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Clinical Research

Do We Need to Stabilize All Reduced Metaphyseal Both-bone Forearm Fractures in Children with K-wires?

Leon W. Diederix MD[1], Kasper C. Roth MD[2], Pim P. Edomskis MD[3], Linde Musters MD[4], Jan Hein Allema MD, PhD[5], Gerald A. Kraan MD, PhD[6], Max Reijman PhD[2], Joost W. Colaris MD, PhD[2]

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Abstract

Background Short-term follow-up studies have shown that reduced metaphyseal both-bone forearm fractures in children should be treated with K-wires to prevent redisplacement and inferior functional results. Minimum 5-year follow-up studies are limited. Range of motion, patient-reported outcome measures, and radiographic parameters at minimum 5-year follow-up should be evaluated because they could change insights into how to treat pediatric metaphyseal forearm fractures.

Questions/purposes (1) Does K-wire stabilization of reduced metaphyseal both-bone forearm fractures in children provide better forearm rotation at minimum 5-year follow-up? (2) Do malunions (untreated redisplaced fractures) of reduced metaphyseal both-bone forearm fractures in children induce worse functional results? (3) Which factors lead to limited forearm rotation at minimum 5-year follow-up?

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This work was performed at the Erasmus Medical Centre, Rotterdam, the Netherlands.

The first two authors contributed equally to this manuscript.

[1]Department of Orthopaedic Surgery, Elkerliek Hospital, Helmond, the Netherlands

[2]Department of Orthopaedics and Sports Medicine, Erasmus Medical Centre, Rotterdam, the Netherlands

[3]Department of General Surgery, Erasmus Medical Centre, Rotterdam, the Netherlands

[4]Department of Orthopaedic Surgery, Noordwest Ziekenhuis Groep, Alkmaar, the Netherlands

[5]Department of General Surgery, Haga Hospital, The Hague, the Netherlands

[6]Department of Orthopaedic Surgery, Reinier de Graaf Hospital, Delft, the Netherlands

L. W. Diederix ✉, Department of Orthopaedic Surgery, Elkerliek Hospital, Wesselmanlaan 25, 5707 HA, Helmond, the Netherlands, Email: lwdiederix@gmail.com

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Methods We analyzed the extended minimum 5-year follow-up of a randomized controlled trial in which children with a reduced metaphyseal both-bone forearm fracture were randomized to either an above-elbow cast (casting group) or fixation with K-wires and an above-elbow cast (K-wire group). Between January 2006 and December 2010, 128 patients were included in the original randomized controlled trial: 67 in the casting group and 61 in the K-wire group. For the current study, based on an a priori calculation, it was determined that, with an anticipated mean limitation in prosupination (forearm rotation) of 7° ± 7° in the casting group and 3° ± 5° in the K-wire group, a power of 80% and a significance of 0.05, the two groups should consist of 50 patients each. Between January 2014 and May 2016, 82% (105 of 128) of patients were included, with a mean follow-up of 6.8 ± 1.4 years: 54 in the casting group and 51 in the K-wire group. At trauma, patients had a mean age of 9 ± 3 years and had mean angulations of the radius and ulna of 25° ± 14° and 23° ± 18°, respectively. The primary result was limitation in forearm rotation. Secondary outcome measures were radiologic assessment, patient-reported outcome measures (QuickDASH and ABILHAND-kids), handgrip strength, and VAS score for cosmetic appearance. Assessments were performed by the first author (unblinded). Multivariable logistic regression analysis was performed to analyze which factors led to a clinically relevant limitation in forearm rotation.

Results There was a mean limitation in forearm rotation of 5° ± 11° in the casting group and 5° ± 8° in the K-wire group, with a mean difference of 0.3° (95% CI -3° to 4°; p = 0.86). Malunions occurred more often in the casting group than in the K-wire group: 19% (13 of 67) versus 7% (4 of 61) with an odds ratio of 0.22 for K-wiring (95% CI 0.06 to 0.80; p = 0.02). In patients in whom a malunion occurred (malunion group), there was a mean limitation in forearm rotation of 6° ± 16° versus 5° ± 9° in patients who did not have a malunion (acceptable alignment group), with a mean difference 0.8° (95% CI -5° to 7°; p = 0.87). Factors associated with a limited forearm rotation ≥ 20° were a malunion after above-elbow casting (OR 5.2 [95% CI 1.0 to 27]; p = 0.045) and a refracture (OR 7.1 [95% CI 1.4 to 37]; p = 0.02).

Conclusion At a minimum of 5 years after injury, in children with a reduced metaphyseal both-bone forearm fracture, there were no differences in forearm rotation, patient-reported outcome measures, or radiographic parameters between patients treated with only an above-elbow cast compared with those treated with additional K-wire fixation. Redisplacements occurred more often if treated by an above-elbow cast alone. If fracture redisplacement is not treated promptly, this leads to a malunion, which is a risk factor for a clinically relevant (≥ 20°) limitation in forearm rotation at minimum 5-year follow-up. Children with metaphyseal both-bone forearm fractures can be treated with closed reduction and casting without additional K-wire fixation. Nevertheless, a clinician should inform parents and patient about the high risk of fracture redisplacement (and therefore malunion), with risk for limited forearm rotation if left untreated. Weekly radiographic monitoring is essential. If redisplacement occurs, remanipulation and fixation with K-wires should be considered based on gender, age, and direction of angulation. Future research is required to establish the influence of (skeletal) age, gender, and the direction of malunion angulation on clinical outcome.

