Which Axial Deviation Results in Limitations of Pro- and Supination Following Diaphyseal Lower Arm Fracture in Childhood?

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Abstract

Background: Pediatric diaphyseal forearm fractures, if considered stable, are usually treated conservatively. Recently, however, there has been a trend towards stabilizing diaphyseal forearm fractures operatively, generally by intramedullary nailing, to avoid angular deformities and functional impairment. The aim of this study was to examine patients with an unsatisfactory outcome after diaphyseal forearm fracture for a possible correlation between their outcome and a remaining axial deviation or a combined angular deformity in order to better ensure that only essential operations are performed.

Patients and Methods: Analysis of 581 pediatric forearm fractures showed a similar distribution concerning age, cause, and fracture site as previously reported in other studies.

Results: 14.8% of our patients showed an unsatisfactory outcome. In some patients, this was due to residual ulnar and palmar angular deformities of the radial shaft. Another reason for a poor outcome was an angular deformity > 15° not depending on the plane the dislocation occurred in; these values, however, were not statistically significant. A discriminating analysis (CART®) of combined mid-diaphyseal fractures with angular deformities of up to 15° demonstrated that the relation of the bony deformities to each other had relevant consequences for the outcome. For example, radiopalmar angular deformities of the radial shaft combined with a nondeformed ulna had a high probability of an unsatisfactory outcome. If this deformity of the radius was combined with a dorsal deformity of the ulnar diaphysis, however, the probability of a satisfactory outcome was high.

Conclusions: In summary, this study indicates that the prognosis of a satisfactory outcome of forearm fractures regarding function and cosmesis is complex and influenced by both the radius and ulna. Diaphyseal angular deformities > 10° should be avoided in the treatment of pediatric forearm fractures.

Key Words
Forearm · Childhood · Diaphysis · Fracture · Axial deviation

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Introduction

Diaphyseal forearm fractures are usually treated conservatively [1, 2, 4, 17, 20, 26, 33, 38]. Recently, however, there has been an increasing number of operatively treated patients. In the early 90s, 3–7% of all pediatric forearm fractures were treated operatively, while this number has been as high as 20% lately [16, 29, 38]. Cast treatment can result in an increased number of angular deformities which have been shown to impair forearm rotation and can have negative cosmetic effects [6, 9, 15, 23]. Later correction of a forearm shaft

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deformity can be complicated and the functional outcome may be poor [3, 25]. When operative treatment is chosen, intramedullary stabilization systems are frequently used [7, 15, 24, 27, 30]. Advantages of this technique are small incisions, shorter inpatient treatment, and the ability to retain closed reduction [15, 21, 27].

Sarmiento et al [34] analyzed the influence of angular deformities on the impairment of forearm rotation in adult cadavers. In pediatric patients, however, little is known about the exact influence of an angular deformity on forearm rotation. Specially, it is difficult to account for the remodeling process. One reason why little is known about the effect of deformity on functional outcome is that some previous studies did not exclude metaphyseal fractures; these fractures close to the physis have a much higher potential for spontaneous correction [8, 10, 11, 22, 31]. Other studies did not take the relation of angular diaphyseal deformities of the radius and ulna to each other into account.

The relatively simple operative technique of intramedullary stabilization combined with the fear of rotational impairment from an angular deformity seems to favor the tendency to operate on every diaphyseal pediatric forearm fracture [28, 35, 36, 39, 40].

There is a danger of "overtreating" diaphyseal pediatric forearm fractures because the data on the exact influence of axial deformities on cosmetic and functional outcome is sparse and controversial.

The aim of this retrospective study was to evaluate a large series of pediatric forearm fractures to see how the patients' outcome was related to the fracture type and level, and also what influence angular deformity at the end of therapy had on outcome. This would allow us to more accurately issue a prognosis of the outcome as well as to determine which fractures would benefit from operative interventions.

Patients and Methods

In this retrospective study, all patients up to an age of 14 years were included. Children were treated in the municipal hospital of Braunschweig, Germany, between 1986 and 1996 and at the childrens' hospital auf der Bult in Hannover, Germany, between 1992 and 1996. Excluded from this study were all intraarticular and metaphyseal fractures, as well as all Galeazzi and Monteggia fractures. The metaphysis was defined to begin at the proximal and distal fifth of the forearm. Documentation was based on a form developed in cooperation with the Section for Pediatric Traumatology of the German Association for Traumatology.

