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ORIGINAL ARTICLE

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Remodeling capacity and functional outcome of palmarly versus dorsally displaced pediatric radius fractures in the distal one-third

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Abstract *Introduction:* The purpose of this retrospective study was to compare the remodeling capacity and functional outcome of palmarly and dorsally displaced pediatric radius fractures in the distal one-third. *Materials and methods:* Fifty-three children with a residual dorsal angulation of 15° (range 10°–28°, ±SD 5.32) and 31 children with a residual palmar angulation of 15° (range 10°–30°, ±SD 4.88) at fracture healing were re-examined clinically and radiologically with a median follow-up time of 10 years (range 5–15 years). *Results:* There was no difference in the remodeling capacity, palmar tilt, radial inclination, and ulnar variance between both groups at follow-up. Pain as well as flexion/extension of the wrist and pronation showed no difference in both groups. Palmarly displaced fractures showed a significantly higher restriction of supination (p=0.01). *Conclusion:* We conclude that remodeling of residual palmar angulation occurs to the same extent as it does in dorsal angulation. Functional outcome differs in forearm supination.

Keywords Forearm fracture · Immature skeleton · Radius · Remodeling

Introduction

Fractures of the distal one-third of the radius are among the most common childhood injuries [3, 11, 21, 31], and the capacity of spontaneous correction of residual angulation has been demonstrated to be greatest in this area [2, 10, 14, 15, 16, 20, 26]. Previous papers have investigated the capacity for remodeling and the amount of acceptable residual angulation [11, 7, 8, 9, 14, 17, 19, 26]. There is, however, little agreement as to how much angulation deformity upon fracture healing is acceptable. Generally speaking, a reduction to near perfect anatomic alignment is not always a necessity because of the remodeling properties inherent in the growing bone, especially in children under 10 years old [7, 8, 9, 14, 17]. Palmarly displaced fractures are not as frequent as dorsally displaced fractures in the distal forearm [30, 31]. This may be the reason why previous publications did not differentiate between palmarly and dorsally displaced fractures [7, 8, 9, 11, 17, 21], and it is assumed that the capacity for correction is the same. In children, palmarly displaced fractures fortunately do not undergo late displacement during immobilization [27]. Evans [5] believed that the angulation of a greenstick fracture was more apparent than real and that the deformity was mainly rotatory. He stated that dorsal angulation resulted from supination and palmar angulation from pronation and could be corrected by rotating the forearm to the opposite side. Some authors [2, 4, 5, 19, 25] advised immobilizing the forearm in supination after palmarly displaced fractures and in pronation after dorsally displaced fractures, others recommended immobilization in neutral forearm rotation regardless of the fracture dislocation [16, 28, 31].

The aim of the present study was to determine whether residual palmar angulation corrects as spontaneously as residual dorsal angulation does, whether this correction includes changes in radial inclination, palmar tilt, and ulnar variance, and whether there is a difference in the clinical long-term results between palmarly and dorsally displaced radius fractures in the distal one-third.

Patients and methods

Out of 1200 pediatric fractures of the distal one-third of the radius treated from 1980 to 1998, 84 patients with an isolated displacement of the radius in the sagittal plane of more than 10° at the time of fracture healing were included in this study. In 53 patients (63%), the fractures were dorsally displaced (Fig. 1) and in 31 patients (37%), palmarly displaced (Fig. 2). Details of the characteristics of the patients are given in Table 1.

All fractures were treated by conservative means. In case of completely displaced fractures or greenstick fractures angulated more than 20°, closed reduction under general anesthesia followed by cast immobilization was performed (30 patients: 8 palmarly dis-

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Fig. 1a–d Male patient, aged 10 years at time of accident, right handed, fell while running, metaphyseal greenstick fracture of the right radius, conservative treatment, 4 weeks below-the-elbow cast. **a** Anteroposterior (AP) and lateral radiograms at time of injury. **b** AP and lateral radiograms at time of cast removal, 4 weeks after the accident. **c** AP and lateral radiograms at time of follow-up, 9 years after the accident. **d** AP and lateral radiograms of the uninjured contralateral side, at time of follow-up

placed fractures, 22 dorsally displaced fractures). Casting without reduction (54 patients: 23 palmarly displaced fractures, 31 dorsally displaced fractures) was performed in cases of less than 20° displacement. A short arm cast was applied for torus fractures and greenstick fractures. An above-the-elbow cast was applied for complete, displaced fractures and fractures of both the radius and the ulna. Casting lasted 3–6 weeks, average 4 weeks.

