

Is there a standard treatment for displaced pediatric diametaphyseal forearm fractures?

A STROBE-compliant retrospective study

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Abstract

To review our institutional results and assess different surgical and non-surgical techniques for the treatment of displaced diametaphyseal forearm fractures in children and adolescents.

Thirty-four children (25M, 9F) with a total of 36 diametaphyseal forearm fractures who underwent treatment under general anesthesia between July 2010 and February 2016 were recruited to this retrospective study. From October 2016 until March 2018 patients and/or parents were contacted by telephone and interviewed using a modified Pediatric Outcomes Data Collection Instrument (PODCI).

Median age at the time of injury was 9.1 years (range, 1.9–14.6 years). Initial treatment included manipulation under anesthesia (MUA) and application of plaster of Paris (POP) (n=9), elastic stable intramedullary nailing (ESIN) (n=10), percutaneous insertion of at least one Kirschner wire (K-wire) (n=16), and application of external fixation (n=1). Eleven children (32%) experienced a total of 22 complications. Seven complications were considered as major, including delayed union (n=1) and extensor pollicis longus (EPL) tendon injury (n=1) following ESIN, as well as loss of reduction (n=2) and refractures (n=3) after MUA/POP. The median follow-up time was 28.8 months (range, 5.3–85.8 months). In 32 out of 34 cases (94%) patients and/or parents were contacted by telephone and a PODCI score was obtained. Patients who experienced complications in the course of treatment had a significantly lower score compared with those whose fracture healed without any sequelae ($P=.001$). There was a trend towards an unfavorable outcome following ESIN compared with K-wire fixation ($P=.063$), but not compared with POP ($P=.553$). No statistical significance was observed between children who were treated initially with a POP and those who had K-wire fixation ($P=.216$).

There is no standard treatment for displaced pediatric diametaphyseal forearm fractures. Management with MUA/POP only is associated with an increased refracture rate. Based on our experience K-wire fixation including intramedullary positioning of at least one pin seems to be favorable compared with ESIN.

Abbreviations: EPL = extensor pollicis longus, ESIN = elastic stable intramedullary nailing, GA = general anesthesia, K-wire = Kirschner wire, MUA = manipulation under anesthesia, OR = operating room, PODCI = Pediatric Outcomes Data Collection Instrument, POP = plaster of Paris.

Keywords: children, complications, diametaphysis, forearm fractures, therapy

1. Introduction

Forearm fractures are among the most common injuries in pediatric traumatology. Of these, approximately 75% to 84%

occur in the distal third, 15% to 18% in the middle third, and 1% to 7% in the proximal third.^[1–3]

Traditionally closed reduction and cast immobilization is the gold standard for treating most of these fractures, mainly because of the fast bone healing and excellent remodeling capacity seen in the pediatric age group.

Over the last 3 decades with changes in lifestyle, improved implant technology and the changing expectations of society, surgical intervention has become more popular in children, particularly in complex forearm fractures.^[4,5]

For displaced metaphyseal fractures of the distal radius percutaneous Kirschner wire (K-wire) fixation has been advocated as a safe and reliable technique for maintaining the alignment of the fracture and avoiding re-displacement and further manipulation.^[2,6,7] In contrast, elastic stable intramedullary nailing (ESIN) is the method of choice for the treatment of diaphyseal forearm injuries.^[2,5,8] In fractures that are located at the metaphyseal–diaphyseal junction pinning may be difficult due to the angle at which that the pins must be directed to engage the proximal fracture fragment.^[2] On the other hand, regarding the ESIN technique, the distal fragment is often too short in order to provide an optimal 3-point fixation and a perfectly aligned healing.^[5,9] These obstacles have led to a variety of different treatment options, including modification of the K-wire and ESIN

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RK and DA have contributed equally towards this study.

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techniques, internal fixation with plates and external fixation, of which none have been established as a method of choice.^[2,8–11]

The purpose of this study was to review our institutional results and assess different surgical and non-surgical techniques for the management of displaced diaphyseal forearm fractures in children and adolescents.

2. Methods

This report is a retrospective review of all children below 16 years of age who sustained a displaced diaphyseal forearm fracture and subsequently underwent treatment under general anesthesia (GA) within the operating room (OR) between July 2010 and February 2016. Fractures that were solely managed in the emergency department (e.g., with oral analgesia and/or under deep sedation), primarily treated elsewhere, or those with a postoperative follow-up time <4 months, were excluded.

