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Age-related Outcomes and Complications of Osteodistraction in the Pediatric Upper Extremity: A Large Retrospective Single-center Study of 61 Cases

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Background: The study purpose was to assess: (1) the complication rate of osteodistraction in the pediatric upper extremity, its severity and relation to patient-specific and treatment-specific parameters, and (2) dedicated patient-reported outcome scores after these procedures.

Methods: This retrospective study analyzed a chart of patients undergoing osteodistraction of the upper limb between 2003 and 2020. Demographics, distraction-specific parameters, healing index, and any complications graded according to the Sink grading scale (grades 1 to 5) were extracted. An additional phone interview was performed to assess patient satisfaction and functionality of the elongated limb using the Quick-DASH (Disabilities of Arm, Shoulder, and Hand) score.

Results: This study included 61 cases from 48 individual patients. The mean age at the start of distraction was 11.5 ± 3.6 years. The ulna was the most frequently lengthened bone, with 21 (34.4%) cases. Ninety-four complications were observed, with an average complication rate of 77.0%. Based on the Sink grading scale (1 to 5), grade 3 complications were most common (n = 29; 47.5%) followed by grade 1 (n = 14; 23.0%), 2 (n = 14; 23.0%), and 4 (n = 4; 6.6%). A significantly lower and thus better bone healing index was observed for the age category less than 10 years compared with the 14 to 18 years group ($P = 0.006$). The average satisfaction was 4.2 ± 1.0 points of 5. The mean Quick-DASH score was 14.1 ± 12.5, indicating very good clinical outcomes.

Conclusions: Despite the occurrence of numerous complications, high patient satisfaction and good daily life functionality of the treated limb was observed. An age of more than 14 years at the beginning of therapy had a negative prognostic effect on bone healing during distraction. Thus, osteodistraction in the upper extremity may preferably be performed less than 10 years of age because of enhanced bone regeneration.

Level of Evidence: Level IV—retrospective case series.

Key Words: bone, osteodistraction, bone lengthening, limb lengthening, distraction, deformity correction, complications, hand and wrist, upper extremity

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Osteodistraction is a procedure commonly used to correct congenital or acquired length discrepancies in long bones and restore alignment and function.[1] Numerous conditions in the upper extremity, such as radial longitudinal deficiency, multiple hereditary exostosis, brachymetacarpia, or injury/infection-related length discrepancies, can be improved after gradual osteodistraction.[2–6] Common devices used to achieve the desired bone lengthening include external fixators (ie, Ilizarov apparatus, hexapods) and intramedullary motorized nails.[4,7–9]

However, despite the success and perceived patient satisfaction attributed to its clinical use, osteodistraction at specific sites in the upper extremity may have a much higher complication rate than that in the lower extremity.[2,10] Reported complications include nerve injury, delayed or absent bone consolidation, fractures, or hardware failure; however, more detailed studies on such complications and their causes are scarce.[11] It was hypothesized that the lack of load-bearing of the treated extremity might be detrimental to bone healing after lengthening. Moreover, the current literature lacks dedicated, patient-reported outcomes after such upper extremity lengthening procedures.

Therefore, the aim of this study was to assess the complication rate of osteodistraction in the pediatric upper extremity, its severity, and relation to patient-specific

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TABLE 1. Frequency of Diagnoses

Diagnoses	N [n (%)]
Radial longitudinal deficiency	22 (36.1)
Multiple hereditary exostosis	17 (27.9)
Brachymetacarpia	9 (14.8)
Injury/infection-related growth plate closure	9 (14.8)
Other	4 (6.6)
Total	61 (100)

and treatment-specific parameters. Second, we sought to determine the patient-reported outcome scores in terms of functionality and patient satisfaction.