The following parameters were surveyed: age, cause, fracture type (Table 1), fracture site (proximal, middle and the distal third of the shaft; Table 2), and type of treatment (Table 3).

Follow-up examination was performed at least 2 years after the injury in a standardized fashion: range of motion of the elbow in extension/flexion, forearm rotation (elbow in 90° of flexion), and wrist dorsal extension/palmar flexion and radial/ulnar abduction were examined (Figure 1). Any clinical impairment of the forearm > 10° was noted. X-rays in the anteroposterior and lateral view were assessed and angular deformities of both forearm bones measured in steps of 5°.

The outcome was defined to be satisfactory or better if there were no functional impairment of forearm rotation, no visible angular deformity of the forearm, and no negative cosmetic aspects. If these parametric criteria were not met, the outcome was defined to be unsatisfactory.

Figure 1. Clinical examination of forearm function at follow-up.

Statistics

Data was evaluated using the statistics program SPSS® for Windows 9.0 (SPSS 1999). The mean value, the standard deviation, and the maximum and minimum values were calculated. The t-test was used to determine the statistical significances ($p < 0.05$), after checking the normal distribution as well as the χ^2-test according to Pearson. For cross tables with ordinal level, the test according to Cochran-Armitage was used with a significance level of $p < 0.05$ (two-sided).

Discriminating Analysis of Combined Angular Deformities: The CART® (classification and regression trees) program was used to assess the prognostic probability of a satisfactory outcome (target variables) by combining the predictive values [5, 37]. This program formed clusters of deformities and calculated the probability of a satisfactory or unsatisfactory outcome in percent.

To receive a homogeneous study group, only mid-diaphyseal fractures were included in the CART® analysis, resulting in 225 images (62.3%) used for the analysis.

A group of 16 was considered the smallest size of node to be further subdivided. The smallest possible size of the final node was limited to eight. A tenfold cross-validation resulted in a stable tree with seven clusters. Various classification trees were established using the evaluations of different defective classifications (false-positive and false-negative). Finally, the tree with the rate of the least nonclassified cases was selected. Evaluation of the defective classification rate of 4.5 : 1 (false-positive vs. false-negative) revealed a specificity of 0.41 and a sensitivity of 0.62 for establishing an optimal cross-validated tree.

Results

581 forearm fractures in 578 children were assessed. The patients' age at the time of injury was 7.4 ± 3.6 years (1/14). The most frequent mechanism of injury was a fall from < 1 m, representing 54% of all injuries (n = 314). 16% of the children were involved in a traffic accident (n = 93). The fracture type was distributed as follows: 220 patients (37.9%) sustained bilateral greenstick fractures, 145 (24.9%) had bilateral complete fractures, 62 (10.7%) fractured just one bone, and 154 (26.5%) showed a combination of different fracture types (Table 1).

The following fractures sites were seen: 288 fractures of both the radius and the ulna (49.6%) occurred in the mid diaphysis, 103 (17.7%) in the distal third of the shaft and 17 (2.9%) in the proximal third, and 173 patients (29.8%) had fractures of the radius and ulna at different levels of the shaft (Table 2).

182 patients (31.3%) were treated on an outpatient basis compared to 399 (68.7%) who were hospitalized.

14.1% fractures (n = 82) did not require reduction. 68.5% fractures (n = 398) were reduced once or more often; 82 patients (14.1%) were treated operatively (Table 3).

Table 1. Type of forearm fracture.

Radius \ Ulna	Number (n) No fracture	Greenstick fracture	Complete fracture	Bowing fracture	Comminuted fracture	Total amount
No fracture	0	8	8	1	0	17
Greenstick fracture	24	220	57	10	3	314
Complete fracture	6	37	145	6	8	202
Bowing fracture	1	18	3	12	1	35
Comminuted fractures	0	1	5	2	5	13
Total amount	31	284	218	31	17	581

Table 2. Site of forearm fracture.

Radius \ Ulna	Number (n) No fracture	Proximal part	Mid part	Distal part	Total amount
No fracture	0	0	8	0	8
Proximal part	2	17	52	3	74
Mid part	13	24	288	41	366
Distal part	7	0	23	103	133
Total amount	22	41	371	147	581

Table 3. Treatment data (n = 581 fractures).

