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Does Early Conversion to Below-elbow Casting for Pediatric Diaphyseal Both-bone Forearm Fractures Adversely Affect Patient-reported Outcomes and ROM?

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Abstract

Background For distal forearm fractures in children, it has been shown that a below-elbow cast is an adequate treatment that overcomes the discomfort of an above-elbow cast and unnecessary immobilization of the elbow. For reduced diaphyseal both-bone forearm fractures, our previous randomized controlled trial (RCT)—which compared an above-elbow cast with early conversion to a below-elbow cast—revealed no differences in the risk of redisplacement or functional outcomes at short-term follow-up. Although studies with a longer follow-up after diaphyseal both-bone forearm fractures in children are scarce, they are essential, as growth might affect the outcome.

Questions/purposes In this secondary analysis of an earlier RCT, we asked: (1) Does early conversion from an above-elbow to a below-elbow cast in children with reduced, stable diaphyseal forearm fractures result in worse clinical and radiological outcome? (2) Does a malunion result in inferior clinical outcomes at 7.5 years of follow-up?

Methods In this study, we evaluated children at a minimum of 5 years of follow-up who were included in a previous RCT. The median (range) duration of follow-up was

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Ethical approval for this study was obtained from Erasmus University Medical Centre, Rotterdam, the Netherlands (Protocol number NL41839.098.12).
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7.5 years (5.2 to 9.9). The patients for this RCT were included from the emergency departments of four different urban hospitals. Between January 2006 and August 2010, we treated 127 patients for reduced diaphyseal both-bone forearm fractures. All 127 patients were eligible; 24% (30) were excluded because they were lost before the minimum study follow-up or had incomplete datasets, leaving 76% (97) for secondary analysis. The loss in the follow-up group was comparable to the included population. Eligible patients were invited for secondary functional and radiographic assessment. The primary outcome was the difference in forearm rotation compared with the uninjured contralateral arm. Secondary outcomes were the ABILHAND-kids and QuickDASH questionnaire, loss of flexion and extension of the elbow and wrist compared with the contralateral forearm, JAMAR grip strength ratio, and radiological assessment of residual deformity. The study was not blinded regarding the children, parents, and clinicians.

Results At 7.5-year follow-up, there were no differences in ABILHAND-kids questionnaire score (above-elbow cast: 41 ± 2.4 versus above/below-elbow cast: 41.7 ± 0.7, mean difference -0.7 [95% confidence interval (CI) -1.4 to 0.04]; p = 0.06), QuickDASH (above-elbow cast: 5.8 ± 9.6 versus 2.9 ± 6.0 for above-/below-elbow cast, mean difference 2.9 [95% CI -0.5 to 6.2]; p = 0.92), and grip strength (0.9 ± 0.2 for above-elbow cast versus 1 ± 0.2 for above/below-elbow cast, mean difference -0.04 [95% CI -1 to 0.03]; p = 0.24). Functional outcomes showed no difference (loss of forearm rotation: above-elbow cast 7.9 ± 17.7 versus 4.1 ± 6.9 for above-/below-elbow cast, mean difference 3.8 [95% CI -1.7 to 9.4]; p = 0.47; arc of motion: above-elbow cast 152° ± 21° versus 155° ± 11° for the above/below-elbow cast group, mean difference -2.5 [95% CI -9.3 to -4.4]; p = 0.17; loss of wrist flexion-extension: above-elbow cast group 1.0° ± 5.0° versus 0.6° ± 4.2° for above/below-elbow cast, mean difference 0.4° [95% CI -1.5° to 2.2°]; p = 0.69). The secondary follow-up showed improvement in forearm rotation in both groups compared with the rotation at 7 months. For radiographical analysis, the only difference was in AP ulna (above-elbow cast: 6° ± 3° versus above/below-elbow cast: 5° ± 2°, mean difference 1.8° [0.7° to 3°]; p = 0.003), although this is likely not clinically relevant. There were no differences in the other parameters. Thirteen patients with persistent malunion at 7-month follow-up showed no clinically relevant differences in functional outcomes at 7.5-year follow-up compared with children without malunion. The loss of forearm rotation was 5.5° ± 9.1° for the malunion group compared with 6.0° ± 13.9° in the no malunion group, with a mean difference of 0.4 (95% CI of -7.5 to 8.4; p = 0.92).