METHODS

The institutional review board approved this study (EK 20-144-VK). In this monocentric retrospective study, data were analyzed with a single phone interview, and the clinical charts of patients who underwent osteodistraction of the upper limb between 2003 and 2020 were reviewed. Inclusion criteria for this study were age less than 19 years at the time of initial surgery and osteodistraction for correction of a congenital or acquired deformity or malformation. The exclusion criteria were age above 19 years and insufficient documentation. The following parameters were extracted: sex, age, side, distraction distance (mm), distraction period (d), total time in a frame (d), time until full load-bearing/complete consolidation of the bone showing 3 to 4 consolidated cortices (d), healing index (d/cm), elongation index (mm/d), location of distraction, type of distraction device, any planned or unplanned modification of the distraction device during the lengthening process, the initially planned lengthening distance based on preoperative x-ray images, observation period after distraction device removal, and complications. Complications were classified according to the grading scale by Sink et al.[12] In cases with >1 complication, the most severe complication was considered for classification.

To assess patient satisfaction and functionality of the elongated limb after surgery, an additional one-time phone interview was performed. Patient satisfaction was assessed using a Likert scale ranging from 1 (very dissatisfied) to 5 (very satisfied). Furthermore, patients were asked whether they would choose to undergo the lengthening procedure again (yes vs. no), considering the course and outcome. Functionality was assessed using the standardized Quick-DASH (Disabilities of Arm, Shoulder, and Hand) score.[13] This questionnaire contains 11 five-point scaled questions that are aggregated into a PR score (0 to 100; 0 to best, 100 to worst).

Statistical Analysis

Descriptive and inferential statistical evaluations were performed using IBM SPSS, version 20 (IBM Deutschland GmbH, Ehningen, Germany). Statistical

TABLE 2. Characteristics of Study-relevant Parameters Regarding Age Categories

	Age Category (y)				
Parameters	**< 10 (n = 22)**	**10-14 (n = 21)**	**14-18 (n = 18)**	**Total (N = 61)**	***P***
Female [n (%)]	12 (36.4)	11 (33.3)	10 (30.3)	33 (100)	0.979†
Male [n (%)]	10 (35.7)	10 (35.7)	8 (28.6)	28 (100)	
Age at lengthening (y)	7.4 ± 2.1	12.5 ± 0.9	15.4 ± 0.8	11.5 ± 3.6	
Distraction distance (cm)					0.310‡
M ± SD	3.8 ± 1.9	3.3 ± 2.1	2.9 ± 1.6	3.4 ± 1.9	
Median	3.5	2.2	2.5	3.0	
Range	1.0-7.5	1.1-8.0	1.0-5.6	1.0-8.0	
Distraction period (d)					0.698‡
M ± SD	75.1 ± 43.4	70.4 ± 47.5	73.4 ± 42.0	73.0 ± 43.8	
Median	62.5	50.0	69.5	59.0	
Range	17-203	17-192	10-167	10-203	
Total time in frame (d)					0.256‡
M ± SD	170.9 ± 68.7	147.1 ± 54.3	195.7 ± 98.4	170.0 ± 75.9	
Median	158.0	134.0	178.5	157.0	
Range	71-301	70-273	77-462	70-462	
Time until full load-bearing (d)					0.562‡
M ± SD	244.6 ± 129.5	258.2 ± 137.5	277.7 ± 121.7	259.1 ± 128.7	
Median	203.5	220.0	242.5	221	
Range	77-591	122-556	92-498	77-591	
Healing index (d/cm)					**0.017**‡*
M ± SD	76.1 ± 55.1	94.0 ± 46.5	120.9 ± 83.5	95.5 ± 64.0	
Median	66.6	89.0	115.5	79.0	
Range	29-269	32-203	35-392	29-392	
Elongation index (mm/d)					0.339‡
M ± SD	0.55 ± 0.22	0.51 ± 0.21	0.48 ± 0.29	0.52 ± 0.24	
Median	0.50	0.50	0.41	0.50	
Range	0.27-1.16	0.23-0.94	0.18-1.06	0.18-1.16	

Statistically significant value is in bold.
*$P \leq 0.05$.
†Pearson χ^2.
‡Kruskal-Wallis *H*.