Within the AO Pediatric Comprehensive Classification of Long Bone Fractures^[12] the metaphysis is defined as the square over the widest part of the physis of both bones on the anterior–posterior radiographic view. Since there has been no distinct definition of the diaphysis (i.e., the transitional zone between metaphysis and diaphysis) we applied a definition that was suggested by Lieber et al.^[9] Our internal database was used to identify all distal and diaphyseal forearm fractures that were treated under GA during the study period. Subsequently x-rays were graded independently by 2 investigators (RK and DA) in accordance with the above definition. Finally, only these fractures, which lay clearly within the “diaphyseal area” were included into this study (Fig. 1).

The hospital charts and outpatients records were reviewed with respect to sex, age at fracture, cause of injury, method of treatment, and length of hospital stay. Post-interventional sequelae were graded according to the Clavien-Dindo Classification.^[13] Complications grade III° (or above) were considered as “major.” Refracture was defined as a new fracture at the same location within 18 months after the first injury.^[14]

From October 2016 until March 2018 patients and/or parents were contacted by telephone and interviewed using a modified Pediatric Outcomes Data Collection Instrument (PODCI).^[15] In order to apply the questionnaire effectively within a telephone setting, instead of the standard PODCI questionnaire that consists of 5 domains, we focused on only “Upper Extremity and Physical Function,” “Pain/Comfort,” and “Happiness.” Whereas the PODCI for children aged between 2 and 10 years has only a parent-reported form, the PODCI for adolescents aged between 11 and 18 years has both, self-reported and parent-reported forms. All PODCI scores (range 0–100) were calculated online in a worksheet such that higher scores represent less disability and better functioning.^[16]

For qualitative factors absolute and relative frequencies were given. Ordinally scaled variables were expressed as median values (range) and quantitative variables as mean (\pm SEM). In order to compare 2 or 3 groups regarding a qualitative factor Fisher exact test was applied. For the comparison of age one-way analysis of variance was performed. The Mann–Whitney *U* test was used to analyze 2 groups with regard to the PODCI score. The result of a statistical test was considered significant if the *P*-value was <.05.

We considered the PODCI score as the primary outcome measure. Assuming sample sizes of 9 in each subgroup, a significance level of 0.10 (because of the rather small sample sizes) and an effect size of 0.20 (denoting the probability that any



Figure 1. Definition of the diaphysis (C) in the distal forearm: area between the squares over the radial physis alone (A) and both forearm physes (B). Fractures that were not clearly located within the shaded diaphyseal region (arrow) were excluded from this study.

observation from one group will be less than any observation from the other group), a power of about 0.71 was assessed based on Noether formula.^[17]

SAS, version 9.4 (SAS Institute Inc., Cary, North Carolina) was used for statistical analysis.

The study and the follow-up interview were approved by the Research Ethics Committee of the Medical Faculty Mannheim, Heidelberg University, Germany (2015–625N-MA).

3. Results

During the study period a total of 431 children underwent GA and treatment within the OR for either a distal and/or mid-shaft forearm fracture. Of these, 59 cases were identified, in which the fracture line was located near the junction between the metaphysis and diaphysis. Following accurate review of each x-ray and application of our exclusion criteria, a total of 34 children with 36 diaphyseal fractures were included in this study.

There were 25 boys (74%) and 9 girls (26%). Median age at the time of injury was 9.1 years (range, 1.9–14.6 years). In 17 cases the fracture was located on the left arm and in 15 cases on the right. Two children sustained a bilateral diaphyseal forearm fracture. There was no significant difference in 35 out of

Table 1
Demographics, cause of fracture, associated injuries, and comparison of different treatment groups.

	MUA+POP (n=9)	ESIN (n=10)	K-wire (n=16)	P-value
Age, y	7.96 (±1.16)	10.43 (±0.78)	9.07 (±0.82)	.238
Sex	7M:2F	7M:3F	11M:5F	1.00
L/R ratio	6/3	3/7	9/7	.238
Cause of fracture				.889
Road traffic accident	2	2	2	
Sporting activities*	3	5	7	
Falls/others	4	3	7	
Associated injuries†	2	0	3	.405

ESIN=elastic stable intramedullary nailing, F=female, K-wire=Kirschner wire, L=left, M=male, MUA=manipulation under anesthesia, POP=plaster of Paris, R=right.

