

Results after treatment of congenital radioulnar synostosis: a systematic review and pooled data analysis

Sitanshu Barik^a, Sebastian Farr^b, Giovanni Gallone^c,
Paola Zarantonello^c, Giovanni Trisolino^c and Giovanni L. Di Gennaro^c

Congenital radioulnar synostosis (CRUS) is one of the most common congenital disorders affecting the elbow and forearm, with the forearm being fixed in a range of positions usually varying from neutral rotation to severe pronation. The aim of this study, apart from a systematic review of all surgical procedures described for CRUS, is to derive any correlation between various influencing factors, outcomes and complications. This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses format by an electronic literature search of *Ovid*, *MEDLINE* and the *Cochrane Library* databases. Grading was according to the Newcastle-Ottawa scale and the Modified Coleman Methodology Score. Demographic data, surgical procedures, outcomes and complications were analyzed. Outcome data were pooled to establish means and ranges across all studies. Spearman correlations were performed. A total of 23 articles, showing a poor overall study quality (all Level of Evidence IV), met the inclusion criteria. A total of 374 forearms with a mean age of 6.7 years (2.0–18.8) were analyzed. Derotational surgeries were more commonly performed (91%) than motion-preserving surgeries (9%). The mean deformity improved from 64.8° pronation (–75° to 110°) to a mean of 2.8° pronation (–50° to 80°). In total, 17.9% of patients presented with complications. A significant correlation was noted between age and major

complications, proximal osteotomies and complications, and postoperative loss of reduction and double level osteotomies as the primary treatment modality. Most of the complications occurred above the threshold of 65–70° of correction and in children 7 years and above. Surgery is essential to improve the quality of life of children with CRUS. However, each type of surgery is associated with complications, along with the respective hardware being used in rotation osteotomies. Caution is, nevertheless, warranted in interpreting these results in view of the inherent limitations of the included studies. *J Pediatr Orthop B* 30: 593–600 Copyright © 2020 The Author(s). Published by Wolters Kluwer Health, Inc.

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^aDepartment of Orthopedics, All India Institute of Medical Sciences, Rishikesh, Uttarakhand, India, ^bDepartment of Pediatric Orthopaedics and Adult Foot and Ankle Surgery, Orthopedic Hospital Speising, Vienna, Austria and ^cDepartment of Pediatrics Orthopedics and Traumatology, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

Correspondence to Sebastian Farr, MD, Department of Pediatric Orthopaedics and Foot and Ankle Surgery, Orthopedic Hospital Vienna-Speising, Speisingerstrasse 109, 1130 Vienna, Austria
Tel: +43 1 80182 1610; fax: +43 1 80182 1644; e-mail: sebastian.farr@oss.at

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Introduction

Congenital radioulnar synostosis (CRUS) is one of the most common congenital disorders affecting the elbow and forearm, with the forearm being fixed in a range of positions usually varying from neutral rotation to severe pronation. The deformity shows a bilateral affection in 60% of cases [1]. The deformity was originally described by Sandifort in 1793 [2]. CRUS can be associated with syndromes, chromosomal disorders and other abnormalities of the upper limb [3]. Shoulder and wrist joints usually compensate for any functional deficit in cases of mild deformities, whereas activities of daily living can be severely diminished in fixed pronation deformities

of a higher grade or whenever bilateral involvement is present. The deformity is classified on the basis of the presence of an osseous synostosis and the location of the radial head into four categories [4].

The deformity can be managed by either [1] no surgery in cases where the forearm is fixed in a useful, functional position, [2] mobilization surgery, which excises the bar and the created space is filled by a tissue such as fat or fascia, and [3] corrective (rotation) osteotomy, which places the forearm in a more functional position. The latter is currently the most preferred according to the literature [5]. In such cases undergoing osteotomy, there is improvement in functional activities aided by the compensatory action of the shoulder and wrist joints. In contrast, the motion of the forearm after undergoing mobilization surgery is usually around 82 degrees, ranging from 45 to 110 degrees [6].