TABLE 3. Characteristics for Healing Index Regarding the Localization, the Diagnosis, and the Distraction Device

	Localization						
Healing Index (d/cm)	**Humerus (n = 5)**	**Radius (n = 7)**	**Ulna (n = 21)**	**Radius and Ulna (n = 19)**	**Metacarpals (n = 9)**	**Total (N = 61)**	***P***
M ± SD	69.3 ± 46.5	84.0 ± 44.6	109.5 ± 89.3	76.0 ± 34.6	127.6 ± 48.4	95.5 ± 64.0	0.090†
Median	47.4	61.0	79.0	67.3	118.0	79.0	
Range	29.0-124.0	56.4-178.0	31.7-392.0	32.0-142.0	51.0-203.0	29.0-392.0	
	Diagnosis						
Healing Index (d/cm)	**Radial Longitudinal Deficiency (n = 22)**	**Multiple Hereditary Exostosis (n = 17)**	**Brachymetacarpia (n = 9)**	**Injury/Infection-Related Growth Plate Closure (n = 9)**	**Other (n = 4)**	**Total (N = 61)**	***P***
M ± SD	70.7 ± 24.6	120.7 ± 92.7	127.5 ± 48.4	69.9 ± 48.6	110.8 ± 75.9	95.5 ± 64.0	**0.015***†
Median	68.1	89.0	118.0	56.5	89.1	79.0	
Range	31.7-121.3	32.0-392.0	51.0-203.0	29.0-178.0	45.0-220.0	29.0-392.0	
	Distraction Device						
Healing Index (d/cm)	**Unilateral (n = 21)**			**Circular Frame (n = 39)**		**Total (N = 60)**	***P***
M ± SD	117.3 ± 63.5			83.3 ± 62.6		95.2 ± 64.5	**0.016***‡
Median	116.0			67.3		78.0	
Range	29.0-269.0			31.7-392.0		29.0-392.0	

Statistically significant values are in bold.
*$P \leq 0.05$.
†Kruskal-Wallis *H*.
‡Mann-Whitney *U* test.

significance was set at *P*-value ≤ 0.05. The standardized effect size *b*, according to the effect size classification published by Cohen, with values ≥ 0.10 for small weights, ≥ 0.30 for medium weights, and ≥ 0.50 for considerable weights used in model tests to assess the significance of results in terms of content.[14]

The χ^2 tests were used for the correlations of 2 nominally scaled variables due to cross-tabulations (Fisher exact test). The Kruskal-Wallis test or Mann-Whitney *U* test was used to examine the study-relevant parameters regarding differences with respect to age categories, locations, diagnoses, and distraction devices, respectively. The age categories were chosen based on the fact that some surgeons prefer to distract during childhood (less than 10 y), while others prefer adolescence (10 to 14 y) or later adolescence/early adulthood (14 to 18 y).

By means of model checking using binary logistic regression, the explanatory value of relevant parameters was examined in 3 blocks (demographic, distraction-specific, and location) for the criterion *complication*. To verify the prediction of the metric criterion healing index (d/cm), the multiple linear regression method was used. Likewise, multiple linear regression was used to test the prediction of the severity criterion according to Sink grading (1 to 5).

TABLE 4. Characteristics, Frequencies for Target Achievement, and Success Quotient Regarding the 3 Age Categories

	Age Category (y)				
Parameter	**< 10 (n = 19)**	**10-14 (n = 20)**	**14-18 (n = 18)**	**Total (N = 57)**	***P***
Target achieved [n (%)]	13 (68.4)	16 (80.0)	15 (83.3)	44 (77.2)	0.533†
Quotient (%)					
M ± SD	103 ± 21	106 ± 27	97 ± 14	102 ± 22	0.359‡
Median	100	105	100	100	
Range	57-169	44-157	50-113	44-169	

†Fisher exact test.
‡Welch-analysis of variance.