Therapy	Number (n)
No reduction	82
Closed reduction	438
Wedging	32
Open reduction	48
Closed and open reduction	14
Closed reduction and wedging	7
Total	621[a]

[a]fractures could receive several treatment procedures

Regarding the remaining axial deviation at the time of consolidation, the radius showed the following results: radial deviation in 33.5% (n = 195), ulnar deviation in 18% (n = 104), dorsal deviation in 40.3% (n = 234), and palmar deviation in 21.5% (n = 125). For the ulna, the following data was acquired: radial deviation in 23.4% (n = 136), ulnar deviation in 17.4% (n = 101), dorsal deviation in 24.5% (n = 142), and palmar deviation in 26.1% (n = 152; Table 4).

420 patients (72.3%) returned for follow-up. Time of follow-up averaged 67.1 ± 29.3 (24/132) months after the injury. 14.8% (n = 62) showed an unsatisfactory outcome, 85.2% (n = 358) had a satisfactory or better outcome.

Angular ulnar and palmar deformities of the radial shaft were significantly associated with unsatisfactory results (Tables 5a to 5d, Figures 2a and 2b).

Angular deformities ≥ 15° were associated with a poor outcome; this was not statistically significant (Tables 6a and 6b). Discriminating analysis of combined deformities showed that clusters IV, VI, and VII had a high probability of good outcome. All other clusters indicated a high probability of poor outcome (Table 7, Figure 3).

Discussion

Children frequently sustain diaphyseal forearm fractures [6, 18, 19, 39]. Treatment of these fractures is controversial [13, 30]. In the past, only unstable and completely displaced fractures were treated operatively [12, 15, 32]. Recently, even moderately displaced fractures have been stabilized operatively to obtain and keep optimal reduction [24, 27, 30, 35]. Conservatively treated diaphyseal forearm fractures are reported to have a rate of angular deformities ranging from 10–60% [3, 6, 12, 35, 38]. At consolidation time, this study revealed a remaining axial deviation of the ulna or the radius in 18–40% of all cases presented, depending on the plane of deviation (Table 4). Previous studies have shown that deformities – most authors relate the axial deviation to the radius – are commonly directed dorsally and radially [4, 11, 13, 20, 22, 23, 26, 28].

Angular deformities of the radius and ulna are associated with impairment of forearm rotation in 10–50% of all patients [4, 10, 11, 13, 23, 39]. In our study, 14.8% of patients who were treated conservatively had an unsatisfactory outcome with impairment of forearm rotation and/or cosmetic deficits.

Table 4. Retained axial deformity of the radius and ulna at the time of consolidation (n = 581).

Deformity	Frontal plane			Sagittal plane		
	None	To radial	To ulnar	None	To dorsal	To palmar
Radius	282 (48.5%)	195 (33.5%)	104 (18%)	222 (38.2%)	234 (40.3%)	125 (21.5%)
Ulna	344 (59.2%)	136 (23.4%)	101 (17.4%)	287 (49.5%)	142 (24.5%)	152 (26.1%)

Table 5a. Retained axial deformity of the radius in the frontal plane at the time of consolidation in relation to the outcome. n: number of cases.

Radius	No axial deformity	Palmar deformity	Ulnar deformity	Total amount (n)
Unsatisfactory (n)	21 (10%)	10 (10.2%)	28 (26.9%)*	59 (14.3%)
Satisfactory (n)	189	88	76	353
Total amount (n)	210	98	104	412 (100%)

*significant (p = 0.002)

Table 5b. Retained axial deformity of the ulna in the frontal plane at the time of consolidation in relation to the outcome. n: number of cases.

Ulna	No axial deformity	Palmar deformity	Ulnar deformity	Total amount (n)
Unsatisfactory (n)	33 (12.9%)	16 (20%)	11 (13.5%)	60 (14.4%)
Satisfactory (n)	222	64	70	356
Total amount (n)	255	80	81	416

Table 5c. Retained axial deformity of the radius in the sagittal plane at the time of consolidation in relation to the outcome. n: number of cases.

Radius	No axial deformity	Dorsal deformity	Palmar deformity	Total amount (n)
Unsatisfactory (n)	13 (8.7%)	31 (16.9%)	14 (20.8%)*	58 (14.1%)
Satisfactory (n)	136	152	63	351
Total amount (n)	149	183	77	409

*significant (p = 0.034)

Table 5d. Retained axial deformity of the ulna in the sagittal plane at the time of consolidation in relation to the outcome. n: number of cases.