Conclusion In light of these results, we suggest that surgeons perform an early conversion to a below-elbow cast for reduced diaphyseal both-bone forearm fractures in children. This study shows that even in patients with secondary fracture displacement, remodeling occurred. And even in persistent malunion, these patients mostly showed good-to-excellent final results. Future studies, such as a meta-analysis or a large, prospective observational study, would help to establish the influence of skeletal age, sex, and the severity and direction of malunion angulation of both the radius and ulna on clinical result. Furthermore, a similar systematic review could prove beneficial in clarifying the acceptable angulation for pediatric lower extremity fractures.

Level of Evidence Level I, therapeutic study.

Introduction

Diaphyseal forearm fractures are far less forgiving than distal forearm fractures in the growing skeleton. Almost half of pediatric fractures are forearm fractures of both bones, with 20% of fractures located in the diaphysis [4, 5, 26]. Although there is an increasing tendency to treat diaphyseal forearm fractures with intramedullary nails, stable fractures after reduction can also be treated with an above-elbow cast [29]. The disadvantage of treatment in a cast remains fracture redisplacement, which has been described in up to 39% [19, 27, 29]. Redisplaced fractures left untreated often result in a malunion [1, 5, 8, 9-11, 13, 16]. In general, these diaphyseal malunions demonstrate less remodeling capacity compared with distal forearm fractures. Such a malunion can result in rotational impairment caused by either collision of the forearm bones or tightness of the soft tissues as the central band of the interosseous membrane [1, 9, 13, 17, 20, 24, 25, 28].

A previous study by Colaris et al. [6] compared two groups of children with stable diaphyseal reduced both-bone forearm fractures. The first group was immobilized in an above-elbow cast for 6 weeks, and the second group was immobilized in an above-elbow cast for 3 weeks followed by 3 weeks of a below-elbow cast [16]. After 7 months, no difference was found in loss of forearm rotation and there was a similar redisplacement proportion. Cast comfort was better in the above/below-elbow cast group. Because this is a population with incredible remodeling capacity and functional recovery, we believe that treatment recommendations should be based on the occurrence of complications and long-term functional outcomes.

Therefore, we performed a secondary analysis of data and asked the following research questions: (1) Does early conversion from an above-elbow to a below-elbow cast in children with reduced, stable diaphyseal forearm fractures result in worse clinical and radiological outcome? (2) Does a malunion result in inferior clinical outcomes at 7.5 years of follow-up?

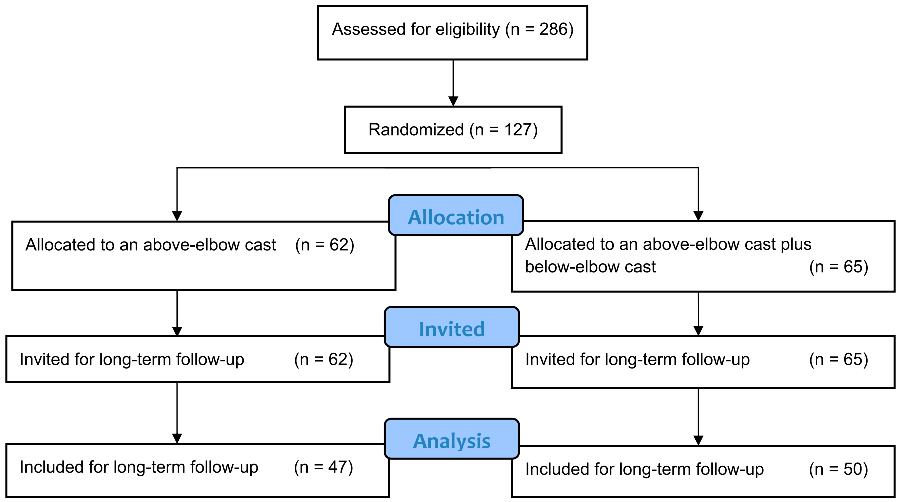

Fig. 1 This CONSORT flow diagram shows how patients were allocated in this study.