* Two patients (fall from parallel bars and high bar, respectively) sustained a bilateral diaphyseal forearm fracture.

† Torus fracture contralateral radius (1), minor head injury (1), blunt abdominal trauma/bruises (1), thigh contusion (1), contralateral distal forearm fracture (1).

36 fractures between the treatment groups in terms of age, sex, side, cause of fracture, and associated injuries (Table 1). The mean time interval between injury and operation was 0.83 (±0.29) days.

Thirty-three out of 36 fractures (92%) were closed injuries. Three patients suffered from first-degree open (n=2) or second-degree open fractures (n=1). In all but 2 cases there was a combined injury to the ulna ranging from a simple torus fracture to total displacement.

The fractures were treated using a variety of different methods including ESIN, percutaneous insertion of up to 4 K-wires, and application of external fixation (Table 2). Of note, 8 out of 10 radial ESIN were inserted distally via the dorsal entry site (Lister tubercle) (Fig. 2). Nine patients underwent manipulation under anesthesia (MUA) and application of plaster of Paris (POP) (Table 2). There were a total of 9 senior surgeons involved during the study period.

The mean length of postoperative hospital stay was 2.09 (±0.22) days.

Eleven children (32%) experienced a total of 22 complications (Table 3). Of these, 7 were considered as “major,” including delayed union (n=1), EPL (extensor pollicis longus), tendon

injury (n=1), and loss of reduction (n=2). Moreover, 3 children suffered from a refracture, resulting in a rate of 8.3%. Of note, in all of the latter cases the initial treatment consisted of MUA/POP (P=.012).

The median follow-up time after initial surgery was 28.8 months (range, 5.3–85.8 months).

Table 2
Treatment of diaphyseal forearm fractures.

Treatment	No. of fractures
MUA*	
POP above elbow	7
POP below elbow	2
ESIN†	
To radius and ulna	8
To radius	2
K-wire	
1× to radius	5
1× (intramedullary) to radius	1
2× to radius	2
2× (of which 1× intramedullary) to radius	3
2× (1 each) to radius and ulna	3
2× (1 each intramedullary) to radius and ulna	1
4× (2 each) to radius and ulna	1
External fixator to radius and ESIN to ulna	1
Total	36

ESIN=elastic stable intramedullary nailing, K-wire=Kirschner wire, MUA=manipulation under anesthesia, POP=plaster of Paris.

* In 2 patients a subsequent cast wedging was performed in the course of treatment.

† In 8 out of 10 cases the radial ESIN was inserted via the dorsal entry site (Lister tubercle).



Figure 2. Distal insertion (circle) of radial ESIN via dorsal entry site (Lister tubercle) with pre-bending of the nail at the fracture level (arrow). ESIN=elastic stable intramedullary nailing.

Table 3
Characteristics and outcome in patients with complications in the course of treatment.

No.	Sex/Age, y	Side	Initial treatment	Complications* (grading according to Clavien-Dindo Classification ^{†‡§})	Implications	PODCI score (F; P/C; H)
1	M/10.1	R	ESIN to radius and ulna	Scar [†] (I°)	-	100 [‡] /100/92
3	M/13.2	L	4× K-wire (2 each) to radius and ulna	Temporary paresthesia of SBRN (II°)	Spontaneous resolution	.. [§]
7	M/10.9	L	ESIN to radius and ulna	Delayed union with limitation of rotation (III°); scar[†] (I°); meteorosen-sitivity post plate osteosynthesis (I°)	Change of treatment (d59) (ESIN→plate)	100/48/33
13	M/8.5	R	POP (above elbow)	Refracture (d20) (III°)	ESIN to radius (d20)	100 [‡] /100/100
19	M/10.7	L	1× K-wire to radius	Scar [†] (I°)	-	100/100/75
22	M/14.6	R+L	ESIN to radius and ulna (R) POP (above elbow) (L)	Pressure ulcer following cast-wedging (L) (II°); Refracture (d36) (L) (III°); scar[†] (R) (I°)	Application of wound dressing; New POP (d36)	92 /67/8
23	M/4.7	L	POP (below elbow)	Refracture (d78) (III°); scar[†] (I°)	ESIN to radius and ulna (d78)	100/100/92
29	F/7.0	L	POP (above elbow)	Loss of reduction (III°); surgical site infection (II°); scar[†] (I°)	2× K-wire to radius (d7); local antiseptics	100/100/75
30	M/8.3	R	POP (above elbow)	Loss of reduction (III°); migration of K-wire below skin (II°); scar[†] (I°)	2× K-wire to radius (d7); removal of K-wire (nitrous oxide)	100/100/83
31	F/10.3	R+L	ESIN to radius and ulna (R) 2× K-wire (of which 1× intramedullary) to radius (L)	Injury to EPL tendon (R) (III°); migration of K-wire below skin (L) (II°); scar[†] (R+L) (I°)	EIP to EPL transfer (d489); removal of K-wire (nitrous oxide)	96 [¶] /89/58
32	M/7.3	R	2× K-wire (one each) to radius and ulna	Scar [†] (I°)	-	100/100/92