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Kanaya *et al.* devised an innovative procedure combining both modalities, with a free vascularized graft placed between the bones after synostosis excision followed by a proximal osteotomy through the synostosis; however, the results of this procedure were rather mediocre and have not been replicated by other studies. Jones *et al.*, however, performing a similar procedure in a case with a posttraumatic synostosis, observed a good result with full forearm motion 3 years postoperatively [7]. In general, osteotomies can be performed proximally at the level of the synostosis, distally in the radius, or as a double-level osteotomy. According to the literature, bone fixation is most often performed using K-wires or plates [1,8,9]. Several complications such as loss of correction, nerve palsies and compartment syndrome have been reported [10]. The aim of this study, apart from a systematic review of all various surgical procedures described for CRUS so far, is to derive any correlation between various influencing factors, outcomes and complications.

Materials and methods

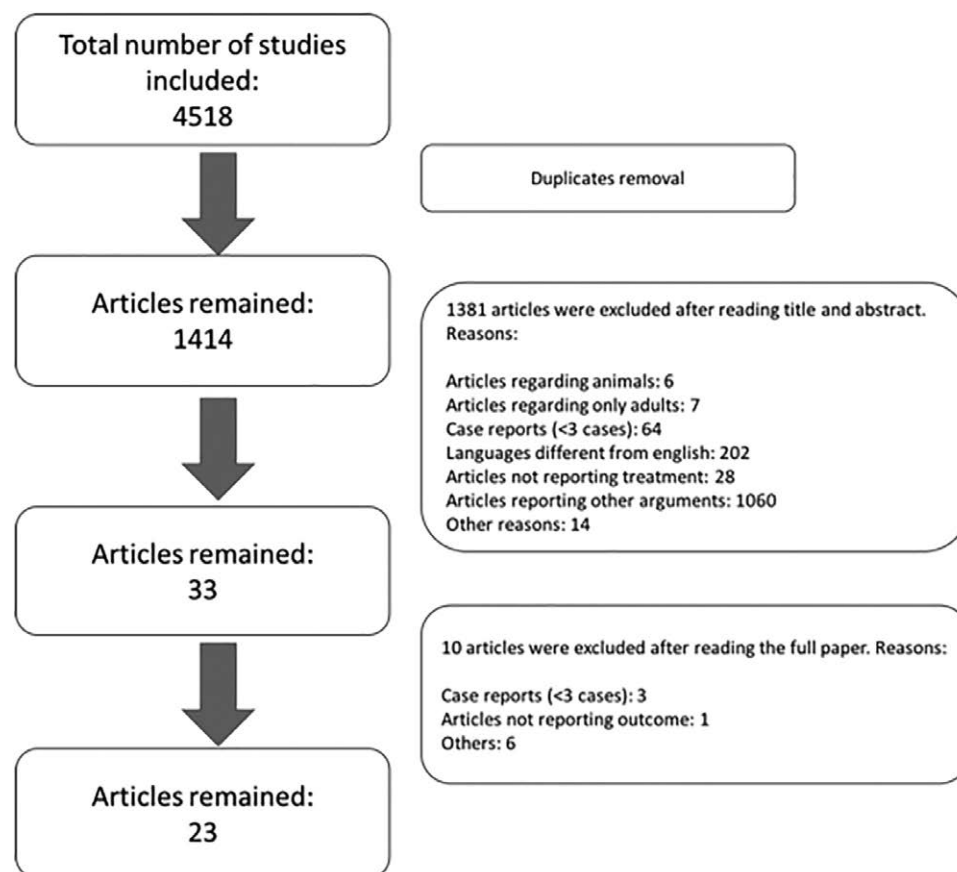
This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and

Meta-Analyses format (Fig. 1). An electronic literature research of *Ovid*, *MEDLINE* and the *Cochrane Library* databases was conducted in April 2020 by two observers (G.G. and P.Z.) using the terms “synostosis”, “radioulnar”, “elbow”, “forearm” and “synonymous”. The research was then replicated using the appropriate MeSH terms. We aimed to keep our search strategy fairly general in order to increase our search results. Furthermore, our search was not limited by year of publication, certain journals, or level of evidence. All bibliographies were checked for further relevant studies.