Patients and Methods

Trial Design and Participants

This was a secondary analysis with clinical follow-up (with a minimum of 5 years) of a previous RCT by Colaris et al. [6]. Children younger than 16 years of age who visited the emergency department of one of four participating Dutch hospitals (Erasmus Medical Center [Rotterdam], HAGA Hospital [The Hague], Reinier de Graaf Hospital [Delft], and Franciscus Vlietland Hospital [Schiedam]), were eligible for participation. This study complies with the CONSORT statement (Fig. 1).

Participants

We approached the 127 patients who were included between January 2006 and August 2010. All patients were invited to visit the outpatient clinic for clinical and radiological reassessment between January 2014 and April 2017. Children younger than 16 years of age were eligible for the initial RCT if they presented with a displaced, diaphyseal, both-bone forearm fracture that was stable after reduction. A fracture was defined as unstable if full pronation and supination of the proximal forearm caused redisplacement of the fracture under fluoroscopic vision. This test for stability has been used before in a group of children with forearm fractures [7]. The exclusion criteria were: no response to our invitation for follow-up, refracture, or secondary surgery of the affected forearm. At 7 years, follow-up measurement and informed consent were reobtained from all children and parents of children aged younger than 12 years. We considered 127 patients as potentially eligible; 24% (30) were excluded because they were lost before the minimum study follow-up or had incomplete datasets, leaving 76% (97) for secondary analysis. Those lost to follow-up were comparable to the included population (Supplemental Table 1; http://links.lww.com/CORR/B297).

Interventions

For the initial study, a surgeon reduced the fracture in the operating room under general anesthesia with fluoroscopic guidance. The fracture was checked for stability; if unstable, the patient was excluded and treated with intramedullary nails. The remaining fractures were defined as stable and the patients were randomized to 6 weeks of an above-elbow cast or to 3 weeks of an above-elbow cast followed by 3 weeks of a below-elbow cast. All casts were applied the same way, following a protocol set up by the research group. Clinical and radiographic evaluation happened at 1, 3, and 6 weeks after initial trauma. Fracture displacement, as defined by the loss of reduction according to the primary reduction criteria (Supplemental Table 2; http://links.lww.com/CORR/B298), required new fracture reduction. Finally, the cast was removed 6 weeks after initial treatment. At 2 and 6 months after the initial trauma, patients were assessed for clinical and radiological outcome. For prosupination, two different methods were used: visual estimation and conventional goniometry. For the visual measurement, the elbow was held in 90° of flexion against the body and an estimate was made by two examiners (LWD, JWC). For the goniometer, a 180° protractor goniometer with two movable arms was used

Table 1. Baseline characteristics of the study sample

Characteristic	Above-elbow cast (n = 47)	Above/below-elbow cast (n = 50)
Age at time of fracture in years	8 ± 3	8 ± 3
Age at follow-up in years	16 ± 4	15 ± 31
Length of follow-up in years	7.6 ± 1.2	7.4 ± 1.4
Boys	64 (30)	64 (32)
Fracture type, radius		
Buckle	0 (0)	0 (0)
Greenstick	32 (15)	60 (30)
Complete	68 (32)	40 (20)
Fracture type, ulna		
Buckle	0 (0)	0 (0)
Greenstick	47 (22)	62 (31)
Complete	53 (25)	38 (19)

Data presented as mean ± SD or % (n).

and both examiners performed three independent measurements, which they averaged.

Children with more than 30° of functional impairment at the 2-month examination were referred to a physiotherapist. At the 7-year mark, all patients who consented to follow-up were invited to the clinic for clinical and radiological evaluation.