EIP = extensor indicis pollicis, EPL = extensor pollicis longus, ESIN = elastic stable intramedullary nailing, F = female, F = Function, H = Happiness, K-wire = Kirschner wire, L = left, M = male, P/C = Pain/Comfort, PODCI = Pediatric Outcomes Data Collection Instrument, POP = plaster of Paris, R = right, SBRN = superficial branch of the radial nerve.

* Major complications (III° Clavien-Dindo^{†‡§}; [n = 7]) are highlighted in bold. Of note, all refractures occurred in patients who were initially treated with a plaster of Paris ($P = .012$).

[†] Unsatisfactory appearance of hypertrophic scar.

[‡] A temporary limitation of forearm rotation was noted in the course of treatment that either resolved spontaneously or following a course of physiotherapy.

[§] The patient was lost of follow-up. When last reviewed in outpatients (17 months post-injury) a 30° limitation of forearm supination was still present.

^{||} At follow-up a 30° limitation of supination of the right forearm (following ESIN) was reported.

[¶] At follow-up there were slight intermittent pain and reduced grip strength reported on the right side (following EIP to EPL transfer).

In 32 out of 34 cases (94%) patients and/or parents were contacted by telephone and a PODCI score was obtained. The follow-up group consisted of 11 pediatric (<11 years) and 21 adolescent patients (≥11 years), of which 9 had self-reported assessments (Fig. 3). With exception of “Happiness” in the self-reported assessment (median 92; range, 33–100), the median PODCI score regarding “Function” (range, 92–100), “Pain/Comfort” (range, 48–100), and “Happiness” (range, 8–100) was 100 (Fig. 3). On analysis, there were only 3 patients who scored less than the maximum of 100 for function. Of these, 2 children (patients 22,31) had developed complications (Table 3). Another boy with a right forearm fracture fixed with ESIN self-reported on minimal pain when jerkily lifting heavy items, resulting in a score of 96 for “Function.” With regard to the accumulative PODCI we did not observe a statistical significance between the outcome and the interview setting (parental vs self-reported).

Overall, patients who experienced complications had a significantly lower score compared with those whose fracture healed without any sequelae. Median values were 275 (range, 167–300) and 300 (range, 246–300), respectively ($P < .001$).

Regarding a possible correlation between the method of treatment and the cumulative PODCI we observed a trend towards a lower score (i.e., less favorable outcome) following ESIN compared with K-wire fixation ($P = .063$), but not compared with MUA/POP ($P = .553$). There was no statistical significance in outcome between children who were treated

initially with MUA/POP and those who had K-wire fixation ($P = .216$). Of note, the only patient whose fracture was fixed using an external fixation device was excluded from the above analysis (Table 1).

4. Discussion

Physicians dealing with pediatric traumatology are aware of the fact that displaced forearm fractures at the transition zone between the distal metaphysis and diaphysis are unpleasant to treat. Nevertheless, this region has not been specifically acknowledged by the AO classification, and literature regarding this subject is sparse. Due to a relative small diameter of the bone with little contact surface diaphyseal injuries tend to be more unstable with less remodeling potential, particularly in older children and adolescents, compared with distal metaphyseal fractures.^[18,19]

In general, management of distal pediatric forearm fractures is nonoperative. In younger patients <10 years of age a considerable degree of angulation is tolerated and treatment with a cast as well as general reluctance to perform remanipulation is recommended.^[2,20,21] Most recently, there is concern about high rates of overtreatment in children.^[4,22]

In this study, we focused on diaphyseal forearm fractures, including those with total displacement, rotational deformity, and open injuries that underwent treatment under GA. Of these,