Median follow-up was 10 years (range 5–15 years). All examinations were done by the same examiner. Functional and radiological outcomes were compared with the unaffected side.

Standard posteroanterior and lateral radiograms of both wrists were used to assess the radial inclination and palmar tilt of the distal articular surface, ulnar variance, and residual angulation of the shaft of the radius in the sagittal plane at follow-up [17, 23, 29] (Fig. 3a–d). Residual angulation at fracture healing (cast removal) was defined as the angle between a line oriented perpendicular to

Fig. 2a–d Female patient, aged 4 years at time of accident, right handed, fell while running, metaphyseal greenstick fractures of the right radius and ulna, conservative treatment, 3 weeks above-the-elbow cast. **a** AP and lateral radiograms at time of injury. **b** AP and lateral radiograms at time of cast removal, 3 weeks after the accident. **c** AP and lateral radiograms at time of follow-up, 10 years after the accident. **d** AP and lateral radiograms of the uninjured contralateral side, at time of follow-up

Table 1 Characteristics of patients

	Residual dorsal angulation	Residual palmar angulation
Patients	n=53	n=31
Age at accident	3–14 years (average 8)	3–13 years (average 8)
Age at follow-up	15–26 years (average 20)	14–24 years (average 19)
Sex: boy/girl	40/13	22/9
Type of radius fracture:		
Torus fracture	13 (24.5%)	8 (25.8%)
Greenstick fracture	15 (28.3%)	14 (45.2%)
Complete, displaced fracture	15 (28.3%)	6 (19.4%)
Salter/Harris type I or II	10 (18.9%)	3 (9.7%)
Type of ulna fracture:		
Torus fracture	15 (28.3%)	1 (3.2%)
Grennstick fracture	4 (7.5%)	4 (12.9%)
Complete, displaced fracture	7 (13.2%)	4 (12.9%)
Salter/Harris type I or II	1 (1.9%)	1 (3.2%)

the epiphyseal plate and the long axis of the proximal fragment [11, 16, 17] (Fig. 3e). To determine the remodeling of residual angulation in the sagittal plane, we compared the deformities at the time of fracture healing (Fig. 3e) to those at follow-up (Fig. 3d).

In compliance with Larsen et al. [17], remodeling was defined as the difference in fracture angulation at the time of healing and at follow-up. Remodeling, palmar tilt, radial inclination, and ulnar variance were assessed for torus, greenstick, and complete fractures, and we compared incomplete fractures (torus and greenstick fractures) with complete fractures.

The patients were arbitrarily divided into two age groups: 3–10 years and 11–14 years.

Pain was rated mild if it occurred at the extremes of movement and did not interfere with daily activity, moderate if it was sufficient to cause alteration in work or leisure activities, and severe if it occurred during activities of daily living or at rest.

The range of active flexion and extension of both wrists as well as forearm rotation were measured with a goniometer. In compliance with Roberts [26], a loss of 15° or more of forearm rotation compared with the contralateral side was regarded as abnormal and related to the fracture.

Statistical analysis

Analyses were performed using SPSS 8.0 for Windows software (SPSS Inc, Chicago, IL,USA). The similarities or differences between the two groups and the contralateral side in terms of pain, active range of forearm rotation, wrist flexion and extension, as well as radiological appearances were analysed using Student's t-test. Results were considered statistically significant if p values were <0.05.