Descriptive Data

Seventy-six percent (97 of 127) of patients with stable reduced diaphyseal both-bone forearm fractures were included in this secondary analyses. Forty-eight percent (47 of 97) had an above-elbow cast and 52% (50 of 97) had an above/below-elbow cast. The median (range) age in the

Table 2. Loss of forearm rotation of the fractured arm, subgroup analysis

Loss of rotation	Above-elbow cast	Above/below-elbow cast	Mean difference (95% CI)	p value
2 months after trauma	**(n = 62)**	**(n = 65)**		
None	6 (4)	14 (9)		
1°-10°	19 (12)	31 (20)		
11°-20°	26 (16)	18 (12)		
21°-30°	16 (10)	8 (5)		
> 31°	32 (20)	29 (19)		
Mean limitation in °	27 ± 22	22 ± 19	5.3 (-2 to 13)	0.15
7 months after trauma	**(n = 62)**	**(n = 65)**		
None	19 (12)	32 (21)		
1°-10°	19 (12)	28 (18)		
11°-20°	31 (19)	22 (14)		
21°-30°	13 (8)	11 (7)		
> 31°	18 (11)	8 (5)		
Mean limitation in °	18 ± 16	12 ± 12	5.7 (0.6 to 11)	0.03
7.5 years after trauma	**(n = 47)**	**(n = 50)**		
None	49 (23)	58 (29)		
1°-10°	23 (11)	28 (14)		
11°-20°	21 (10)	12 (6)		
21°-30°	2 (1)	2 (1)		
> 31°	4 (2)	0 (0)		
Mean limitation in °	8 ± 18	4 ± 7	4 (-2 to 9)	0.16

Data presented as mean ± SD or % (n).

Table 3. Data on primary and secondary outcomes at 7.5 years of follow-up

	Above-elbow cast (n = 47)	Above/below-elbow cast (n = 50)	Mean difference (95% CI)	p value
ABILHAND-kids questionnaire[a]	41 ± 2.4	41.7 ± 0.7	-0.7 (-1.4 to 0.04)	0.06
QuickDASH score[b]	5.8 ± 9.6	2.9 ± 6.0	2.9 (-0.5 to 6.2)	0.92
JAMAR score (ratio)[c]	0.9 ± 0.2	0.9 ± 0.2	-0.04 (-1 to 0.03)	0.24
Loss of forearm rotation in °	7.9 ± 17.7	4.1 ± 6.9	3.8 (-1.7 to 9.4)	0.47
Arc of motion in °	152 ± 21	155 ± 11	-2.5 (-9.3 to 4.4)	0.17
Loss of wrist flexion-extension in °	1.0 ± 5.0	0.6 ± 4.2	0.4 (-1.5 to 2.2)	0.69
Loss of elbow flexion-extension in °	0 ± 0	0 ± 0		

Mean values have been rounded to either whole numbers or one digit to the right of the decimal point.
[a]ABILHAND-kids questionnaire score 0 to 42, higher score represents better function.
[b]QuickDASH score 0 to 100, lower score represents better function.
[c]JAMAR ratio = grip strength in the affected wrist/grip strength in the collateral side.

above-elbow cast group was 16 years (9 to 24), and it was 15 (9 to 22) for the above/below-elbow group. In both groups, 64% (30 of 47 and 32 of 50) were men/boys. The median length of follow-up of 7.6 (5.2 to 9.9) in the above-elbow cast group and 7.4 (5.2 to 9.8) in the above/below elbow cast group. There were no differences in baseline characteristics (Table 1).

Outcomes Measures and Outcomes Assessment

Our primary goal was to compare the difference in forearm rotation with the contralateral uninjured arm between the two groups. This outcome was also used in the initial RCT. We compared the outcomes at 7.5 years to the outcomes at 7 months of follow-up (Table 2).