RESULTS

This study included 61 cases from 48 individual patients (treated as an independent) who underwent upper extremity osteodistraction. A summary of the diagnoses is shown in Table 1. The mean age at the start of distraction was 11.5 ± 3.6 years (range, 1.6 to 16.8 y; median = 12.3 y). Three age categories (less than 10, 10 to 14, and 14 to 18 y) were defined to assess and compare treatment outcomes. Osteodistraction was performed using an external fixator in 60 (98.4%) cases. Distraction via an intramedullary lengthening nail was performed in 1 (1.6%) case. The ulna was the most frequently lengthened bone, with 21 (34.4%) cases, followed by the radius *and* ulna in 19 (31.1%) cases, metacarpals in 9 (14.8%) cases, radius in 7 (11.5%), and humerus in 5 (8.2%) cases, respectively. No significant differences in location distribution were observed between the 3 age groups ($P = 0.662$). The average observation period after distraction device removal was 3.78 ± 3.27 years (range, 0 to 11.22 y; median = 3.03 y). There was no difference between the age groups with regard to follow-up ($P = 0.140$).

Osteodistraction Outcome

The analyses of the relevant parameters of distraction distance, distraction period, total time in frame, time until full weight-bearing (allowing routine use of the

TABLE 5. Characteristics, Frequencies for Complications, and Complication Classification Based on the System of Sink Regarding the 3 Age Categories, the Localization, the Diagnosis, and the Distraction Device

	Age Category (y)				
	< 10 (n = 22)	10-14 (n = 21)	14-18 (n = 18)	Total (N = 61)	*P*
Complication [n (%)]	16 (72.7)	18 (85.7)	13 (72.2)	47 (77.0)	0.589†
M ± SD	1.64 ± 1.56	1.86 ± 1.42	1.06 ± 0.87	1.54 ± 1.36	0.185‡
Median	1.0	2.0	1.0	1.0	
Range	0-5	0-6	0-3	0-6	
Sink (1-5)					0.508‡
M ± SD	2.45 ± 1.10	2.48 ± 0.75	2.17 ± 0.86	2.38 ± 0.92	
Median	3.0	3.0	2.0	3.0	
Range	1-4	1-3	1-3	1-4	

	Localization						
	Humerus (n = 5)	Radius (n = 7)	Ulna (n = 21)	Radius and Ulna (n = 19)	Metacarpals (n = 9)	Total (N = 61)	*P*
Complication [n (%)]	2 (40.0)	7 (100)	16 (76.2)	14 (73.7)	8 (88.9)	47 (77.0)	0.176†
M ± SD	0.40 ± 0.55	1.57 ± 1.13	1.71 ± 1.38	1.42 ± 1.31	2.0 ± 1.73	1.54 ± 1.36	0.187‡
Median	0	1.0	2.0	1.0	2.0	1.0	
Range	0-1	1-4	0-5	0-5	0-6	0-6	
Sink (1-5)							0.126‡
M ± SD	1.40 ± 0.55	2.57 ± 0.54	2.57 ± 1.08	2.32 ± 0.89	2.44 ± 0.73	2.38 ± 0.92	
Median	1.0	3.0	3.0	3.0	3.0	3.0	
Range	1-2	2-3	1-4	1-3	1-3	1-4	