Eligibility criteria

The inclusion criteria for the final selection were original articles that addressed surgical management (1) of CRUS, (2) performed in children (<18 years of age at the time of surgery), (3) involving three or more cases, (4) reporting a surgical outcome or functional result and (5) written in English. Initially, the two authors reviewed all abstracts for potential relevance according to the above criteria. If a study met all criteria or the abstract did not provide enough information to include or exclude the report, full texts were obtained, reviewed by the two observers and

Fig. 1



The flowchart highlights the study acquisition details.

considered for data extraction. Whenever an agreement about study inclusion could not be resolved by consensus between the two reviewers, a third senior author (G.L.D.G.) decided about the inclusion.

Data extraction and analysis

We extracted the following data: demographics (patient age at surgery, sex, dominant side and side of synostosis), affected forearm position before and after treatment, Cleary-Omer classification [4] or other if present, factors related to the surgical treatment (kind of treatment, kind of hardware, length of immobilization and consolidation, and length of follow-up), complications and outcomes. We classified complications as ‘major’ or ‘minor’ defined as compartment syndrome, permanent nerve palsy, loss of correction $\geq 30^\circ$, deep infection and others, for major, and transient nerve palsy, loss of correction (5–30°), superficial or pin infection, unsightly scarring and others for minor. According to the Clavien–Dindo classification, complications were diversified on the basis of the necessity of additional medical and/or surgical treatment [11]. Regarding outcomes, we differentiated subjective or objective evaluation, specifying the kind of score, if present, that was used. Additionally, we collected the elbow’s range of motion, wherever present, and the suggested position of the affected forearm based on the authors’ opinion. All studies were graded according to the Oxford Center for Evidence-Based Medicine (CEBM), the Newcastle-Ottawa Scale and the Modified Coleman Methodology Score [12,13]. The extraction form used was an Excel spreadsheet (Microsoft, Redmond, Washington, USA).

Statistical analysis

Descriptive analysis using means, SD and ranges (minimum and maximum) of the pooled data across the included studies were performed. Spearman correlations were used to correlate demographic details (e.g. age) with outcomes of interest (e.g. complications). A *P* value of less than 0.05 was considered significant. Calculations were performed using Microsoft SPSS 23.0 (Redmond).

Results

The research identified 1414 potentially eligible studies, and a total of 23 studies were eventually included in the analysis (Fig. 1). All studies were case series, which were considered CEBM level IV. The Cleary-Omer classification was used by all the studies, except nine: seven of them did not report any classification [10,14–19], and two others analyzed data according to Tachdjian’s criteria [20,21].

The interventions were well described in all but one [22]. We distinguished the type of treatment into two groups: those that sought forearm mobility and those that changed the forearm position [9,23,24]. Some articles did not report the length of immobilization and consolidation or only the second one [8–10,14,15,17,19,21–24].

Miura *et al.* did not report the preoperative fixed position of the affected forearm and the length of follow-up [17]. The majority indicated subjective outcomes, whereas only three reports used objective scores [5,18,25].

The mean Newcastle-Ottawa and modified Coleman scores of 3.3 and 32.4, respectively, indicated inherent systematic deficiencies of the studies due to the poor overall study quality (Table 1). The mean follow-up in these studies was 68.6 months (5–306 months).

Demographic data

A total of 374 forearms were extracted for this review, with a mean age of 6.7 years (range, 2–18.8 years), male preponderance (167/256; 65.2%) and right hand dominance (63/75; 84%) (Table 2). Dominant extremities operated varied from 25 to 85% in various studies, with the left forearm being operated commonly (120/224; 53.5%) [1,8,16,24,26–29]. Grade III synostoses (Cleary-Omer classification) formed the majority of cases (152/257; 59.1%) followed by grade II (67/257, 26%).

Surgery

Commonly used surgeries were those that changed forearm position (364/400; 91%) and those that preserved motion (36/400; 9%) (Table 3). Proximal osteotomy (158/364; 43.4%), double level osteotomy (131/364; 35.9%) and distal osteotomy (75/364; 20.6%) were the surgeries performed to change the forearm position. Among the motion-preserving surgeries, bar resection (21/36; 58.3%) and soft tissue interposition (15/36; 41.7%) were performed. These motion-preserving surgeries were combined with osteotomy in 11 cases (11/58; 18.9%).