Our secondary study goals were the loss of flexion-extension of the elbow and wrist compared with the contralateral forearm, the QuickDASH (score 0 to 100, higher scores representing worse function, MCID 15.9 to 20 points) ABILHAND-kids questionnaire (score 0 to 42, higher scores representing better function), grip strength (measured with a Jamar dynamometer) displayed as a ratio of affected forearm/contralateral side, and radiological assessment of the angulation of radius and ulna [8, 14, 16-18, 20]. One orthopaedic surgeon (LWD) performed the unblinded standardized physical examination (Table 3). Finally, we performed a radiological assessment on radiographs at the final follow-up, where we measured the coronal and sagittal angulation of the radius and ulna (Table 4). Different cutoff values were used to define a malalignment for different ages (Supplemental Table 2; http://links.lww.com/CORR/B298). Radiological measurements were conducted in a blinded fashion by one of the coauthors (PPE) [12, 14, 22, 30]. Analyses were done using locally available analysis programs (PACS and JiveX). Finally, we performed subanalyses where we looked at the

Table 4. Radiological analysis of angulation at 7 months compared with 7.5 years of follow-up

Angulation	Above-elbow cast	Above/below-elbow cast	Mean (95% CI)	p value
7 months of follow-up	**(n = 62)**	**(n = 65)**		
AP radius in °	7 ± 5	5.5 ± 4	1.5 (-0.7 to 3.0)	0.06
AP ulna in °	6 ± 4	6 ± 5	0.1 (-1.4 to 1.6)	0.90
Lateral radius in °	8 ± 5	8 ± 5	-0.4 (-2 to 1.4)	0.66
Lateral ulna in °	6 ± 5	4 ± 4	1.7 (0.2 to 3)	0.02
Bowing radius[a]	12 ± 2	13 ± 2	-1 (-2 to 0.1)	0.08
7.5 years of follow-up	**(n = 47)**	**(n = 50)**		
AP radius in °	9 ± 2	9 ± 4	0.3 (-1.0 to 1.7)	0.61
AP ulna in °	6 ± 3	5 ± 2	1.8 (0.7 to 3.0)	0.003
Lateral radius in °	5 ± 3	5 ± 4	-0.1 (-1.5 to 1.4)	0.94
Lateral ulna in °	5 ± 3	5 ± 2	0.2 (-0.8 to 1.2)	0.70
Bowing radius[a]	2 ± 2	13 ± 3	-1.6 (-2.7 to -0.5)	0.004

Data presented as mean ± SD.
[a]Bowing is given as %, calculated with the following formula: r/Y*100 [12].

same primary and secondary outcomes but compared the malunion group to the no malunion group.

Ethical Approval

We obtained ethical approval for this study from Erasmus University Medical Centre, Rotterdam, the Netherlands (Protocol number NL41839.098.12). The original RCT was registered in ClinicalTrials.gov with registry identifier NCT00398242.

Statistical Analysis

To evaluate whether the patients included in the current study are representative of the total initial study population and to address the potential effects of attrition, we performed a sensitivity analysis. We compared the baseline characteristics, functional outcomes, and complications at short-term follow-up (7 months) between the included patients (responders) and the patients lost to follow-up (nonresponders). We compared 7.5-year results of the primary and secondary outcome measures of the two treatment groups (above-elbow cast versus above/below-elbow cast). Differences between both groups were analyzed using independent t-tests and chi-square tests. Results are presented as mean ± SD and p value or % (n) for categorial variables. In addition, we performed the Levene test for equality to compare means. Finally, we conducted a linear mixed-model analysis for multiple follow-up moments (moment of trauma, 6 weeks posttrauma, 7 months posttrauma, and 7.5 years posttrauma) in time to address possible missing data.

To assess the interrater reproducibility of radiographic assessment, two authors (LWD, PPE) measured radiological angulations of 45 patients (at cast removal and final follow-up). The interrater reproducibility of the radiological assessment showed an intraclass correlation coefficient (ICC) of 0.8 (95% confidence interval [CI] 0.7 to 0.9) and 0.9 (95% CI 0.8 to 0.9) for the radioulnar angulation of the ulna and radius, respectively. The ICC of sagittal angulation was 0.9 (95% CI 0.9 to 1) for the ulna and 0.9 (95% CI 0.8 to 0.9) for the radius [7]. We performed statistical analyses using SPSS Statistics version 27 (IBM).