Level of Evidence Level I, therapeutic study.

Introduction

Background

Reduced metaphyseal both-bone forearm fractures have been shown to redisplace in a cast in up to 46% of patients [9, 26] and have a 3.6- to 23-times higher risk for redisplacement than isolated distal radius fractures [16, 31]. In 2013, we published [9] a randomized controlled trial (RCT) that included 128 children with a reduced, stable, metaphyseal, both-bone forearm fracture who were randomized to an above-elbow cast with or without percutaneous K-wire fixation. Children treated with an above-elbow cast alone had a higher risk of redisplacement and a higher risk of limiting prosupination (forearm rotation) than children who had additional K-wire fixation, after a mean follow-up of 7 months. Thus, pinning of apparently stable both-bone distal forearm fractures in children was recommended to prevent redisplacement [9].

Rationale

There has been a recent increase in operative management of fractures in children, despite the fact that there have been no long-term outcome studies showing superior results after operative treatment [12, 14]. As mentioned, the goal of operative treatment is to prevent redisplacement. If redisplacement of a metaphyseal forearm fracture occurs after conservative treatment, a clinician has two options: to reduce the fracture again (with or without K-wire fixation) or to accept malunion and hope that the remodeling that occurs during growth will result in acceptable cosmetics and function (Fig. 1) [25]. Tremendous remodeling is especially apparent in young children (younger than 10 years) with a distal fracture near the most active growth plate [19, 27, 30]. Treatment discussion is ongoing about what degree of malunion results in an acceptable long-term clinical result [23, 32, 33]. Minimum 5-year follow-up should be evaluated because it could change insights into the treatment of pediatric metaphyseal forearm fractures.

Therefore, we asked: (1) Does K-wire stabilization of reduced metaphyseal both-bone forearm fractures in children

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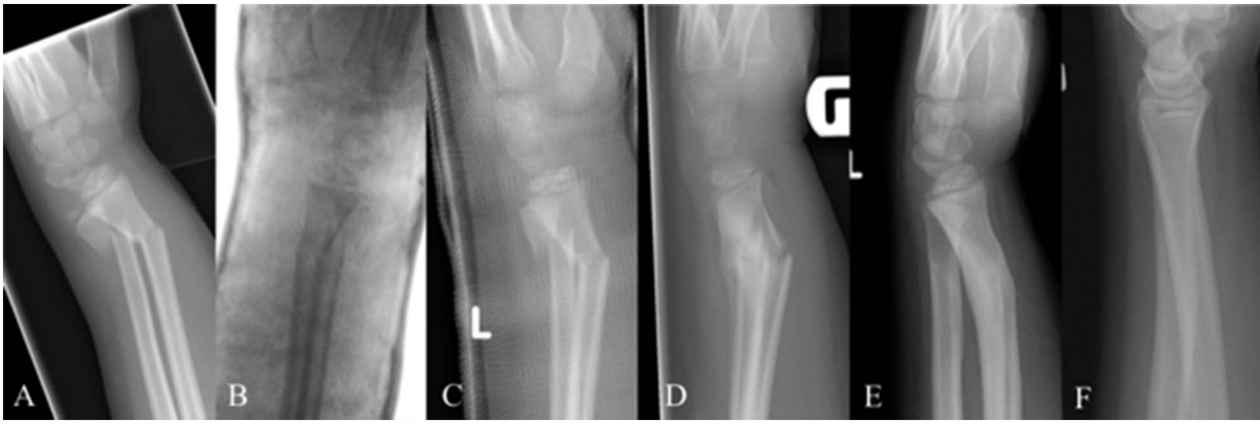

Fig. 1 A-F These sagittal radiographs are from a patient with a displaced metaphyseal both-bone forearm fracture, including (**A**) an initial radiograph of the fracture, (**B**) after reduction, (**C**) redisplacement after 10 days, (**D**) 25 days after trauma, (**E**) 5 months after trauma, and (**F**) 7.5 years after trauma.

provide better forearm rotation at minimum 5-year follow-up? (2) Do malunions (untreated redisplaced fractures) of reduced metaphyseal both-bone forearm fractures in children induce worse functional results? (3) Which factors lead to limited forearm rotation at minimum 5-year follow-up?

Patients and Methods

Study Design and Setting

We report the extended follow-up of a published RCT with a minimum follow-up of 5 years. Children with a displaced metaphyseal both-bone forearm fracture were included in one of four participating hospitals in the Netherlands: Erasmus Medical Center (Rotterdam), Haga Hospital (The Hague), Reinier de Graaf Hospital (Delft), and Franciscus Hospital (Rotterdam). Our initial institutional review board protocol did not specify another follow-up moment 5 years later. However, after finishing data collection of the original RCT, we thought this would be informative and initiated the current extended follow-up study. In the published RCT, between January 2006 and December 2010, 128 patients were included (67 in the casting group and 61 patients in the K-wire group). For the current study, we invited all 128 patients to revisit the outpatient department. Between January 2014 and May 2016, 82% (105 of 128) of patients were included: 54 in the casting group and 51 in the K-wire group (Fig. 2).