Table 1 Grading of the studies included [Newcastle Ottawa Scale (0–9); Modified Coleman Methodology Score (0–100)]

	Level of evidence	Newcastle Ottawa Scale	Modified Coleman Methodology Score
Bishay (2016) [1]	IV	5	34
Castello <i>et al.</i> (1996) [8]	IV	3	35
Dal Monte <i>et al.</i> (1987) [22]	IV	2	22
El-adl (2007) [26]	IV	1.6	30
Fujimoto <i>et al.</i> (2005) [2]	IV	1.2	29
Green and Mital (1979) [14]	IV	2.8	26
Horii <i>et al.</i> (2014) [15]	IV	4	36
Hung (2008) [20]	IV	3	44
Hwang <i>et al.</i> (2015) [25]	IV	3	38
Kanaya <i>et al.</i> (1998) [9]	IV	2	32
Kanaya <i>et al.</i> (2016) [23]	IV	3	48
Khalil Vizkelety (1993) [21]	IV	2.3	17
Lin <i>et al.</i> (1995) [16]	IV	5	35
Miura <i>et al.</i> (1984) [17]	IV	1	10
Murase <i>et al.</i> (2003) [27]	IV	3	27
Ogino <i>et al.</i> (1987) [10]	IV	5	29
Pei <i>et al.</i> (2019) [5]	IV	5	59
Ramachandran <i>et al.</i> (2005) [28]	IV	3	29
Rubin <i>et al.</i> (2013) [29]	IV	3	35
Sakamoto <i>et al.</i> (2014) [24]	IV	5	22
Satake <i>et al.</i> (2018) [18]	IV	3	48
Simcock <i>et al.</i> (2015) [30]	IV	5	32
Simmons <i>et al.</i> (1983) [19]	IV	5	29

Table 2 Demographic details of the studies included

	No of cases	Age (years)	Sex	Dominant side	Affected side	Clary-Omer classification (I, II, III, IV)	Follow-up (months)
Bishay (2016) [1]	14	5 ± 1 (5–6)	10 male, 4 female	14 right	12 right, 2 left	0, 4, 10, 0	31 ± 4 (24–36)
Castello <i>et al.</i> (1996) [8]	4	7	Not available	4 right	1 right, 3 left	0, 1, 3, 0	96
Dal Monte <i>et al.</i> (1987) [22]	26	10	6 male, 16 female	Not available	4 right, 14 left, 4 bilateral	1, 24, 1, 0	5–40
Ei-adi <i>et al.</i> (2007) [26]	11	6 ± 2 (4–8)	8 male, 3 female	11 right	8 right, 3 left	0, 2, 9, 0	27 ± 9 (13–38)
Fujimoto <i>et al.</i> (2005) [2]	5	5 ± 0.4 (4.5)	3 male, 2 female	2 right, 2 left	Not available	0, 0, 5, 0	21 ± 10 (12–36)
Green and Mital (1979) [14]	13	8 ± 5 (4–18)	7 male, 6 female	Not available	2 right, 11 left	Not available	190 ± 52 (120–306)
Horii <i>et al.</i> (2014) [15]	35	5	Not available	Not available	Not available	Not available	60
Hung (2008) [20]	52	6	22 male, 12 female	Not available	9 right, 7 left, 18 bilateral	0, 6, 28, 18	64
Hwang <i>et al.</i> (2015) [25]	28	7	21 male, 7 female	Not available	25 dominant, 3 nondominant	3, 5, 20, 0	33 ± 4 (27–36)
Kanaya <i>et al.</i> (1998) [9]	7	8 ± 2 (6–12)	Not available	2 right, 1 left, 4 – NOD	3 right, 4 left	0, 0, 5, 2	44 ± 8 (28–53)
Kanaya <i>et al.</i> (2016) [23]	6	8 ± 3 (5–12)	4 male, 2 female	Not available	2 right, 4 left	1, 1, 1, 3	118 ± 18 (96–144)
Khalil and Vizeley (1993) [21]	10	8 ± 3 (4–13)	9 male, 1 female	Not available	6 right, 4 left	0, 10, 0, 0	8–84
Lin <i>et al.</i> (1995) [16]	12	6 ± 4 (2–14)	Not available	4 right, 4 left, 2 – NOD	5 right, 7 left	Not available	95 ± 62 (20–174)
Miura <i>et al.</i> (1984) [17]	8	Not available	Not available	Not available	Not available	Not available	Not available
Murase <i>et al.</i> (2003) [27]	4	4 ± 1 (2–5)	1 male, 3 female	4 right	1 right, 3 left	0, 0, 4, 0	46 ± 26 (14–73)
Ogino <i>et al.</i> (1987) [10]	13	7 ± 3 (4–13)	11 male, 2 female	Not available	3 right, 10 left	Not available	24
Pei <i>et al.</i> (2019) [5]	36	5	20 male, 11 female	Not available	11 right, 25 left	0, 9, 23, 4	55
Ramachandran <i>et al.</i> (2005) [28]	6	5 ± 2 (4–8)	4 male, 2 female	5 right	2 right, 4 left	0, 1, 5, 0	29
Rubin <i>et al.</i> (2013) [29]	4	11 ± 1 (9–13)	2 male, 2 female	3 right, 1 left	2 right, 2 left	0, 0, 4, 0	100 ± 15 (85–120)
Sakamoto <i>et al.</i> (2014) [24]	15	6 ± 4 (3–17)	14 male, 1 female	14 right	6 right, 9 left	0, 2, 7, 6	64 ± 38 (13–132)
Satake <i>et al.</i> (2018) [18]	12	6 ± 2 (5–10)	8 male, 4 female	Not available	3 right, 9 left	Not available	152 ± 56 (55–230)
Simcook <i>et al.</i> (2015) [30]	31	7 (3–19)	15 male, 11 female	Not available	Not available	0, 2, 27, 0, 2NOD	46
Simmons <i>et al.</i> (1983) [19]	22	8	Not available	Not available	Not available	Not available	150