	Diagnosis						
	Radial Longitudinal Deficiency (n = 22)	Multiple Hereditary Exostosis (n = 17)	Brachymetacarpia (n = 9)	Injury/infection-related Growth Plate Closure (n = 9)	Other (n = 4)	Total (N = 61)	*P*
Complication [n (%)]	20 (90.9)	12 (70.6)	8 (88.9)	5 (55.6)	2 (50.0)	47 (77.0)	0.078†
M ± SD	1.91 ± 1.23	1.29 ± 1.31	1.89 ± 1.76	1.0 ± 1.32	1.0 ± 1.16	1.54 ± 1.36	0.175‡
Median	2.0	1.0	1.0	1.0	1.0	1.0	
Range	0-5	0-5	0-6	0-4	0-2	0-6	
Sink (1-5)							0.113‡
M ± SD	2.73 ± 0.83	2.29 ± 0.99	2.44 ± 0.73	1.89 ± 0.93	1.75 ± 0.96	2.38 ± 0.92	
Median	3.0	3.0	3.0	2.0	1.5	3.0	
Range	1-4	1-4	1-3	1-3	1-3	1-4	

	Distraction Device			
	Unilateral (n = 21)	Circular Frame (n = 39)	Total (N = 60)	*P*
Complication [n (%)]	16 (76.2)	31 (79.5)	47 (78.3)	0.755†
M ± SD	1.62 ± 1.66	1.54 ± 1.19	1.57 ± 1.36	0.705§
Median	1.0	1.0	1.0	
Range	0-6	0-5	0-6	
Sink (1-5)				0.452§
M ± SD	2.29 ± 0.90	2.46 ± 0.91	2.40 ± 0.91	
Median	2.0	3.0	3.0	
Range	1-4	1-4	1-4	

†Fisher exact test.
‡Kruskal-Wallis *H*.
§Mann-Whitney *U* test.

hand/arm for daily life activities), and elongation index revealed no significant differences between the age groups ($P \geq 0.256$; Table 2). However, a comparison of the healing index yielded a statistically significant result ($P = 0.017$). Post hoc pairwise comparisons showed a significantly lower healing index, and thus, better bone healing only for the age category less than 10 years compared with the 14 to 18 years group ($P = 0.006$; considering the Bonferroni correction, $\alpha^* = 0.0167$). Online Appendix Figure 1 (Supplemental Digital Content 1, http://links.lww.com/BPO/A432) illustrates the relationship between age at lengthening and the healing index considering the 3 age categories.

For the healing index with respect to location, no significance ($P = 0.090$) was detected, as shown in Table 3. Furthermore, there was no significance ($P = 0.083$) regarding the healing index for the metacarpals when compared with the humerus.

In addition, the healing index was examined with respect to the diagnoses and the distraction devices. There

TABLE 6. Characteristics [Quick-DASH (Disabilities of Arm, Shoulder and Hand), 0 to 100] of the Assessment of Functionality Considering the Age Categories

	Age Category (y)				
	0-10 (n = 11)	10-14 (n = 8)	14-18 (n = 6)	Total (N = 25)	*P*
M ± SD	19.2 ± 15.4	9.1 ± 5.7	11.4 ± 11.1	14.1 ± 12.5	0.299†
Median	13.6	8.0	8.0	11.4	
Range	0-45.5	2.3-18.2	0-27.3	0-45.5	

†Kruskal-Wallis *H.*

was a significant difference in the healing index regarding the diagnoses ($P = 0.015$). Post hoc pairwise comparisons showed a significantly lower healing index only for the radial longitudinal deficiency compared with the brachymetacarpia group ($P = 0.001$; considering the Bonferroni correction, $\alpha^* = 0.005$). Regarding the distraction devices, a significant difference in the healing index ($P = 0.016$) in favor of the circular frames was found.

The relative success of the therapy approach was based on whether the target length (based on preoperative x-ray images) was achieved (yes/no) and the corresponding success rate in percentage (achieved value of the distraction in mm/target value of distraction in mm×100). Overall, the desired target length was achieved in 77.2% (95% confidence interval: 66.3%; 88.1%) of cases, with an average success rate of 102% (Table 4).