Participants

In the original RCT, we included children younger than 16 years who had a displaced metaphyseal fracture of the distal radius and ulna. We included only children with a displaced forearm fracture that was stable after closed reduction in the operating room. The criteria for fracture reduction were defined a priori: a fracture was reduced if the radius and/or ulna showed displacement on a posteroanterior and/or lateral radiograph. Fracture displacement was based on angulation (> 15° for children aged younger than 10 years and > 10° for children between 10 to 16 years) and/or translation (more than half bone diameter) and/or any rotation. Fracture redisplacement was defined by the loss of reduction (angulation and/or translation) according to these primary reduction criteria [9]. Based on the occurrence of redisplacement, we divided all included patients into two additional groups (malunion and acceptable alignment group). Malunion was defined as the occurrence of fracture redisplacement, meeting the abovementioned criteria for reduction but left untreated (contrary to RCT protocol) and thus consolidated in a malunited position.

Description of Treatment

All included patients underwent closed reduction. Thereafter, the fracture was tested for stability. The fracture was defined as unstable if full forearm pronation and supination caused redisplacement [9]. Unstable fractures were excluded and were treated with K-wire fixation. The remaining fractures were defined as stable and were randomized between above-elbow casting alone (casting group) or K-wire pinning with an above-elbow cast (K-wire group), both for 4 weeks.

Randomization

In the previous RCT, participants were randomly assigned and treated in the casting or K-wire group. An independent clinician randomized the children by sealed envelopes with varied block sizes. The children, parents, and clinicians were not blinded for randomization. For the current RCT,

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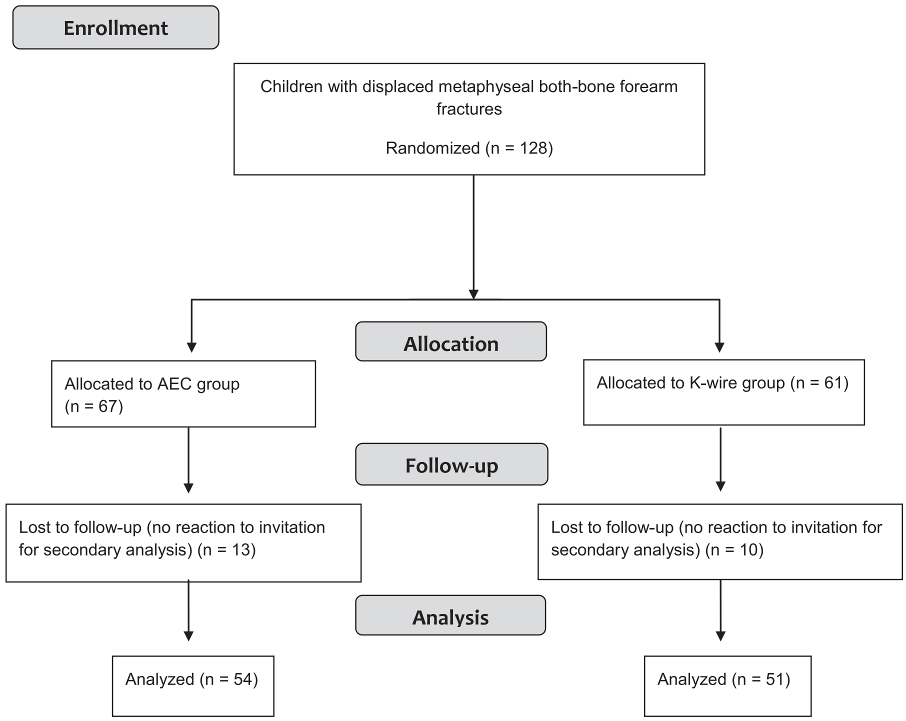

Fig. 2 This CONSORT study flow diagram demonstrates the selection and flow of patients; AEC = above-elbow cast.

we obtained informed consent from all parents and all children aged at least 12 years. Patients unable to attend were, if possible, interviewed via telephone to complete patient-reported outcome measure questionnaires.

Variables, Outcome Measures, Data Sources, and Bias

Our primary outcome measure was limitation in prosupination (forearm rotation) compared with the contralateral side. Secondary outcome measures were radiologic assessment; patient-reported outcome measures, including the Dutch version of the QuickDASH questionnaire and ABILHAND-kids questionnaire [2, 3, 6]; handgrip strength percentage of the contralateral side; and the VAS score for cosmetic appearance.

One unblinded orthopaedic surgeon (JWC) examined all patients during short-term follow-up (mean of 7.1 months) after the initial trauma for the original RCT [9]. A second independent orthopaedic surgeon (LWD) examined all patients at minimum 5-year follow-up (unblinded). Forearm rotation was evaluated using a standardized procedure: visual estimation and a two-increment goniometer [8]. Handgrip strength was measured using a JAMAR dynamometer (Lafayette Instrument Company). Cosmetic appearance (forearm morphology and possible scars) was assessed by the first author (LWD) and either by the patient or by the parent, if the patient was younger than 17 years. The VAS was scored in the traditional way on a 10-cm line [13]. A score of 10 was defined as cosmetically best. Radiographic examination was performed. One of the authors (PPE) measured the radiologic intramedullary angulation of the radius and ulna on posteroanterior and lateral radiographs taken at the time of cast removal (consolidation) and at final follow-up [17]. Radiographic angulation was remeasured in 25 patients by the primary author (LWD) to assess reproducibility.

