractures has become the surgical technique of choice in those cases that warrant surgical intervention. This method offers both technical advantages (short operation time, small tissue trauma) and patient benefits (plaster freedom, quick return to daily activities). Although excellent clinical results are described with intramedullary fixation, relevant complications related to technical failures can be expected. Improvement of equipment, refinement of technique and analysis of indications decreased the incidence of well-known complications on the one hand, but gave rise to new complications on the other. Therefore, continued evaluation of complications and problems is required, because only detailed knowledge of technical principles and procedural recommendations constitutes the mainstay in prevention. Such high demands should particularly be made on a technique frequently used and already well established such as ESIN in children's limb fractures.

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