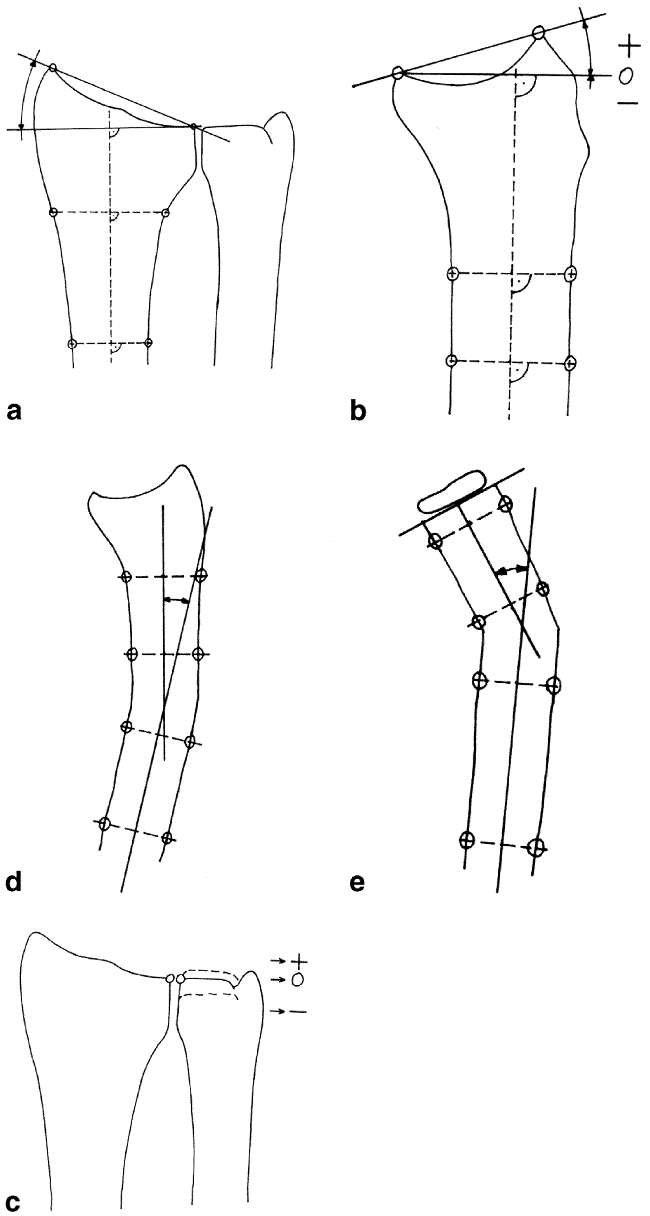

Fig. 3a–e Radiological assessment. **a** Radial inclination is the angle measured between the plane of the distal radial articular surface as seen on the AP radiogram and a line perpendicular to the shaft of the radius. **b** Palmar tilt is the angle measured between a line tangential to the distal radial articular surface as seen on the lateral radiogram and a line perpendicular to the shaft of the radius. **c** AP radiogram for ulnar variance. Vertical distance between a line parallel to the proximal surface of the lunate facet of the distal radius and a line parallel to the articular surface of the ulnar head. **d** Angular deformity in the sagittal plane of the radius at the time of follow-up was defined as the angle between the central axis of the proximal and distal fragments. **e** Angular deformity in the sagittal plane of the radius at fracture healing was defined as the angle between a line oriented perpendicular to the epiphyseal plate and the long axis of the proximal fragment [2, 9, 15]

Table 2 Radiological results

	Remodeling of residual angulation	Palmar tilt	Radial inclina- tion	Ulnar variance
<10 years old	p=0.32	p=0.46	p=0.76	p=0.68
>10 years old	p=0.07	p=0.9	p=0.56	p=0.86
Torus fractures	p=0.95	p=0.89	p=0.75	p=0.82
Greenstick fractures	p=0.27	p=0.91	p=0.58	p=0.71
Complete fractures	p=0.35	p=0.49	p=0.57	p=0.68

Table 3 Pain

Pain	Dorsal angulation	Plamar angulation
Pain-free	43 (81%)	25 (81%)
Mild	7 (13%)	5 (16%)
Moderate	3 (6%)	1 (3%)
Severe	0 (0%)	0 (0%)
Statistics	p=0.9	

Table 4 Active range of motion (compared with the contralateral side)

Active ROM	Dorsal angulation	Palmar angulation
Wrist flexion	100%	100%
Wrist extension	100%	100%
Forearm pronation:		
Equal	50 (94%)	29 (94%)
Restriction 15°–25°	3 (6%)	2 (6%)
Restriction >25°	0 (0%)	0 (0%)
Statistics	p=0.8	
Forearm supination:		
Equal	51 (96%)	24 (77%)
Restriction 15°–25°	2 (4%)	7 (23%)
Restriction >25°	0 (0%)	0 (0%)
Statistics	p=0.01	

Results

Remodeling of residual angular deformity in the sagittal plane

The average residual dorsal angulation of the radius at fracture healing was 15° (range 10°–28°, ±SD 5.32), while the average residual palmar angulation was 15° (range 10°–30°, ±SD 4.88). The average dorsal angulation to the longitudinal axis of the radius at follow-up was 0.3° (range 0°–5°, ±SD 1.1), the average palmar angulation was 0.2° (range 0°–5°, ±SD 1.0). No significant difference existed between the two correction capacities (p=0.7), the longitudinal axis of the radius at follow-up for either dorsally and palmarly displaced fractures (p=0.9), the two age groups and the three different fracture types (Table 2).