Ethical Approval

Our institutional review board approved this post-trial follow-up study, which was registered under protocol number NL41839.098.12. The original RCT [9] was registered in ClinicalTrials.gov with registry identifier NCT 00397852.

Statistical Analysis, Study Size

In the previous RCT, after a mean follow-up of 7 months, a limitation of forearm rotation of 14° ± 14° was seen in the casting group and 7° ± 9° in the K-wire group [9]. We expected that over time, limitation of prosupination would decrease with approximately 50% at minimum 5-year follow-up. With an a priori calculation, we determined that

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with an anticipated mean limitation in prosupination of 7° ± 7° in the casting group and an anticipated mean limitation in prosupination of 3° ± 5° in the K-wire group, a power of 80%, and a significance of 0.05, the two groups should consist of 50 patients each.

It was established whether the variables had a normal distribution using the normality Shapiro-Wilk test. Based on these analyses, the results are presented as mean ± SD, mean difference (95% confidence interval), and p values. Patient demographics included for minimum 5-year follow-up were compared between the study groups (casting group versus K-wire group) using the independent samples t-test (Table 1).

Radiographic and functional results were analyzed using independent-samples t-tests comparing the casting group versus K-wire group (Table 2) and comparing patients in whom a malunion occurred (malunion group) with patients who did not have a malunion (acceptable alignment group) (Table 3). To assess the interrater reproducibility of the radiographic assessment, we calculated the intraclass correlation coefficient (Type C).

Multivariable logistic regression analysis was performed to analyze which factors led to a clinically relevant limitation in forearm rotation at minimum 5-year follow-up, defined as a limitation of forearm rotation ≥ 20° (as dependent variable), a cutoff point that has been used previously [10]. The following factors were included in our exploratory analysis (univariate logistic regression): intervention (casting group versus K-wire group), occurrence of a malunion (malunion versus acceptable alignment group) and occurrence of a refracture (group versus nonrefracture group), age at trauma (age younger than 10 years versus age 10 years or older), and sex (male versus female). A p value < 0.05 during univariate logistic regression was used as a threshold to determine which factors progressed to the more definitive multivariable logistic regression analysis. Statistical analyses were performed using IBM SPSS Statistics, version 23 (SPSS Inc).

Patient Demographics

Of the patients who were included in the original RCT [9], 82% (105 of 128) participated in the current study. Fifty-four of the original 67 participants who were allocated to the casting group and 51 of the original 61 participants who were allocated to K-wire fixation participated. Eighteen percent (23 of 128) of patients were lost to follow-up. The mean length of follow-up was 6.8 ± 1.4 years. Baseline characteristics were similar between the groups (Table 1). At trauma, patients had mean angulations of the radius and ulna of 25° ± 14° and 23° ± 18°, respectively. The interrater reliability of the radiologic measurement had an intraclass correlation of 0.83 (95% CI 0.57 to 0.94).

In the original RCT, redisplacement occurred in 30 patients in the casting group during the first weeks after trauma. Seventeen of these patients underwent remanipulation (six received additional K-wire fixation) and 13 accepted redisplacement (the malunion group). Eighty-three percent (25 of 30) of patients with redisplacements were available for minimum 5-year follow-up. In this group of 25 patients, 14 patients underwent remanipulation and 11 patients accepted the redisplacement (the malunion group). Refractures occurred in 11 of 128 patients, nine of whom were reevaluated at final follow-up.

Results

Does K-wire Stabilization of Reduced Metaphyseal Both-bone Forearm Fractures in Children Provide Better Forearm Rotation at Minimum 5-year Follow-up?

K-wire stabilization of reduced metaphyseal both-bone forearm fractures in children did not provide better forearm rotation at minimum 5-year follow-up. There was a mean limitation in prosupination in the K-wire group of 5° ± 8°

Table 1. Patient demographics

Characteristic	Casting group (n = 54)	K-wire group (n = 51)	Mean difference (95% CI)	p value
Age at trauma, years	9 ± 3	9 ± 3	-0.4 (-1.6 to 0.8)	0.49
Sex (% male)	61 (33)	69 (35)	7.5% (-11% to 26%)	0.43
Dominant arm	52 (28)	45 (23)	6.8% (-13% to 26%)	0.49
Fracture type, radius				
Complete	76 (41)	84 (43)	19.1% (1% to 37%)	0.04
Greenstick	24 (13)	16 (8)	-19.1% (-37% to -1%)	0.04
Fracture type, ulna				
Complete	44 (24)	47 (24)	1.3% (-1.8% to 2.1%)	0.89
Greenstick	50 (27)	45 (23)	-4.9% (-24% to 15%)	0.62
Torus	6 (3)	8 (4)	3.6% (-3.9% to 11%)	0.34
Angulation radius, °	27 ± 16	23 ± 15	4.6 (-0.9 to 10)	0.10
Angulation ulna, °	25 ± 21	20 ± 13	5.0 (-1.7 to 12)	0.15

Data presented as % (n) or mean ± SD, unless noted otherwise.