NOD, not determined.

Intramedullary implants (94/362; 25.9%) and Kirschner wire (84/362; 23.2%) were commonly used to fix the osteotomy. Osteotomy was immobilized without the use of any implants in 29% (105/362) of the cases. Moreover, plates (62/362; 17.1%) and external fixators (4/362, 1.1%) were rarely used for fixation.

Deformity

The mean preoperative deformity of the forearm was 64.8° (range, 75° supination to 110° pronation) in pronation, which changed to a mean of 2.8° (50° supination – 80° pronation) of pronation postoperatively (Table 3). The suggestion for the best forearm position according to hand dominance has been discussed in various studies. A position of pronation (0–30 degrees) and supination (0–35 degrees) has been indicated as the best positions for dominant extremity and nondominant side [1,2,8,14,15,19,21,22,25,26], respectively.

Immobilization and consolidation times

The forearms were immobilized for a mean of 6.7 weeks (range, 4–8.5 weeks) and consolidation was noted at a mean of 6.1 weeks (range, 5.9–11.3 weeks) in the studies reviewed (Table 3). The forearms that did not use any implant for stability were immobilized for a period of 8.1 weeks as compared to 4–6 weeks for forearms where any implant was used. The consolidation times across various implant groups did not vary and ranged from 6.9 to 8 weeks.

Range of motion

The postoperative range of pronation and supination in motion-preserving techniques has eventually been assessed in three studies [9,23,24]. The mean fixed deformity noted in supination and pronation was 16.1° (25° to neutral) and 40° (neutral to 80°), respectively. In the study by Sakamoto *et al.*, the mean arch of pronation and supination was 53.3°.

Outcome scores

Outcomes were assessed objectively in three of the studies reviewed [5,18,25]. The scores used in these studies were the Liverpool Elbow Score, Failla classification system and quick disabilities of the arm, shoulder, and hand score (QDASH) [5,18,25]. These studies noted a significant improvement in the objective scores assessed.