Results

Clinical and Radiological Outcomes

This study showed no difference in clinical and radiological outcomes with early conversion to a below-elbow cast. At 7.5-year follow-up, the loss of forearm rotation was 7.9° ± 17.7° for the above-elbow cast group and 4.1° ± 6.9° for the above/below-elbow cast group, with a mean difference of 3.8° (95% CI -1.7° to 9.4°; p = 0.16). A mixed linear model analysis also showed improvement in forearm rotation over time for both groups. The above-elbow cast group improved from a mean loss of rotation of 27° ± 22° at 2 months to 18° ± 16° at 7 months to 8° ± 18° at 7.5 years (Table 2). For the above/below-elbow cast group, this was 22° ± 19° at 2 months, 12° ± 12° at 7 months, and 4° ± 7° at 7.5 years.

There were no differences in the secondary outcome measures. The ABILHAND-kids questionnaire had similar results in both groups (above-elbow cast: 41 ± 2.4 versus above/below-elbow cast: 41.7 ± 0.7, mean difference -0.7 [95% CI -1 to 0.04]; p = 0.06). The QuickDASH (above-elbow cast: 5.8 ± 9.6 versus above/below-elbow cast 2.9 ± 6.0, mean difference 2.9 [95% CI -0.5 to 6.2]; p = 0.92), loss of forearm rotation (above-elbow cast: 7.9° ± 17.7° versus above/below-elbow cast: 4.1° ± 6.9°, mean difference 3.8° [95% CI -1.7° to 9.4°]; p = 0.47), loss of wrist flexion-extension (above-elbow cast: 1.0° ± 5.0° versus above/below-elbow cast: 0.6° ± 4°, mean difference 0.4 [95% CI -1.5 to 2.2]; p = 0.69), and grip strength (above-elbow cast: 0.9 ± 0.2 versus above/below-elbow cast: 0.9 ± 0.2, mean difference -0.04 [95% CI -1 to 0.03]; p = 0.24) also demonstrated no differences (Table 3).

For radiographical analysis, the only difference was in ulnar angulation in the coronal plane (above-elbow cast: 6° ± 3° versus above/below-elbow cast: 5° ± 2°, mean difference 1.8° [0.7° to 3°]; p = 0.003), although that is likely not clinically relevant. Less ulnar angulation in the coronal view and more ulnar bowing were found in the above/below-elbow cast group (Table 4). When we compared all time points, we found an increase in radial angulation over time in the coronal view for the above/below-elbow cast group (p = 0.003) but not for the below-elbow cast group.

Association of Malunion With Clinical Outcomes

Children with malunion showed more radial angulation in the sagittal plane at final follow-up but no difference in clinical outcome. Accepted secondary displacement in the cast resulted in malalignment in 34 patients during the cast treatment; 22 patients still had a radiological malunion based on the previously set criteria, and 12 had remodeled at 7-month follow-up. Of the 22 patients with malunion, only one patient was lost to follow-up for the secondary measurements. At 7.5 years of follow-up, 13 of 22 patients still had a radiologic malunion, of which seven patients were in the above-elbow cast group and six patients were in the above/below-elbow cast group. Thirteen patients with persistent malunion at 7 months of follow-up showed no clinically relevant differences in functional outcomes at

Table 5. Outcome of subgroup with malunion at final follow-up compared with the group without malunion

	Malunion (n = 13)	No malunion (n = 84)	Mean difference (95% CI)	p value
Primary/secondary outcomes				
Loss of forearm rotation in °	6 ± 9	6 ± 14	0.4 (-7.5 to 8.4)	0.92
ABILHAND-kids questionnaire[a]	41.7 ± 0.5	41.4 ± 1.9	-0.3 (-1.4 to 0.7)	0.53
QuickDASH score[b]	5.0 ± 6.4	4.2 ± 8.2	-0.8 (-5.6 to 4.0)	0.75
JAMAR score (ratio)[c]	0.94 ± 0.2	0.97 ± 0.2	0.04 (-0.06 to 0.1)	0.43
Radiologic analysis				
AP radius in °	9 ± 4	9 ± 3	-0.1 (-2 to 2)	0.93
AP ulna in °	5 ± 3	6 ± 3	0.3 (-1.5 to 2)	0.74
Lateral radius in °	8.2 ± 4.0	4.3 ± 3.1	-4 (-5.9 to -1.9)	< 0.001
Lateral ulna in °	5 ± 3	5 ± 2	-0.01 (-1.5 to 1.5)	0.99
Bowing radius, %[d]	13 ± 3	13 ± 3	-0.5 (-2 to 1)	0.52

Data presented as mean ± SD.
[a]ABILHAND-kids questionnaire score 0 to 42, higher score represents better function.
[b]QuickDASH score 0 to 100, lower score represents better function.
[c]JAMAR ratio = grip strength in the affected wrist/grip strength in the collateral side.
[d]Bowing is given as %, calculated with the following formula: r/Y*100 [12].