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Table 2. Radiographic and functional results (casting vs K-wire group)

		Casting group (n = 67)	K-wire group (n = 61)	Mean difference (95% CI)	p value
Radiographic outcomes					
Consolidation[a]	Radius - PA	8° ± 7°	6° ± 4°	2° (-0.6° to 4°)	0.12
	Radius - lateral	13° ± 10°	8° ± 4°	5° (2° to 9°)	0.01
	Ulna - PA	7° ± 4°	6° ± 4 °	1° (-0.7° to 3°)	0.25
	Ulna - lateral	7° ± 5°	7° ± 5°	0.5° (-2° to 3°)	0.67
		(n = 54)	**(n = 51)**		
7-year follow-up	Radius - PA	4° ± 3°	5° ± 3°	-1° (-3° to -0.4°)	0.04
	Radius - lateral	4° ± 3°	4° ± 3°	-0.4° (-2° to 0.9°)	0.52
	Ulna - PA	5° ± 3°	5° ± 3°	-0.3° (-2° to 1°)	0.68
	Ulna - lateral	3° ± 3°	4° ± 3°	-1° (-3° to 0.2°)	0.08
Functional outcomes					
7- year follow-up	Limitation in prosupination	5° ± 11°	5° ± 8°	0.3° (-3° to 4°)	0.86
	QuickDASH	5.8 ± 11	3.4 ± 5	2.4 (-1.0 to 5.8)	0.16
	ABILHAND	41 ± 2	42 ± 1	-0.5 (-1.1 to 0.8)	0.09
	Cosmetics (patient)	8.3 ± 2	7.8 ± 3	0.5 (-0.4 to 1.4)	0.29
	Cosmetics (clinician)	8.7 ± 2	8.1 ± 2	0.6 (-0.2 to 1.4)	0.17
	Hand grip strength, %	99 ± 21	100.0 ± 18	-1.8 (-9.6 to 6.0)	0.64

[a]Data in these rows are from a prior publication [9]; PA = posteroanterior.

and a mean limitation of 5° ± 11° in the casting group with a mean difference of 0.3° (95% CI -3° to 4°; p = 0.86) (Table 2). Radiographic results were similar. There was less residual angulation of the radius in the coronal plane in the casting group (4° [95% CI 3° to 5°]) than in the K-wire group (5° [95% CI 4° to 6°], mean difference -1° [95% CI -3° to -0.4°];

Table 3. Radiographic and functional results (malunion vs acceptable alignment group)

		Malunion group (n = 13)	Acceptable alignment group (n = 115)	Mean difference (95% CI)	p value
Radiographic outcomes					
Consolidation[a]	Radius - PA	15° ± 7°	6° ± 4°	9.6° (4.0° to 15°)	< 0.001
	Radius - lateral	17° ± 6°	9° ± 8°	7.2° (1.5° to 13°)	0.01
	Ulna - PA	7° ± 5°	6° ± 4°	1.6° (-1.2° to 4.3°)	0.26
	Ulna - lateral	10° ± 7°	6° ± 5°	3.4°(-1.0° to 6.9°)	0.06
		(n = 11)	**(n = 94)**		
7-year follow-up	Radius - PA	5° ± 3°	5° ± 3°	-0.1° (-2.4° to 2.1°)	0.91
	Radius - lateral	4° ± 3°	4° ± 3°	0.3° (-1.7° to 2.3°)	0.76
	Ulna - PA	5° ± 3°	5° ± 3°	0.01° (-2.2° to 2.2°)	0.99
	Ulna - lateral	1° ± 2°	4° ± 4°	-2.8° (-5.2° to -0.4°)	0.02
Functional outcomes		**(n = 11)**	**(n = 94)**		
7-year follow-up	Limitation in prosupination	6° ± 16°	5° ± 9°	0.8° (-5.2° to 6.9°)	0.87
	QuickDASH	3.4 ± 6	4.6 ± 9	-1.3 (-6.8 to 4.2)	0.64
	ABILHAND	41 ± 2	41 ± 2	0.01 (-1.0 to 1.1)	0.98
	Cosmetics (patient)	8.0 ± 2	8.3 ± 2	-0.2 (-1.5 to 1.1)	0.58
	Cosmetics (clinician)	8.6 ± 1	8.7 ± 2	0.2 (-1.0 to 1.4)	0.76
	Hand grip strength %	98 ± 15	99 ± 20	-1.0 (-14 to 12)	0.88

[a]Data in these rows are from prior publication [9]; PA = posteroanterior.

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p = 0.04). We found no differences in patient-reported outcome measures (QuickDASH and ABILHAND-kids), VAS score for cosmetics, and handgrip strength (Table 2).

Do Malunions of Reduced Metaphyseal Both-Bone Forearm Fractures in Children Induce Worse Functional Results?

Malunions of reduced metaphyseal both-bone forearm fracture in children occurred more often in the casting group than the K-wire group at short-term follow-up: 19% (13 of 67) versus 7% (4 of 61) with an odds ratio of 0.22 for K-wires (95% CI 0.06 to 0.80; p = 0.02). At minimum 5-year follow-up, there was a mean limitation of forearm rotation of 6° ± 16° in the malunion group versus 5° ± 9° in the acceptable alignment group, with a mean difference of 0.8° (95% CI -5° to 7°; p = 0.87). Angulation of the ulna in the sagittal plane was less in the malunion group (1° [95% CI -0.8° to 3°]) than in the acceptable alignment group (4° [95% CI 3° to 5°]), with a mean difference of -3° (95% CI -5 to -0.4°; p = 0.02). Patient-reported outcomes (QuickDASH and ABILHAND-kids), cosmetic appearances scores, and grip strength were not different (Table 3).