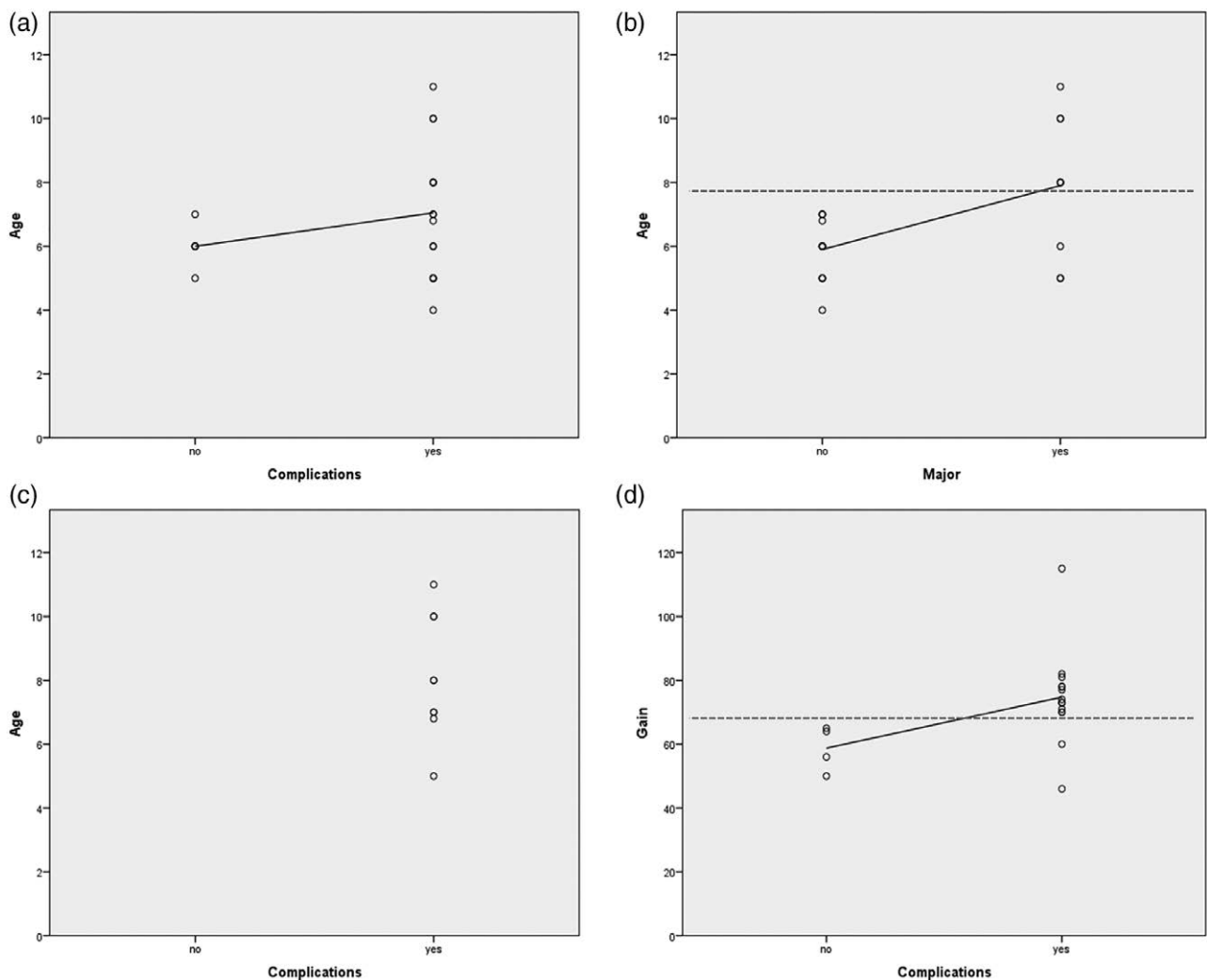
Complications

Complications were noted in 17.9% (67/374) of the cases reviewed (Table 3). Loss of correction and neurovascular complications in the form of transient and permanent palsies were the most common complications across the studies [5,10,16,17,19,22,23,27,29,30]. The only articles that reported loss of correction in the weeks after surgery (during cast immobilization) were Murase *et al.* (one forearm), Hung *et al.* (five forearms) and Simmons *et al.* (three forearms). Hwang *et al.* reported a nonsignificant