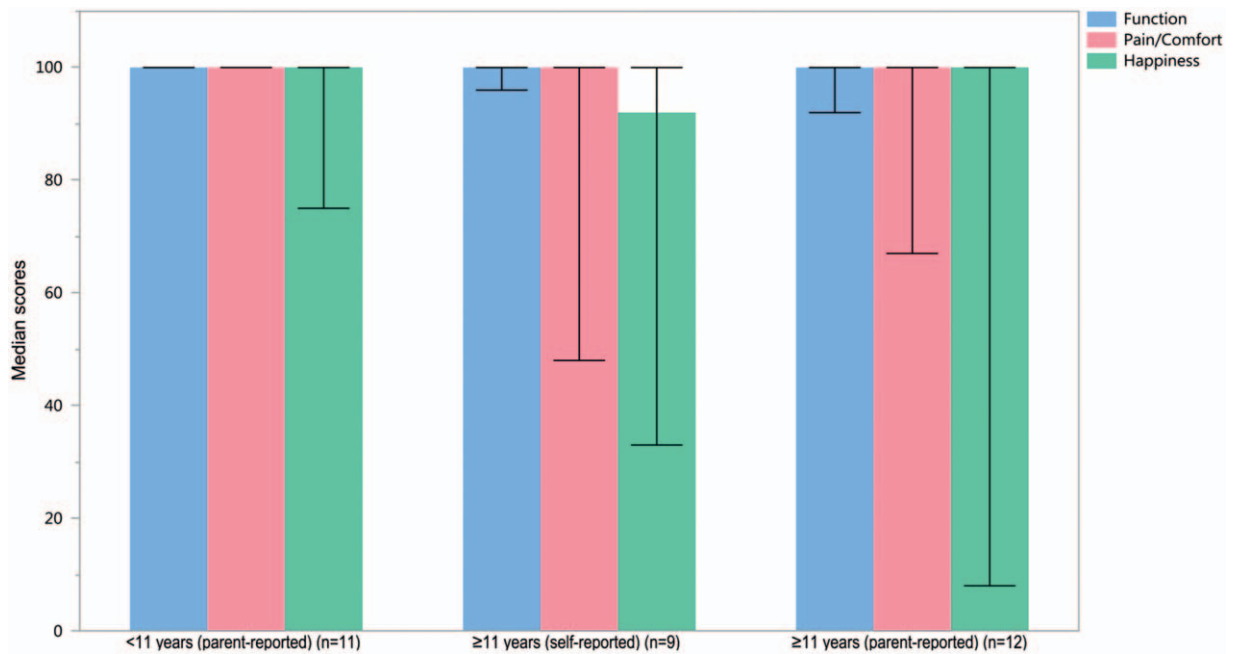


Figure 3. Median Pediatric Outcomes Data Collection Instrument (PODCI) scores for function, pain/comfort, and happiness at follow-up.

25% were initially managed with MUA/POP. Of note, all 3 refractures occurred in this subgroup ($P=.012$). In children, several risk factors for refractures of the forearm have been reported, including greenstick fractures, younger and active patients, inadequate reduction, and early cast removal.^[2,23,24] In 1999 Bould and Bannister reported on a refracture rate between 1.5% and 2.7% at the metaphysis, and up to 14.7% in diaphyseal fractures.^[23] This study together with others^[14,23,25] implies that diametaphyseal fractures are at an increased risk to refracture and should be considered rather as mid-shaft fractures. With regard to the time of immobilization 1 patient developed a refracture on day 20, despite an x-ray revealed a solid callus formation at 3 cortical borders with no clinical signs of discomfort. In retrospect, we consider this as an avoidable treatment mistake since there has been an increased refracture rate described with early cast removal and no clear quadricortical union on radiograph.^[14,23,25] Therefore, we propose cast immobilization for up to 6 weeks for diametaphyseal fractures treated non-operatively.

In this series, 2 patients who were initially treated with MUA/POP developed loss of reduction and subsequently underwent remanipulation and K-wire fixation. In 2005 Miller et al^[7] published a prospective randomized trial regarding cast immobilization versus pin fixation in displaced radius fractures in children. They found a loss of reduction in 39% in the casting group, but no case of further dislocation in the pinning group. In a similar setting McLaughlan et al^[6] demonstrated a significant increase of loss of reduction in the MUA-group compared with the K-wire group.