Which Factors Lead to Limited Forearm Rotation of More than 20°?

At minimum 5-year follow-up, two factors were associated with a clinically relevant limitation in forearm rotation of ≥ 20°: occurrence of a malunion after above-elbow casting (OR 5.2 [95% CI 1.0 to 27]; p = 0.045) and a refracture (OR 7.1 [95% CI 1.4 to 37]; p = 0.02). Limitation in forearm rotation ≥ 20° was seen in the malunion group in 27% (3 of 11) versus 7% (7 of 94) in the acceptable alignment group. Also, this limitation was seen in 33% (3 of 9) of patients in whom a refracture occurred versus in 7% (7 of 96) of patients without a refracture (Table 4). Sex and age at trauma older than 10 years were not associated with a limitation in forearm rotation ≥ 20° at minimum 5-year follow-up during exploratory univariate logistic regression analysis (p values of 0.11 and 0.49, respectively).

Discussion

Background and Rationale

Displaced metaphyseal both-bone forearm fractures in children, which are stable after closed reduction, show high risk of redisplacement in a cast, which can cause malunion and limitation in forearm rotation [9, 26]. Redisplacement can be prevented with K-wire stabilization. To determine whether K-wire stabilization is essential for all reduced metaphyseal both-bone forearm fractures in children or that such malunions will correct by growth, we reassessed ROM, patient-reported outcome measures, and radiographic parameters of patients included in our previous RCT after a minimum of 5-year follow-up.

Limitations

A key limitation is that we could not include enough patients to perform a powerful multivariable analysis including more potentially relevant factors, such as the direction of malunion angulation and degree of initial displacement, but also, we could not adequately control for patient age and sex. Concerning direction of malunion angulation, Roberts [24] demonstrated that radial deviation is more closely related to loss of forearm rotation than dorsal angulation. Zimmermann et al. [33] compared palmar versus dorsal displaced pediatric metaphyseal radius fractures and found no differences in remodeling capacity, but they did find a higher restriction of supination in palmar displaced malunions. Furthermore, the degree of initial angulation at trauma may be predictive for redisplacement risk after 1 or 2 weeks. Initial angulation may predict the degree of fracture stability. Although in our study female sex and being older than 10 years at trauma were not associated with a clinically relevant limitation in forearm rotation (≥ 20°), we still cannot assume the findings will apply equally to both sexes at any age. Girls can be more skeletally advanced than boys with the same age, as the mean age for ossification of the physis differs between boys and girls (14.5 and 12.9 years, respectively), which results in less remodeling potential [25]. Greater remodeling potential is generally found in patients with more residual

Table 4. Multivariable logistic regression analysis

Subgroup	≥ 20° of limitation	Odds ratio (95% CI)	p value
Malunion group	27 (3 of 11)	5.2 (1.0-27)	0.045
Nonmalunion group	7 (7 of 94)		
Refracture	33 (3 of 9)	7.1 (1.4-37)	0.02
No refracture	7 (7 of 96)		

Factors associated with limitation in forearm rotation of ≥ 20° at minimum 5-year follow-up.

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growth, a smaller distance to the most active growth plate, and fracture angulation in the sagittal plane [16]. Therefore, in clinical practice, one should be cautious to apply our results especially to nearly skeletally mature girls with severe (radial or volar) redisplacement. A second limitation is that although the RCT protocol stated that remanipulation should be performed for redisplacement, 13 of 30 redisplacements were left untreated. This introduced a treatment bias because there may have been factors influencing a surgeon to accept the redisplacement (for instance younger age), which could skew the impact of that redisplacement on the ultimate clinical result. This indicates that the criteria for reduction possibly were too stringent.

Furthermore, functional and radiologic assessments were not blinded and were performed by only one investigator. Blinded assessment was not possible because of the assessment of cosmetic appearance (including scars). The measurements of forearm rotation could also have inter- and intraobserver variations, thus our conclusions based on these measurements would be stronger if repeated measurements had been performed. Finally, below-elbow cast (compared with above-elbow cast) has been shown to be sufficient in treatment of distal forearm fractures in children, but this became apparent after initiation of our original RCT [4, 11, 29].

Does K-wire Stabilization of Reduced Metaphyseal Both-bone Forearm Fractures in Children Provide Better Forearm Rotation at Minimum 5-year Follow-up?

Although this RCT showed superior results of stabilization with K-wires in addition to an above-elbow cast after 7 months of follow-up [9], a minimum 5-year follow-up stabilization with K-wires did not provide better forearm rotation, radiographic parameters, or patient-reported results. Therefore, children with displaced metaphyseal both-bone forearm fractures can be treated with closed reduction and an above-elbow cast without K-wire fixation. Previously, one meta-analysis compared the results of displaced distal radius fractures between children treated with an above-elbow cast versus K-wire fixation [26]. This meta-analysis included three RCTs [9, 20, 21], one prospective cohort study [15], and two retrospective cohort studies [22, 28]. In this meta-analysis, 76% (292 of 382) of included children had a both-bone forearm fracture. In the casting group, the redisplacement proportion was 46% (90 of 197) of patients versus 4% (7 of 185) in the K-wire group (OR 0.07 [95% CI 0.03 to 0.15]). Complications other than redisplacement occurred more often in the K-wire group than in the casting group (15.7% versus 3.6%). In contrast to the study by Colaris et al. [9], the studies by McLauchlan et al. [20] and Ozcan et al. [22] found no differences in functional results between the two treatment groups at 3 and 20 months of follow-up, respectively. Based on the combined results of these three studies, Sengab et al. [26] concluded that K-wire fixation does not result in better ROM but leads to a lower redisplacement proportion and fewer reinterventions. This is consistent with our findings. Future research, such as a meta-analysis or a large prospective observational study, is required to establish the influence of (skeletal) age, gender, and the severity and direction of malunion angulation of both the radius and ulna on clinical result. Currently, we await the results of the comparison of intervention and conservative treatment for angulated fractures of the distal forearm in children (AFIC) RCT by Adrian et al. [1], in which children (younger than 11 years of age) with displaced distal forearm fractures with up to 30° angulation have been randomized between cast immobilization versus closed reduction with or without additional K-wire fixation.