Complications

A total of 94 complications were observed, with a complication rate of 77.0% (95% confidence interval: 66.5%; 87.6%), and an average of 1.54 complications per examined case (range, 0 to 6) (Table 5). Based on the Sink grading scale (1 to 5) for the most severe complication per case, grade 3 complications were most common (n = 29; 47.5%) followed by grade 1 (n = 14; 23.0%), 2 (n = 14; 23.0%) and 4 (n = 4; 6.6%). No grade 5 complications occurred. There were no significant differences in complication rate and severity with respect to age categories, locations, diagnoses, and distraction devices ($P > 0.05$). In 26 (42.6%) cases, modification of the distraction device was necessary during distraction. Superficial pin-track infection was the most common complication, with 29 (30.9%) cases, followed by nonunion in 14 (14.9%) cases, delayed bone union in 9 (9.6%) cases, regenerate fracture in 9 (9.6%) cases, hardware failure in 9 (9.6%) cases, axial deviation in 6 (6.4%) cases, premature consolidation in 4 (4.3%) cases, deep infection in 3 (3.2%) cases, joint subluxation in 3 (3.2%) cases, and other complications in 8 (8.5%) cases.

It was shown that for osteodistraction of the metacarpals compared with the humerus, a relative risk of at least 1.177 ($P = 0.041$) can be assumed. The other predictors did not show significant findings based on our data (Online Table 1, Supplemental Digital Content 2, http://links.lww.com/BPO/A433).

For the healing index criterion (d/cm), the age group of 14 to 18 years was the only predictor with a significant,