Radius	No axial deformity	Dorsal deformity	Palmar deformity	Total amount (n)
Unsatisfactory (n)	28 (12.9%)	16 (17.2%)	14 (12.9%)	58 (13.8%)
Satisfactory (n)	189	77	94	360
Total amount (n)	217	93	108	418

Previous studies do not provide evidence of better results after operative treatment. Even if an operation is performed, studies demonstrate that 10% of the patients have functional impairment – not regarding the rate of postoperative complications [7, 15, 24, 27, 30, 32, 38, 40]. Reasons for this might be scar formation and soft tissue irritation.

This study reflects the favored methods of treatment up to 1996 in children sustaining diaphyseal forearm fractures. The data regarding age, type of accident, fracture type and site are comparable with previous studies.

It is known that the soft tissues and the adjacent joints play a significant role in forearm function. Linke et al. stated that not all impairments of forearm rotation of their patients could be explained by angular or torsional deformities [28]. Luhmann et al [30] identified a discrepancy between radiologic results and function. In this retrospective study with a relatively large study group, it was not feasible to examine the soft tissues (e.g., with MRI). Consequently, we focused on the bony structures and excluded fractures combined with joint lesions from the study.

The direction of angular deformity causing functional impairment is still controversial. Daruwalla [8] states that palmar deformities of the radius could block pronation. In his opinion, blockage of supination is caused by a dorsal deformity of the radius, by a narrowing of the

Figure 2a. Example of a 9-year-old girl. 2 years after forearm fracture, the clinical examination shows no limitation of pro- and supination. The X-ray reveals a severe deformity of the ulna. The axial deviation of the ulna is located dorsoradially.

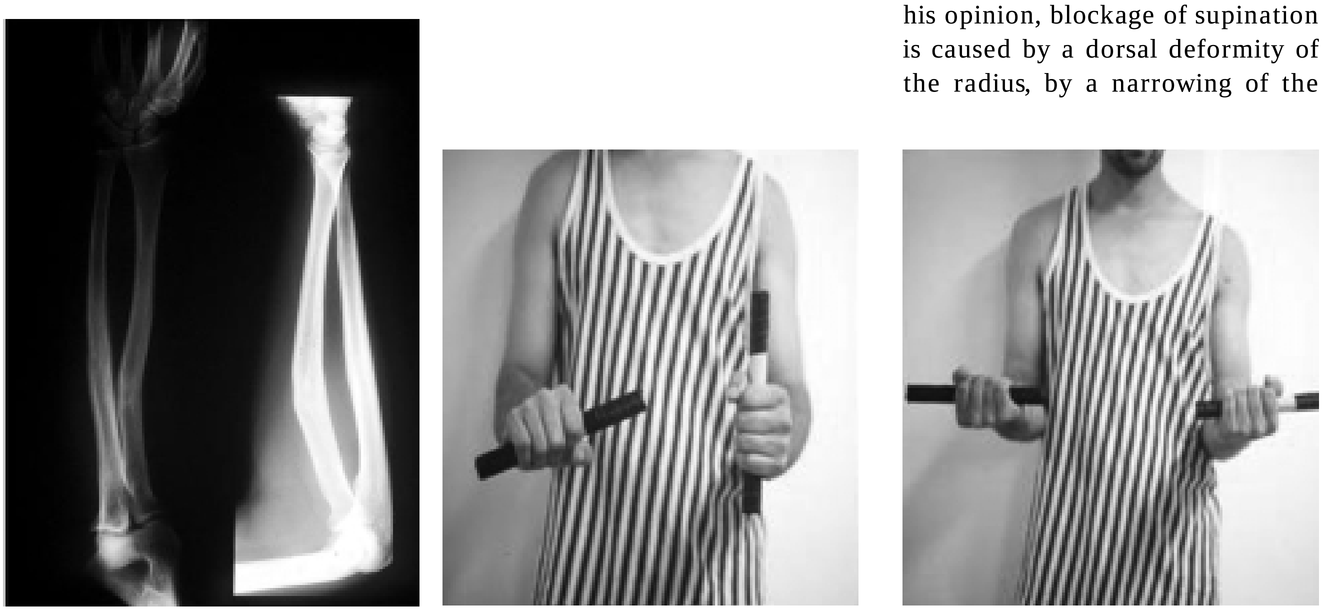

Figure 2b. Example of a 20-year-old man, who had sustained a forearm shaft fracture in childhood (11 years old at time of injury). The volar deformity of the radius results in a deficiency of forearm rotation.