7.5-year follow-up compared with children without malunion. The loss of forearm rotation was 5.5° ± 9.1° for the malunion group compared with 6.0° ± 13.9° in the no malunion group, with a mean difference of 0.4° (95% CI -7.5° to 8.4°; p = 0.92). Secondary outcomes showed no differences between the malunion and no malunion groups. The JAMAR ratio in the no malunion group was 0.97 ± 0.2 compared with 0.94 ± 0.2 in the malunion group, with a mean difference of 0.04 (95% CI -0.06 to 0.14; p = 0.43). The ABILHAND-kids questionnaire score was 41.7 ± 0.5 in the malunion group compared with 41.4 ± 1.9 in the no malunion group, with a mean difference of -0.3 (95% CI -1.4 to 0.7; p = 0.53). The QuickDASH score was 5.0 ± 6.4 in the malunion group compared with 4.2 ± 8.2 in the no malunion, with a mean difference of -0.8 (95% CI -5.6 to 4.0; p = 0.75) (Table 5). Linear mixed analyses showed improvement in rotation over time (p = 0.002). Radiological analysis comparing the malunion with the no malunion group only showed a difference in radial angulation in the sagittal plane (8.2 ± 4.0 in the malunion group compared with 4.3 ± 3.1 in the no malunion group, mean difference -4.0 [95% CI of -5.9 to -1.9]; p < 0.001) (Table 5).

Discussion

Half of pediatric forearm fractures are both-bone forearm fractures, and 20% of these fractures are located in the diaphysis. Diaphyseal both-bone forearm fractures are known for their higher risk of secondary displacement and malunions because of the lower remodeling capacity [1, 5, 19, 27]. They currently are treated with 6 weeks in an above-elbow cast. Colaris et al. [7] showed that early conversion to an below-elbow cast results in more cast comfort with no increase in secondary dislocations. Children have a great remodeling capability and capacity for functional recovery; we believe that treatment recommendations should therefore be based on the occurrence of complications and functional outcomes in the long term. Our secondary analysis of an earlier RCT shows that early conversion to a below-elbow cast should be the recommended treatment strategy for stable, reduced pediatric both-bone forearm fractures because there are no difference in functional and radiological outcome when compared to 6 weeks in an above-elbow cast. Even the secondary displaced malunions showed excellent clinical outcomes at 7.5 years despite the fact that 62% of the malunions were not fully corrected by growth.

Limitations

This study has some limitations. Primarily, the clinical assessment was not blinded. Blinding of patients was impossible because of the cast morphology. The second limitation is the number of patients lost to follow-up. To address the potential effects of attrition secondary to loss of follow-up, we did a patient-group analysis, showing that the loss-to-follow-up group was representative of the original study group.

Clinical and Radiological Outcomes

We found no differences between the groups at 7.5 years of follow-up in terms of patient-reported outcomes, ROM, or grip strength. Furthermore, we found no clinically important differences in radiological outcomes between the two groups. Because patients find the below-elbow cast more comfortable, we recommend that early conversion to a below-elbow cast should be the treatment of choice for children with stable, diaphyseal both-bone forearm fractures. We observed some differences in radiologic angulation between the two treatment groups, but none of these were clinically relevant. Regardless of the initial treatment, the radiological outcomes were good. This confirms findings from a study that reported good or excellent outcomes in 92% of patients who were treated with closed reduction and a cast [21]. In that series, results were graded as excellent if there were no complaints with physical activity and/or a loss of ≤ 10° of forearm rotation.