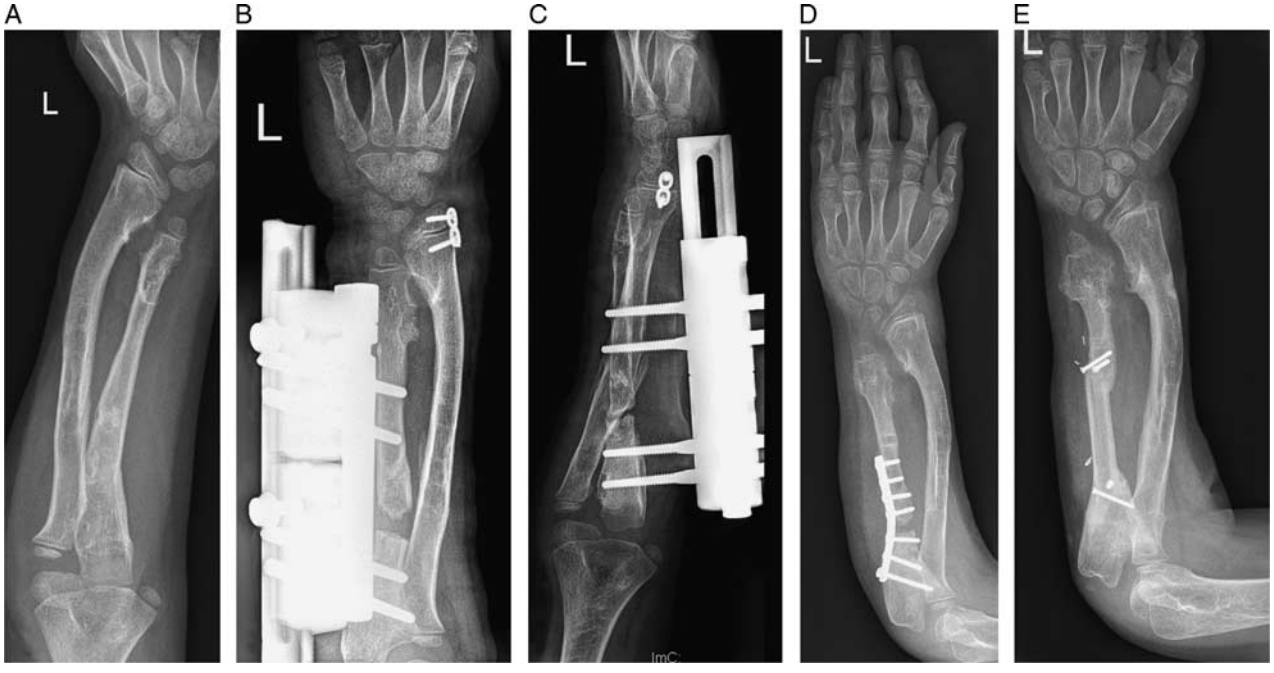

FIGURE 1. A complicated case of a 7.5-year-old boy with multiple hereditary exostosis disease is presented. Due to ulnar shortening and forearm bowing (A), an external monofixator was applied for gradual ulna distraction (B). Despite a relatively slow lengthening speed of 0.5 mm/d, a poor regenerate formed, and nonunion eventually occurred (C). First, an attempt was made to enhance union by using an autologous iliac crest bone graft and plating (D). However, due to unknown reasons, the graft was resolved. Finally, bone consolidation was achieved by the use of a free vascularized fibula graft (E).

moderate explanatory value ($\beta = 0.319$, $P = 0.033$). The other predictors did not show any significant abnormalities in the healing index (Online Table 2, Supplemental Digital Content 3, http://links.lww.com/BPO/A434).

For the criterion severity of the complication (Sink grading), the humerus was the only predictor with a significant, moderate explanatory value ($\beta = -0.348$, $P = 0.022$) as a protective factor compared with the other locations. The other predictors showed no significant influence on the severity of the complications (Online Table 3, Supplemental Digital Content 4, http://links.lww.com/BPO/A435).

Functional Outcome and Satisfaction

Twenty-five (52.1%) of the 48 patients participated in the phone interview. The survey time point was between 1 and 16 (median = 9.4) years after completion of bone lengthening. The average satisfaction score was 4.2 ± 1.0 of 5. Among the 25 respondents, 12 (48%) were *very satisfied*, 8 (32%) were *satisfied*, 4 (16%) were *neither satisfied nor dissatisfied*, and 1 (4%) patient was *very dissatisfied*. Of those studied, 24 (96%) indicated that they would undergo the procedure again. The assessment of functionality using Quick-DASH is shown in Table 6. The average Quick-DASH score was 14.1 ± 12.5 (median = 11.4). Examination of the difference in functional impairment with respect to the 3 age categories were comparable based on the nonsignificant result ($P = 0.299$).

DISCUSSION

The procedure of osteodistraction in the upper extremity is a highly complex procedure, which is associated with a variety of complications.[2,15,16] There are reports ranging from mild complications such as superficial wound infections to more serious complications including fractures requiring further surgical intervention.[17] There are reports of complication rates of up to 100%.[2] This study interestingly revealed that, despite a high complication rate of 77%, patient satisfaction was still remarkably high, with a score of 4.2 of 5. Furthermore, the patient-rated evaluation of the functionality of the lengthened limb using the Quick-DASH was also satisfactory, with an average score of 14.1. These results underline the importance of this treatment modality in achieving enhanced limb function in this pediatric cohort.

The limitations of this study are its retrospective nature and its long recruitment period of cases including its evolution of devices and techniques. Furthermore, there was a wide variation in the time interval between the end of treatment and the completion of the survey. Several patients could not be contacted and interviewed by phone since they had completed therapy a long time ago and could not be traced. An attempt was made to examine the complications that occurred as precisely as possible and to determine whether they were related to the therapy procedure. However, in some cases, it is possible that a complication is not directly caused by the osteodistraction procedure. Moreover, this study lacks preoperative outcome scores.