Table 3 Operative details and complications noted in the studies included

	Preoperative fixed angle (degrees)	Postoperative fixed angle (degrees)	Operative procedure	Implants used	Immobilisation time (weeks)	Consolidation time (weeks)	Complications	Clavien Dindo classification
Bishay 2016 [1]	67 ± 19P (6P–85P)	16 ± 16P (20S–30P)	Double level osteotomy	Intra medullary nail	7	7	No	0
Castello <i>et al.</i> (1996) [8]	80P–100P	0–15P	Proximal osteotomy	K wire	Not available	Not available	Shortening of forearm	1
Dal Monte <i>et al.</i> (1987) [22]	Not available	2 ± 9P (12S–14P)	Derotation osteotomy of middle and distal third transverse osteotomy of synostotic block synostosis release	Not available	Not available	Not available	Neurovascular complication	Not calculable
El-adl <i>et al.</i> (2007) [26]	76 ± 7P (65P–85P)	11 ± 25P (30S–30P)	Double level osteotomy	No implant	8	6	No	0
Fujimoto <i>et al.</i> (2005) [2]	76 ± 8P (70P–85P)	3 ± 10P (10S–10P)	Distal osteotomy	No implant	8 ± 1 (6–9)	11 ± 8 (6–20)	Delayed union	1
Green and Mital (1979) [14]	76 ± 22P (30P–100P)	7 ± 17S (35S–30P)	Proximal osteotomy	K wire	Not available	Not available	Compartment syndrome	3
			Distal osteotomy					
Horii <i>et al.</i> (2014) [15]	72P	0	Double level osteotomy	No implant	6	Not available	Loss of correction	1
Hung <i>et al.</i> (2008) [20]	82P in dominant 74P in nondominant	6P in dominant 10P in nondominant	Proximal osteotomy distal to synostosis	Intra medullary nail	7	7	Loss of correction	1
Hwang <i>et al.</i> (2015) [25]	47P	28S	Double level osteotomy with segmental bone resection	Intra medullary nail in 18 cases No implant in 10 cases	6	7	No	0
Kanaya <i>et al.</i> (1998) [9]	23 ± 28P (0–80P)	Not available	Soft tissue interposition	Plate	3	Not available	Radial head redislocation	3
Kanaya <i>et al.</i> (2016) [23]	14 ± 9P (0–25P)	13 ± 8S (50S–25P)	Soft tissue interposition + Proximal osteotomy	Plate	3	Not available	Residual radial head dislocation	3
			Soft tissue interposition + Proximal osteotomy				Transient radial nerve palsy	
Khalil and Vizelely (1993) [21]	53 ± 22P (10P–80P)	10 ± 23P (10S–80P)	Bar resection	K wire in 5 cases	6	Not available	Flap congestion	1
Lin <i>et al.</i> (1995) [16]	65 ± 47P (75S–90P)	3 ± 20S (40S–30P)	Distal osteotomy	No implant	9	6	Loss of correction	1
Miura <i>et al.</i> (1984) [17]	Not available		Bar resection	No implant	Not available	Not available	Recurrence of synostosis compartment syndrome	1
Murase <i>et al.</i> (2003) [27]	78 ± 5P (70P–80P)	8 ± 10P (0–20P)	Double level osteotomy	Intra medullary nail	5	8 ± 0.4 (7/8)	Loss of correction	1
Ogino <i>et al.</i> (1987) [10]	66 ± 23P (30P–110P)	4 ± 9S (20S–10P)	Proximal osteotomy	Modification of tension band wiring	6		Transient radial nerve palsy	1
Pei <i>et al.</i> (2019) [5]	63P	8S	Proximal osteotomy	Plate	4	8	Transient nerve palsy	3
Ramachandran <i>et al.</i> (2005) [28]	68 ± 16P (40P–80P)	10S	Distal osteotomy	Intra medullary nail	6 ± 1 (6–8)	6 ± 1 (6–8)	Compartment syndrome	3
Rubin <i>et al.</i> (2013) [29]	100 ± 8P (90P–110P)	15 ± 12S (30S–0)	Proximal osteotomy	External fixation	9 ± 1 (9,10)	9 ± 1 (9,10)	Transient nerve palsy	1
Sakamoto <i>et al.</i> (2014) [24]	21 ± 25P (0–90P)	54 ± 20P (20P–80P)	Soft tissue interposition + Proximal osteotomy	(1) Plate	Not available	Not available	superficial infection	0
Satake <i>et al.</i> (2018) [18]	51 ± 21P (30P–90P)	4 ± 14S (30S–20P)	Soft tissue interposition + distal osteotomy	(2) No implant			No	
Simcock <i>et al.</i> (2015) [30]	85P	8P	Distal osteotomy	No implant	9	6	No	1
			Proximal osteotomy	K wire	5	8	Transient nerve palsy (Anterior Interosseous, radial nerve)	1
Simmons <i>et al.</i> (1988) [19]	82P	8P	Proximal osteotomy	(1) K wire	15	Not available	Muscle hemiation	3
			Distal osteotomy	(2) No implant			Compartment syndrome	
							Loss of correction	
							transient nerve palsy	