Table 6a. Degree of axial deviation in the frontal plane in relation to the outcome. n: number of cases.

Bone	Outcome	0–5°	6–10°	11–15°	> 16°	Total (n)
Radius	Unsatisfactory	27 (11.1%)	25 (18.5%)	8 (20.5%)	0	60 (14.4%)
	Satisfactory	215	110	31	0	356
	Total	242	135	39	0	416 (100%)
Ulna	Unsatisfactory	35 (12.1%)	17 (18.8%)	8 (21.1%)	0	60 (14.3%)
	Satisfactory	253	73	29	4	359
	Total	288	90	37	4	419 (100%)

Table 6b. Degree of axial deviation in the sagittal plane in relation to the outcome. n: number of cases.

Bone	Outcome	0–5°	6–10°	11–15°	> 16°	Total (n)
Radius	Unsatisfactory	21 (10.2%)	23 (15.7%)	11 (21.1%)	6 (37.5%)	61 (14.6%)
	Satisfactory	183	123	41	10	357
	Total	204	146	52	16	418 (100%)
Ulna	Unsatisfactory	30 (11.7%)	23 (32.4%)	6 (15.8%)	4 (16.0%)	63 (14.6%)
	Satisfactory	226	75	32	21	354
	Total	256	98	38	25	417 (100%)

interosseous space, or by an injury of the distal radioulnar joint [6, 34].

Rang & Willis [33] suggest that a palmar angular deformity of both bones is associated with limitated supination and a dorsal deformity with limited pronation. Fuller & McCullough [12] emphasize that the radius plays a decisive role in forearm function. They indicate that a palmar and torsional deformity of the radius is more frequently associated with a poor functional outcome, especially regarding pronation. These results are confirmed by Davis & Green and by the data presented here, providing evidence that a poor outcome is significantly associated with a palmar angular deformity of the radial shaft [10, 27]. Other authors emphasize the importance of the radial bow for forearm rotation. Creasman et al [6] have shown that flattening of the radial bow can result in a limitation of up to 10°. Our study confirmed that narrowing the interosseous space could lead to functional impairment.

Many publications propose that angular deformities of the ulna do not have much effect on patients' outcome [6, 17, 34]. Gruber & von Laer [14] and Daruwalla [8], however, have been able to demonstrate that dorsal deformities of the ulna can also yield poor results.

Only a few studies address the effect of combined deformities associated with poor results. Kuderna has posited that angulation directed towards the same plane is followed by a functional deficiency [22, 23]. Contrary to Kuderna's opinion, Matthews et al [31] showed experimentally that deformities directed towards the same plane did not necessarily limit forearm rotation. They also stated that deformities in the frontal plane of both bones being angulated in one direction did not lead to any limitation [31]. Rang & Willis [33] supported these results in their textbook. Daruwalla [8] stated that a palmar or dorsal deformity of the radius in combination with a dorsal deformity of the ulna caused limitation of forearm rotation in 52.5%. This data underline the results obtained by Sarmiento et al [34].

Table 7. Cluster formation with CART® analysis (n = 225). Prognosis: 0: failure, 1: success; KAC 1: axial deformity of the radius in the frontal plane, 0: none, 1: radial, 2: ulnar; KAC 3: axial deformity of the ulna in the frontal plane; KAC 5: axial deformity of the radius in the sagittal plane, 0: none, 1: palmar, 2: dorsal; KAC 7: axial deformity of the ulna in the sagittal plane, 0: normal, 1: palmar, 2: dorsal.