No significant difference in remodeling of angular deformity in the sagittal plane was seen between incomplete and complete fractures (p=0.35).

Palmar tilt

Palmar tilt of the radius at follow-up was 6.1° (range 0°–10°, ±SD 4.65) in the group with initial dorsal deformity, 6.2° (range 0°–12°, ±SD 3.48) in the group with initial palmar deformity, and 7.0° (range 3°–13°, ±SD 3.29) on the contralateral side. No significant difference in palmar tilt was seen between the dorsal angulation group and the contralateral side (p=0.5) as well as between the palmar angulation group and the contralateral side (p=0.14). No difference in palmar tilt was seen between both groups (p=0.9), between incomplete and complete fractures (p=0.33) in the two age groups and in the three different fracture types (Table 2).

Radial inclination

Radial inclination of the radius at follow-up was 26.2 (range 17°–35°, ±SD 3.62) in the group with initial dorsal deformity, 26.4° (range 21°–31°, ±SD 2.98) in the group with palmar deformity, and 25° (range 20°–35°, ±SD 3.08) on the contralateral side. No significant difference in radial inclination was seen between the dorsal angulation group and the contralateral side (p=0.63) as well as between the palmar angulation group and the contralateral side (p=0.45). No difference in radial inclination of the radius was seen between both groups (p=0.70), between incomplete and complete fractures (p=0.35), in the two age groups as well as in the three different fracture types (Table 2).

Ulnar variance

Mean ulnar variance for dorsal angulation was –0.8 mm (range –4 mm to +4 mm, ±SD 5.05), for palmar angulation –1.2 mm (range –4 mm to +3 mm, ±SD 4.39), and on the contralateral side –0.76 mm (range –3 mm to +4 mm, ±SD 4.4). No significant difference in ulnar variance was observed between the involved and the contralateral sides in the dorsal angulation group (p=0.62) and the palmar angulation group (p=0.42). No difference in ulnar variance was seen between both groups (p=0.7), between incomplete and complete fractures (p=0.35), the two age groups and the three different fracture types (Table 2).

Clinical results

Patient's subjective assessment of pain showed no significant difference between the dorsal angulation group and the palmar angulation group (p=0.9). None of the patients had severe pain.

Flexion and extension of both wrists was equal in all patients. While pronation of the forearm was similar in the two groups (p=0.08), patients with residual palmar deformity of the radius showed significantly higher restriction of supination (p=0.01).

The results for subjective assessment of pain and active range of movement are given in Tables 3 and 4.

Discussion

Fractures of the distal one-third of the forearm account for some 20% of all fractures occurring during childhood and are thus among the most common childhood injuries. Fractures in children differ from those in adults in a number of ways. Fractures are easily treated conservatively with the exception of epiphyseal fractures (Salter/Harris type 2 and 3) [31], in which the germinal zone of the growth plate is injured [11, 14, 15, 16, 21, 28]. The reason for this is that fracture healing is quick and sure and that these fractures have an excellent capacity to spontaneously correct residual axial deformities during the growing years [7, 8, 9, 10, 31]. The reasons for this are presumed to be the proximity to the distal growth plate that is mainly responsible for growth [20] and the fact that the most common deformity in the sagittal plane occurs in the main plane of movement of the wrist [2, 20]. Thus, open reduction is rarely indicated.

In the literature, however, there is a great discrepancy as to how much angular deformity is acceptable. Önne and Sandblom [21] showed in 1949 that during the first decade of life, complete correction of angular deformity is usually achieved up to 20°–25°, but above this age or this degree of malposition, the capacity of correction is decreased or is not able to prevent residual detriment.

Gandhi et al. [11] stated in 1963 that angular deformity of the distal one-third of the forearm usually corrects fully with growth of the bone within 5 years, provided the lower radial and ulnar epiphyses do not fuse in the meantime. They stated that the younger the child and the nearer the fracture to the physeal plane, the greater the potential for spontaneous correction.

Hughston [14] recommended that fractures in patients over 14 years of age should be treated as for adults, but felt that 30°–40° was acceptable in children under 10 years with distal one-third fractures.

Pauwels [22] demonstrated that the growth plate is responsive to pressure changes and will reorient perpendicular to the major reaction forces across the physis if there is enough time.