Do Malunions of Reduced Metaphyseal Both-bone Forearm Fractures in Children Induce Worse Functional Results?

Malunions led to a higher risk (27% versus 7%) of a clinically relevant limitation in forearm rotation (≥ 20°) at minimum 5-year follow-up. Our results, however, show no differences in mean limitations between the two groups (malunion versus acceptable alignment group). This may seem contradictory, but it can be explained by the fact that most patients with a malunion (73%) still showed good forearm rotation at minimum 5-year follow-up, leading to a low mean limitation in forearm rotation of the entire malunion group. In clinical practice, if fracture redisplacement occurs 1 or 2 weeks after the initial trauma, we advise to (based on sex, age, and direction of angulation) consider remanipulation and K-wire fixation promptly to decrease the risk of developing a persistent limitation in forearm rotation. Earlier, Colaris et al. [7] showed that pediatric metaphyseal both-bone forearm malunions angulated ≥ 16° developed a clinically relevant limitation in forearm rotation in 60% after a mean follow-up of 7 months.

Which Factors Lead to Limited Forearm Rotation of More than 20°?

At minimum 5-year follow-up, factors associated with a clinically relevant limitation in forearm rotation were malunion after above-elbow casting and a refracture. A study performed by Zimmermann et al. [32] revealed that children older than 10 years whose fractures healed with an angular deformity of more than 20° had the poorest long-term results, while in children younger than 10 years of age, angular deformity did not influence long-term results. The occurrence of a refracture was also associated with limited forearm

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rotation of ≥ 20°, possibly explained by repeated immobilization in a cast leading to soft tissue contractures [10]. Refractures are eight times more likely to reoccur in diaphyseal fractures as in distal forearm fractures [5]. Diaphyseal fractures behave vastly different to metaphyseal forearm fractures. In 1962, Hughston [18] claimed that in diaphyseal fractures "growth will not correct angulation deformity as it does in metaphyseal fractures." Because of the relatively long distance between a diaphyseal fracture and the growth plates, only minimal correction of malalignment by growth can be expected.

Conclusion

At minimum 5-year follow-up in children with metaphyseal both-bone forearm fractures that were stable after closed reduction, we found no differences in forearm rotation between treatment with only an above-elbow cast and treatment with additional K-wire fixation. Redisplacement occurs more often if treated by an above-elbow cast alone. If fracture redisplacement is not treated promptly, a malunion may occur, which is a risk factor for a clinically relevant limitation in forearm rotation at minimum 5-year follow-up. A child with a displaced metaphyseal both-bone forearm fracture can be treated with closed reduction and an above-elbow cast without additional K-wire fixation. The clinician should inform parents and the patient about the high risk of fracture redisplacement, which, if left untreated, results in malunion with risk for forearm rotation limitations. Weekly radiographic monitoring is essential. If redisplacement occurs, remanipulation and K-wire fixation should be considered based on sex, age, and direction of angulation. Future research is needed to establish the influence of (skeletal) age, sex, severity of initial displacement, and the direction of malunion angulation on clinical result.