Association of Malunion With Clinical Outcomes

Children with malunion showed more radial angulation in the sagittal plane on radiographs at the most-recent follow-up, but this was not associated with poorer clinical outcomes. This supports our earlier recommendation to treat stable diaphyseal both-bone forearm fractures with an early conversion to a below-elbow cast, since even when they do secondarily displace, the pediatric skeleton seems very forgiving, and the radiographic finding does not seem to result in pain or loss of function.

The evidence shows that diaphyseal both-bone forearm fractures treated nonoperatively, either with a cast or with manipulation followed by a cast, have a high tendency to redisplace. Bowman et al. [3] retrospectively analyzed radiographs of 282 children with diaphyseal both-bone forearm fractures. Fifty-five percent of children had their first radiographic evidence of redisplacement during the first week postreduction. The authors stated that patients 10 years or older and those with proximal-third radius fractures are at the highest risk for redisplacement. One study looked at risk factors for redisplacement in diaphyseal forearm fractures in 57 children [27]. They found that a poorer reduction (OR 8.5) and a complete fracture (OR 9.6) were factors associated with redisplacement [29].

Whether redisplacement and malunion causes important levels of functional impairment is controversial. Our findings, based on a robust secondary analysis of an earlier RCT, suggest that these residual deformities are well tolerated. However, another prospective study evaluated the relationship between residual deformity and functional outcomes after closed treatment of displaced diaphyseal both-bone forearm fractures in 25 children and found that loss of forearm rotation was correlated with the maximum angulation of the radius seen on either the final AP or lateral radiograph. Of the 25 patients, 20% (5) had malunions with more than 15° of angulation of either the radius or ulna; three of these patients demonstrated more than 30° of loss of forearm rotation [31]. Our study also showed more angulation in the malunion group but no correlation with more loss of rotation.

The evidence shows that some degree of forearm malunion can be accepted in children because the remaining growth in pediatric bones enables remodeling capacity. The degree of correction by growth depends on the remaining growth and the location and plane of the malunion. Earlier studies have demonstrated a relationship between age and the ability to correct the deformity. One study suggested that children younger than 9 years of age can achieve correction of 90% of their malunion, and remodeling capacity decreases with age older than 9 years [18]. Another study showed that the age at the time of the fracture was correlated positively with late residual angulation, with older children being less able to compensate for the fracture deformity. Also, they showed a correlation between the late residual angulation and limitation of pronation and supination [13]. Another study showed that the closer to the growth plate, the higher the remodeling potential. The authors concluded that midshaft fractures in children older than 10 years of age with angulation have a poor diagnosis if left uncorrected [15]. But even when they don't remodel completely, these children seem generally to have good ROM. One study presented the outcomes of 39 children with malunions after severely angulated diaphyseal both-bone forearm fractures with a mean follow-up of 6 years. Complete remodeling occurred in only 12 of 39 patients, almost all younger than 10 years of age, but 92% showed good-or-excellent outcomes despite persistent radiological malunion [21]. Another study showed that most malunions in children result in complete functional recovery or minimal function loss with no influence in daily use [23]. In line with these studies, our secondary analysis of an RCT showed that even though patients with a malunion have more sagittal radial angulation at follow-up, all children remodeled to a clinically acceptable angulation, with good-to-excellent functional outcomes at final follow-up. Having said that, it is worth noting that despite the good final results, it might take years to gain full rotation and a cosmetically straight forearm. Therefore, we believe that children who develop unacceptable angulation after early redisplacement of unstable both-bone forearm fractures may benefit from consideration of surgery, but this needs to be considered in light of its risks.

Conclusion

In light of these results we suggest that surgeons perform an early conversion to a below-elbow cast for reduced stable diaphyseal both-bone forearm fractures in children. Even in patients with secondary fracture displacement, remodeling occurred, and with persistent malunion, most patients showed good to excellent results at 7.5-year follow-up. In the future, meta-analyses or large prospective observational studies would be helpful to establish the influence of skeletal age, sex, and the severity and direction of malunion angulation of both the radius and ulna on clinical result.

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