Friberg [7, 8, 9] stated in 1979 that angular deformity after fracture healing induces a change in orientation of both the distal and proximal epiphyseal plates. The redistribution of growth tends to correct the angular deformity. The rate of correction follows an exponential course. He found that the rate of correction was higher in groups with larger deformities, and there were no significant differences between age, sex, side, treatment, and distance of fracture from the epiphyseal plate and the correction capacities.

Larsen et al. [17] stated in 1988 that in children up to 11 years of age, correction of angular deformity in the sagittal plane up to 28° occurs completely at the distal epiphyseal plate. In children over 11 years of age, remodeling occurs by change of orientation of the epiphyseal plate as well as by appositional bone formation/resorption and growth in width.

Von Laer [16] stated that angular deformity of up to 40°–50° usually corrects fully both in the sagittal and the frontal plane in children up to 12 years old. He considered that correction of angular deformity is the same as in fractures of the metaphysis and in fracture separation of the epiphysis.

Wilkins and O'Brien [31] expect an adequate remodeling of up to 30°–35° of angular deformity in the sagittal plane in children still having at least 5 years of growth.

All these studies did not distinguish between dorsal and palmar deformity; it is assumed that the remodeling capacity is the same, and thus no investigation has been made yet.

The present study demonstrates that both dorsal and palmar deformities remodel in different age groups and different fracture types to the same extent. No difference was seen between incomplete and complete fractures. The average dorsal deformity of the radius at fracture healing remodeled from 15° (range 10°–28°) to 0.3° (range 0°–5°) at follow-up and the average palmar deformity, from 15° (range 10°–30°) at fracture healing to 0.2° (range 0°–5°) (p=0.7). No difference compared with the contralateral side was seen (p=0.9). In addition, no differences were recognized in palmar tilt, radial inclination, and ulnar variance between the dorsally or palmarly displaced fractures and between the fractured side and the uninvolved side in both groups.

Patient's subjective assessment of pain showed similar results in both groups: 81% (dorsally displaced) and 79% (palmarly displaced) of the patients were pain-free at follow-up (p=0.9). None of the patients had severe pain. We conclude that neither residual palmar nor dorsal angular deformity at fracture healing influences the subjective outcome.

Flexion and extension of both wrists were equal in all patients. It appears that recovery of physiological axes leads to a normal range of movement of the wrist. While pronation of the forearm was similar in the two groups (p=0.8), patients with residual palmar deformity of the radius showed a significantly higher restriction of supination (p=0.01). The fact that the direction of residual angulation at fracture healing may affect the functional outcome was stated in previous articles. Roberts [26] demonstrated that radial deviation of the distal fragment is more closely related to loss of forearm rotation than is dorsal angulation in both midshaft and distal one-third fractures. This may be due to the narrowing of the interosseous gap at the fracture site. Högström et al. [13] showed a close correlation between loss of forearm rotation and residual angular deformity in shaft fractures, while Nilsson and Obrant [18] found a decreased forearm rotation after primarily displaced shaft fractures, well reduced by closed methods and with no sign of deformity in the radiograms at follow-up. This finding implies that factors other than residual deformity are responsible for decreased forearm rotation. In palmarly angulated distal one-third fractures of the radius, the distal fragment is often pronated, and an increased tendency to loss of supination has been reported [1]. This rotational deformity of the distal fragment might be the reason for the restriction of forearm rotation because there is no remodeling capacity reported for rotational deformity in the forearm [4, 20]. Rotational deformity of the radius leads to unphysiological tension of the radioulnar ligaments and incongruity of the distal radioulnar joint with loss of forearm rotation [6].

Hagart [12] stated that palmarly displaced distal radius fractures in adults lead to increased problems in the distal radioulnar joint and restriction of forearm rotation.

Evans [5] pointed out that the apparent angular deformity seen in greenstick fractures is in fact rotational deformity, and palmarly displaced fractures have to be immobilized in supination of the forearm and dorsally displaced fractures in pronation to reduce the fractures and to avoid restriction of forearm rotation. Davis and Green [4], however, warn about reduction and immobilization of complete distal one-third fractures by forcible rotation, because malrotation and functional restriction may occur. In our study, we did not see any differences in remodeling of residual angulation between incomplete and complete fractures. Whether and to what extent rotational deformity accompanies fractures of the distal one-third and whether and to what extent they can be reduced or correct spontaneously remain to be determined in future studies.

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