Cluster	Prognosis	KAC 1	KAC 3	KAC 5	KAC 7	n	Failure
I	0	2				60	38.3%
II	0	0		1 or 2	0 or 1	37	29.7%
III	0	1		1 or 2 (7 : 1)	0	14	21.4%
IV	1	1		1 or 2 (7 : 8)	2	8	8.3%
V	0	1		1 or 2 (14 : 0)	1	15	26.7%
VI	1	0		1 or 2	2	16	6.3%
VII	1	0 or 1		0		75	12%

Our data demonstrates that patients with palmar and ulnar diaphyseal deformities of the radius significantly have a poor functional prognosis. Isolated deformities rarely occur after forearm fractures in the pediatric population. A tree analysis (CART®) forming clusters of combined mid-shaft deformities was applied in this study. Although the sensitivity and specificity were not very high, the results underline the little data available in the literature. The analysis shows that in addi-

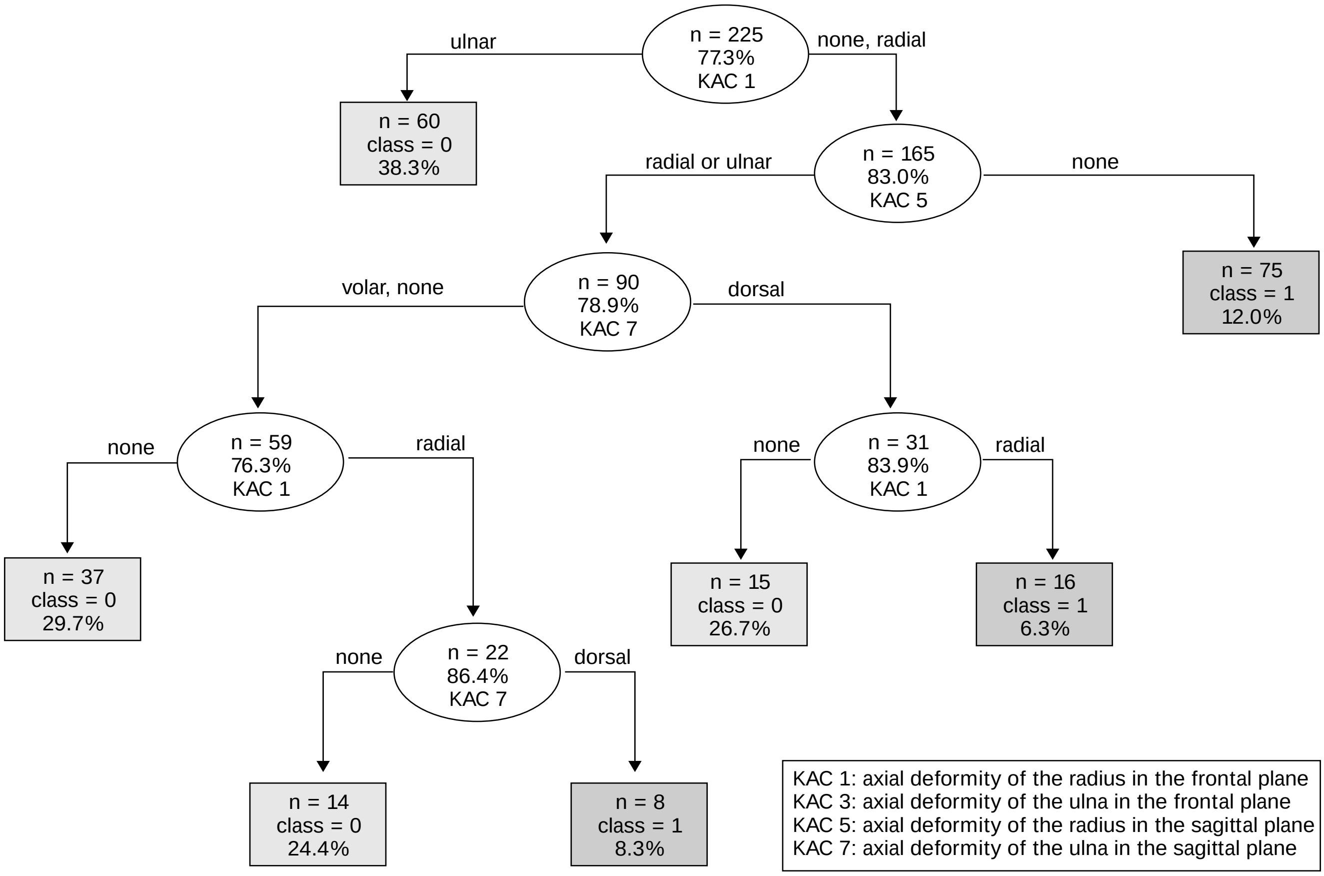

Figure 3. Combined angular deformities and prognosis according to the CART® analysis.