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References

1. Adrian M, Wachtlin D, Kronfeld K, Sommerfeldt D, Wessel LM. A comparison of intervention and conservative treatment for angulated fractures of the distal forearm in children (AFIC): study protocol for a randomized controlled trial. *Trials*. 2015;16:437.
2. Arnould C, Penta M, Renders A, Thonnard JL. ABILHAND-Kids: a measure of manual ability in children with cerebral palsy. *Neurology*. 2004;63:1045-1052.
3. Beaton DE, Wright JG, Katz JN; Upper Extremity Collaborative Group. Development of the QuickDASH: comparison of three item-reduction approaches. *J Bone Joint Surg Am*. 2005;87:1038-1046.
4. Bohm ER, Bubbar V, Hing KY, Dzus A. Above and below-the-elbow plaster casts for distal forearm fractures in children: a randomized controlled trial. *J Bone Joint Surg Am*. 2006;88:1-8.
5. Bould M, Bannister GC. Refractures of the radius and ulna in children. *Injury*. 1999;30:583-586.
6. Buffart LM, Roebroeck ME, Janssen WG, Hoekstra A, Hovius SE, Stam HJ. Comparison of instruments to assess hand function in children with radius deficiencies. *J Hand Surg Am*. 2007;32:531-540.
7. Colaris J, Reijman M, Allema JH, et al. Angular malalignment as cause of limitation of forearm rotation: an analysis of prospectively collected data of both-bone forearm fractures in children. *Injury*. 2014;45:955-959.
8. Colaris J, van der Linden M, Selles R, Coene N, Allema JH, Verhaar J. Pronation and supination after forearm fractures in children: reliability of visual estimation and conventional goniometry measurement. *Injury*. 2010;41:643-646.
9. Colaris JW, Allema JH, Biter LU, et al. Re-displacement of stable distal both-bone forearm fractures in children: a randomised controlled multicentre trial. *Injury*. 2013;44:498-503.
10. Colaris JW, Allema JH, Reijman M, et al. Which factors affect limitation of pronation/supination after forearm fractures in children? A prospective multicentre study. *Injury*. 2014;45:696-700.
11. Colaris JW, Biter LU, Allema JH, et al. Below-elbow cast for metaphyseal both-bone fractures of the distal forearm in children: a randomised multicentre study. *Injury*. 2012;43:1107-1111.
12. Cruz AI Jr, Kleiner JE, DeFroda SF, Gil JA, Daniels AH, Eberson CP. Increasing rates of surgical treatment for paediatric diaphyseal forearm fractures: a National Database Study from 2000 to 2012. *J Child Orthop*. 2017;11:201-209.
13. Delgado DA, Lambert BS, Boutris N, et al. Validation of digital visual analog scale pain scoring with a traditional paper-based visual analog scale in adults. *J Am Acad Orthop Surg Glob Res Rev*. 2018;2:e088.
14. Eismann EA, Little KJ, Kunkel ST, Cornwall R. Clinical research fails to support more aggressive management of pediatric upper extremity fractures. *J Bone Joint Surg Am*. 2013;95:1345-1350.
15. Gibbons CLMH, Woods DA, Pailthorpe C, Carr AJ, Worlock P. The management of isolated distal radius fractures in children. *J Pediatr Orthop*. 1994;14:207-210.
16. Hang JR, Hutchinson AF, Hau RC. Risk factors associated with loss of position after closed reduction of distal radial fractures in children. *J Pediatr Orthop*. 2011;31:501-506.
17. Hansen BA, Greiff J, Bergmann F. Fractures of the tibia in children. *Acta Orthop Scand*. 1976;47:448-453.
18. Hughston JC. Fractures of the forearm in children. *J Bone Joint Surg*. 1962;44:1678-1693.
19. Jeroense KTV, America T, Witbreuk MMEH, Van DS. Malunion of distal radius fractures in children. *Acta Orthop*. 2015;86:233-237.
20. McLauchlan GJ, Cowan B, Annan IH, Robb JE. Management of completely displaced metaphyseal fractures of the distal radius in children. A prospective, randomised controlled trial. *J Bone Joint Surg Br*. 2002;84:413-417.
21. Miller BS, Taylor B, Widmann RF, Bae DS, Snyder BD, Waters PM. Cast immobilization versus percutaneous pin fixation of displaced distal radius fractures in children: a prospective, randomized study. *J Pediatr Orthop*. 2005;25:490-494.
22. Ozcan M, Memisoglu S, Copuroglu C, Saridogan K. Percutaneous Kirschner wire fixation in distal radius metaphyseal fractures in children: does it change the overall outcome? *Hippokratia*. 2010;14:265-270.

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23. Ploegmakers JJW, Verheyen CCPM. Acceptance of angulation in the non-operative treatment of paediatric forearm fractures. *J Pediatr Orthop Part B*. 2006;15:428-432.
24. Roberts JA. Angulation of the radius in children's fractures. *J Bone Joint Surg Br*. 1986;68:751-754.
25. Roth KC, Denk K, Colaris JW, Jaarsma RL. Think twice before re-manipulating distal metaphyseal forearm fractures in children. *Arch Orthop Trauma Surg*. 2014;134:1699-1707.
26. Sengab A, Krijnen P, Schipper IB. Displaced distal radius fractures in children, cast alone vs additional K-wire fixation: a meta-analysis. *Eur J Trauma Emerg Surg*. 2019;45:1003-1011.
27. van der Sluijs JA, Bron JL. Malunion of the distal radius in children: accurate prediction of the expected remodeling. *J Child Orthop*. 2016;10:235-240.
28. Van Egmond PW, Schipper IB, Van Luijt PA. Displaced distal forearm fractures in children with an indication for reduction under general anesthesia should be percutaneously fixated. *Eur J Orthop Surg Traumatol*. 2012;22:201-207.
29. Webb GR, Galpin RD, Armstrong DG. Comparison of short and long arm plaster casts for displaced fractures in the distal third of the forearm in children. *J Bone Joint Surg Am*. 2006;88:9-17.
30. Wilkins KE. Principles of fracture remodeling in children. *Injury*. 2005;36(suppl 1):A3-S-A11.
31. Zamzam MM, Khoshhal KI. Displaced fracture of the distal radius in children. *J Bone Joint Surg Br*. 2005;87:841-843.
32. Zimmermann R, Gschwentner M, Kralinger F, Arora R, Gabl M, Pechlaner S. Long-term results following pediatric distal forearm fractures. *Arch Orthop Trauma Surg*. 2004;124:179-186.
33. Zimmermann R, Gschwentner M, Pechlaner S, Gabl M. Remodeling capacity and functional outcome of palmarly versus dorsally displaced pediatric radius fractures in the distal one-third. *Arch Orthop Trauma Surg*. 2004;124:42-48.

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