In the present study, the average lengthening distance (3.4 cm) was rather low compared with that in other studies. This is attributed to the fact that osteodistractions at different locations, mainly other than the humerus, were investigated. Ruette and Lammens[18] described an average lengthening distance of 8.8 cm in their study, Kiss et al[10] outlined an average rate of lengthening of 6.2 cm, Pawar et al[19] found an average lengthening distance of 7.0 cm, and Malot et al[15] identified a distraction length of 8.8 cm. However, all these studies describe bone lengthening exclusively at the humeral region. A study from 2011 by Hill et al[16] showed an average distraction distance in the forearm of 3.2 cm. Litzelmann et al[11] described an average lengthening of 2.4 cm. Of note, even smaller distraction distances have been described in the hand. Erdem et al[20] described an average lengthening of 1.7 cm and Kato et al[21] of 1.5 cm. In the present study, the humerus was the least frequently observed location, with 5 procedures, whereas distractions in the forearm were the most common, with a total of 28 cases. This had significant implications for the average lengthening distance observed.

Nevertheless, the healing index of 95.5 in our population was higher than that in the literature. In the case of lengthening at the humerus, the healing index in previous studies ranged from 27.1 to 34.5.[3,22] In the humerus cases of the present study, the healing index was approximately twice as high, at 69.3. For the forearm, studies showed a healing index ranging from 27.6 to 64.4.[16,23] For the hand, the healing index was 32.0 to 62.3.[21,24] In the present study, an average value of 127.6 was observed. One possible explanation for these findings may be the high elongation rates of up to 1 mm/d during the introduction of this modality at our department, which have proven unsuitable for most upper extremity localizations (except for the humerus) due to delayed bone healing. Since several years, moderate distraction rates of 0.25 to 0.5 mm/d were followed depending on the bone to be lengthened. Furthermore, the addition of an intramedullary guiding Kirschner-wire might enhance bone regeneration. However, there is hardly any literature on the possible predictors or prognostic factors for the healing index. In this study, it was discovered that the choice of distraction device influenced the healing index. Distraction performed with a circular fixator showed a better healing index compared with a treatment with a unilateral fixator. In addition, in our observation, the diagnosis had a certain influence on the healing index as well since the group of brachymetacarpia showed a worse healing index. In the current study, an age range of 14 to 18 years at the start of distraction was a risk factor for a higher, and thus, worse healing index, likely followed by a longer duration of recovery. In light of these findings, upper extremity lengthening should be performed until the age of 10 years to facilitate the bone consolidation process. This is supported by the fact that complications, in general, were less in the less than 10-year group than in the 10- to 14-year group (86%) and then decreased to almost 73% in the 14- to 18-year group. Despite these findings, functionality was still slightly better in the older age groups. This also underlines the lack of a predictable relationship between complications and eventual functional outcomes.

The overall complication rate of 77% was consistent with the expectations and previous descriptions.[25,26] Superficial pin-track infections were observed most frequently, accounting for 30.9% of all complications. Other studies have

also described this complication, with a prevalence of up to 100%.[2,27] Deep infections, however, accounted for only 3.2% of all complications in the present study. The literature describes a prevalence of up to 11%.[28,29] The second most frequent complication was delayed bone union and nonunion, accounting for 24.5% of all complications (Fig. 1). This is also in line with our expectations, as complication rates of 0% to 43% have been described in the literature.[2] Overall, fractures accounted for 9.6% of all complications. Compared with the current studies, this is a rather low percentage, as fracture rates of up to 50% have been described.[17]

Despite the high complication rate and severity of some complications, high patient satisfaction in terms of the treatment outcome was observed. A Quick-DASH score of 14.1 was noted, which indicates considerably low functional impairment. In 2009, Page and Szabo[30] described a comparable DASH score of 11 for bone lengthening in the forearm. Further, 96% of the patients surveyed reported that they would undergo the entire treatment procedure again, despite several reoperations being required in some cases. This finding is in line with current studies, which also described high patient satisfaction.[31] In addition to the functional improvement, the psychological and cosmetic effect, which was already described in a study by Villa et al,[32] is likely to play a role in this regard.

In summary, osteodistraction of the pediatric upper extremity is a complex procedure with a high complication rate and partially relevant severity of complications. Despite the numerous complications, high patient satisfaction with good functionality of the treated limb in daily life was observed. Based on the current results, bone lengthening up to 10 years of age might be preferred.

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