tion to a radial deformity, an ulnar deformity can affect the prognosis. For example, a dorsoradial or radiopalmar deformity of the radial shaft has an unfavorable prognosis when combined with a palmar deformity of the ulna. On the other hand, a radiopalmar deformity of the radial shaft in combination with a dorsal deformity of the ulna has a favorable prognosis. Our data confirms that deformities of the radial shaft can affect forearm function and shows that deformities of the ulna can strongly influence the prognosis. Even though this study has a large follow-up population, it is difficult to statistically validate the results only by clinical follow-up. Simulation, based on biomechanical and kinetic models, might show advantages for the patients. These simulations can take the patients' individual variables into consideration and can help to calculate the necessary reduction in order to avoid functional deficits.

Using adult human cadavers, Matthews et al [31] found out that deformities > 20° were unacceptable. These deformities caused a considerable impairment of 30% of forearm rotation when compared to the control group. According to Matthews et al. a 10° angulation of the ulna and radius directed to the interosseous space rarely resulted in functional deficits. Most authors report angular deformities between 10° and 20° to have relevant effects [13, 15, 22, 27, 32]. Consequently, these authors emphasize the necessity of near-anatomic reduction and retention [13, 15, 22, 27, 32].

Our data indicate that an angular deformity > 15° can cause a poor outcome, especially if combined with a further angular deformity of the other forearm bone. Combined angular deformities should be analyzed in detail and treated individually.

It is unclear whether the rate of functional impairment due to angular deformities after conservative treatment justifies the increase in operative treatment. In our opinion, it would be beneficial to identify displacements that have a poor functional prognosis. These displacements should be exactly reduced. If, after reduction, these fractures are considered stable, they should be treated conservatively, and if considered unstable, they should be stabilized operatively.