In due consideration of the above studies^[6,7,23] we concur with others to aim for a definitive, stable, and safe fixation once a child has been taken to the OR and undergone GA as part of a “primary definitive fracture care.”^[5,26]

Overall, we found numerous treatment options, mirroring the lack of a standardized therapy in this type of fracture. We could

neither observe a correlation between the method of treatment and patient’s age nor the type of fracture, which implies that the management was based primarily on surgeon’s preference.

Lieber et al^[9] suggested a transepiphyseal intramedullary K-wire fixation in unstable diametaphyseal forearm fractures as a minimally invasive, quick and technically easy treatment option. Similarly, we observed a favorable outcome in 5 patients in which the above technique was applied (Fig. 4).

In order to optimize the ESIN technique for diametaphyseal fractures maximal distal insertion via Lister tubercle and pre-bending of the nail has been suggested.^[5,9] However, transferring theory into practice is often difficult and we consider insertion of ESIN in complex diametaphyseal forearm fractures as a technically demanding procedure reserved to a highly skilled surgeon. Similarly to Lieber et al^[9] we observed 4 patients with a misalignment of $>10^\circ$ following this technique, pushing the remodeling potential of children’s bone to the limit. Of note, the only patient in our study who suffered from a 30° lack of supination at last follow-up occurred after ESIN. Moreover, as observed in one of our cases, nails that require dorsal insertion via Lister’s tubercle are at risk of developing an EPL tendon injury.^[8,27]

PODCI is used to assess children and adolescents with problems specifically related to bone and muscle conditions.^[28,29] In this cohort, the majority of all median PODCI scores were clustered at the very high end of the scales, indicating a normal function, minimal pain, and relative happiness with the outcome. The majority of patients experienced a temporary diminishment of forearm rotation that resolved either spontaneously or following a course of physiotherapy. In this context Colaris et al^[30] recommended extensive physiotherapy towards a better functional outcome.

With regard to a cumulative PODCI and different surgical techniques we observed a trend towards a lower score (i.e., less favorable outcome) following ESIN compared with K-wire



Figure 4. K-wire fixation of the radius with one pin inserted transepiphyseal intramedullary. K-wire=Kirschner wire.



Figure 5. Radial ESIN without sufficient pre-bending of the nail leading to a deviation of the distal fragment with a cosmetically unsatisfactory aspect of the wrist. Of note, forearm function was without limitation at last follow-up. ESIN= elastic stable intramedullary nailing.

insertion. We applied only 3 out of the original validated 5 domains of the PODCI in order to enable a follow-up via telephone. Nevertheless, data were analyzed under maximum possible guidance of our statistician. In addition, in contrast to ESIN no major postoperative complication could be observed following K-wire fixation. Regarding the ESIN technique, posttraumatic deformity without limitations of function might be a cosmetically unsatisfactory aspect for the patients as well as caretakers (Fig. 5). Moreover, additional casting to compensate for instability with ESIN in situ is not in accordance with the basic principle of this method.^[9] Therefore, we recommend the K-wire technique as a standard treatment in this type of injury and consider a transepiphyseal intramedullary insertion of at least one pin beneficial. In cases of unstable diaphyseal forearm fractures an additional antegrade ESIN to the ulna may be considered.^[9]

In our cohort only 2 patients were treated either with an external fixation or a volar plate to the radius (Table 3). Therefore, we cannot draw any conclusions about a possible benefit regarding these devices. However, we would be very reluctant to recommend the routine use of external or internal fixation for diaphyseal forearm fractures in the pediatric age group since complications and disadvantages have been reported in this context.^[31] We agree with others^[2,9] that these techniques should be reserved to selected cases such as multifragmentary fractures, unstable injuries, and adolescents with <2 years of remaining skeletal growth.

This study is limited by its retrospective approach and the relative small number of patients. All injuries were complex and clearly located within the diaphyseal area. However, the degree of fracture displacement varied, making this cohort slightly inhomogeneous. Moreover, there were some variants among each technique which makes it difficult to compare groups. Although the percentage of patients that were successfully recruited for follow-up was high, the use of a modified PODCI score is not as specific as other outcome instruments. With regard to a cumulative PODCI score one must exercise caution in interpreting the results, not least because the 3 domains were rated differently between proxy and self-reported questionnaires. Similarly to Daltroy et al^[15] we observed a trend towards parents and adolescents being generally in agreement about outcomes with observable evidence, such as function and pain, but more frequently disagree on expectations and happiness. Finally, we did not formally compare our results with a control group.

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