References

1. Alpar EK, Thompson K, Owen R, Taylor JF. Midshaft fractures of forearm bones in children. Injury 1981;13:153–8.
2. Bauer G, Gonschorek O. Management of unstable forearm shaft fractures in children. Unfallchirurg 1993;96:224–8.
3. Blackburn N, Ziv I, Rang M. Correction of the malunited forearm fracture. Clin Orthop 1984;188:54–7.
4. Brandesky G, Eberhard D. Analyse und Ergebnisse von 100 kindlichen Unterarmschaftbrüchen. Hefte Unfallheilkd 1989;201:400–2.
5. Briemann L, Friedman R, Olshen R, Stone C. Classification and regression trees. California: Belmont, 1984.
6. Creasman C, Zaleske DJ, Ehrlich MG. Analyzing forearm fractures in children. The more subtle signs of impending problems. Clin Orthop 1984;188:40–53.
7. Cullen MC, Roy DR, Giza E, Crawford AH. Complications of intramedullary fixation of pediatric forearm fractures. J Pediatr Orthop 1998;18:14–21.
8. Daruwalla JS. A study of radioulnar movements following fractures of the forearm in children. Clin Orthop 1979:139:114–20.
9. Daum R, Krastel A, Fey K, Feldkamp G. Long-term results of fractures of the lower arm in childhood: summary. Prog Pediatr Surg 1977;10:241–2.
10. Davis DR, Green DP. Forearm fractures in children. Pitfalls and complications. Clin Orthop 1976;120:172–84.
11. Feldkamp G, Daum R. Long term results of forearm shaft fractures in children. Hefte Unfallheilkd 1978;132:389–92.
12. Fuller DJ, McCullough CJ. Malunited fractures of the forearm in children. J Bone Joint Surg Br 1982;64:364–7.
13. Gräfe G, Tischer W, Wottek G, Eisett C. Spätergebnisse reponierter Unterarmfrakturen unter besonderer Berücksichtigung des Ausgleichs der mit Stellungsfehler verheilten Frakturen. In: Hofmann von Kap-herr S, Hrsg. Die Frakturen an Unterarm und Hand im Kindesalter, Wiesbaden: Universum, 1995:160–4.
14. Gruber R, Laer LR von. The etiology of the refracture of the forearm in childhood (author's translation). Akt Traumatol 1979;9:251–9.
15. Hahn MP, Richter D, Muhr G, Ostermann PA. Pediatric forearm fractures. Diagnosis, therapy and possible complications. Unfallchirurg 1997;100:760–9.
16. Inkelis SH, Stroberg AJ, Keller EL, Christenson PD. Roller skating injuries in children. Pediatr Emerg Care 1988;4:127–32.
17. Jackman KV. Managing forearm fractures in children. Contemp Surg 1977;11:30–6.
18. Jonasch E, Bertel E. Verletzungen bei Kindern bis zum 14. Lebensjahr. Hefte Unfallheilkd 1981;150.
19. Karlbauer A, Helmberger R, Gasperschitz F, Genelin F. Unterarmschaftbrüche bei Kindern und Jugendlichen – Behandlung und Ergebnisse. Hefte Unfallheilkd 1989;201:397–9.
20. Kramhoft M, Solgaard S. Displaced diaphyseal forearm fractures in children: classification and evaluation of the early radiographic prognosis. J Pediatr Orthop 1989;9:586–9.
21. Krösl W, Gambal J. Die Effektivität der Änderung in der Behandlungsindikation bei Unterarmbrüchen. Hefte Unfallheilkd 1989;201:57–69.
22. Kuderna H. Connection between deviated axis and impaired function after fractures of the forearm (author's translation). Unfallchirurgie 1980;6:7–13.
23. Kuderna H, Weinstabl R. Der Einfluss von Unterarmachsenknickungen auf die Umwendbewegung. Hefte Unfallheilkd 1989;201:47–58.
24. Kurz W, Vinz H, Wahl D. Errors and risks in osteosynthesis of forearm fractures in childhood. Zentralbl Chir 1986;111:659–65.
25. Laer L von. Frakturen und Luxationen im Wachstum, 3. Aufl. Stuttgart: Thieme, 1997.
26. Langenberg R. Complete forearm fractures in childhood. Beitr Orthop Traumatol 1987;34:254–8.
27. Lascombes P, Prevot J, Ligier JN, Metaizeau JP, Poncelet T. Elastic stable intramedullary nailing in forearm shaft fractures in children: 85 cases. J Pediatr Orthop 1990;10:167–71.
28. Linke F, Clausner A, Voigt A, Engel V, Düber C. Die diaphysären Vorderarmfrakturn bei Kindern – Analyse von 317 Fällen. In: Hofmann von Kap-herr S, Hrsg. Die Frakturen an Unterarm und Hand im Kindesalter. Wiesbaden: Universum, 1995:150–9.
29. Lovell ME, Galasko CS, Wright NB. Removal of orthopedic implants in children: morbidity and postoperative radiologic changes. J Pediatr Orthop B 1999;8:144–6.
30. Luhmann SJ, Gordon JE, Schoenecker PL. Intramedullary fixation of unstable both-bone forearm fractures in children. J Pediatr Orthop 1998;18:451–6.
31. Matthews LS, Kaufer H, Garver DF, Sonstegard DA. The effect on supination-pronation of angular malalignment of fractures of both bones of the forearm. J Bone Joint Surg Am 1982;64:14–7.
32. Ortega R, Loder RT, Louis DS. Open reduction and internal fixation of forearm fractures in children. J Pediatr Orthop 1996;16: 651–4.
33. Rang MC, Willis RB. Fractures and sprains. Pediatr Clin North Am 1977;24:749–73.
34. Sarmiento A, Ebramzadeh E, Brys D, Tarr R. Angular deformities and forearm function.J Orthop Res 1992;10:121–33.
35. Schmittenbecher PP, Dietz HG, Uhl S. Late results of forearm fractures in childhood. Unfallchirurg 1991;94:186–90.
36. Slongo T. Operative Therapieverfahren am Unterarm und Handskelett. In: Hofmann von Kap-herr S, Hrsg. Die Frakturen an Unterarm und Hand im Kindesalter. Wiesbaden: Universum, 1995:31–9.
37. Steinberg D, Colla P. CART – classification and regression trees. San Diego, CA: Salford Systems, 1997.
38. Van der Reis WL, Otsuka NY, Moroz P, Mah J. Intramedullary nailing versus plate fixation for unstable forearm fractures in children. J Pediatr Orthop 1998;18:9–13.
39. Würfel AM, Voigt A, Linke F, Hofmann von Kap-herr S. New aspects in the treatment of complete and isolated diaphyseal fracture of the forearm in childhood. Unfallchirurgie 1995;21:70–6.
40. Wyrsch B, Mencio GA, Green NE. Open reduction and internal fixation of pediatric forearm fractures. J Pediatr Orthop 1996;16:644--50.

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