Fig. 2



The scatterplot graph shows the correlation between age and complications (a), age and major complications (b), age and complications in commonly performed proximal derotation osteotomies (c) and the correlation between the gain of correction and complications (d). The red dotted lines show threshold values for an increase of complication/major complication occurrence within the study cohort. Major complications and complications in proximal osteotomies seem to increase in children >7 years, whereas a deformity correction amount of around 70° may lead to a higher complication risk.

mean loss of correction of 3° (0–5°). Lin *et al.* reported 9/12 loss of correction; however, the exact interval until its occurrence has not been reported (no fixation device used, only cast) [16,19,20,25,27]. The radial nerve was the most common nerve (3/374; 0.8%) involved in the palsies. Other uncommon complications noted were recurrence of the synostosis (9/374; 2.4%), compartment syndrome (7/374; 1.8%), radial head dislocation (5/374; 1.3%), shortening of the forearm (2/374; 0.4%), delayed union (1/374; 0.2%) and superficial infection (1/374; 0.2%).

Correlations

A moderate significant correlation was found between age and major complications ($r=0.512$; $P=0.015$). The scatterplot in Fig. 2 reveals that many of the severe

complications occurred in children aged 7 years and above. Moreover, a moderate significant correlation was observed between proximal osteotomies and overall complications ($r=0.462$; $P=0.026$), and a significant negative correlation between the use of no hardware material and overall complications ($r=-0.441$; $P=0.035$). The postoperative loss of reduction showed a moderate, significant correlation with a double-level osteotomy as the primary treatment modality ($r=0.490$; $P=0.018$) but not with other surgeries. No correlation was found between preoperative deformity angle and complications. However, the gain of deformity correction in degrees correlated significantly with overall complications ($r=0.567$; $P=0.011$). As highlighted in Fig. 2, most of the complications occurred above the threshold of 65–70° of correction.

Discussion

The need for surgery in cases with CRUS is usually the need for a more functional position of the forearm rather than issues of cosmesis. With the forearm fixed in pronation, numerous activities of daily living are affected. The functional outcomes of the surgery for CRUS have been assessed in only three studies included in this review [5,18,25]. Liverpool elbow score, QDASH and Failla scoring systems were used to gauge the results, which showed statistically significant improvement postsurgery. Activities requiring a supinated forearm, such as washing the face and holding a food plate, showed the most improvements in these studies.

Only 6 of the 23 studies included in this review describe the results of the surgeries that preserved forearm motion [9,17,21–24]. Of these, there were two studies in which isolated resection of the synostosis without any osteotomy or soft tissue interposition was performed [17,22]. These studies reported significant failures of the surgery on follow-up. Results improved when the synostosis resection was accompanied by a free vascularized graft and by an osteotomy [9,23].

Among the osteotomies performed to place the forearm in a more functional position, increased complications were associated with proximal osteotomies, which, however, was likely due to the fact that this technique constituted the largest cohort. With respect to the specific complication of a loss of reduction, this was noted more frequently in double-level osteotomies and less so in proximal osteotomies. The usage of no hardware was associated with fewer overall complications, but in turn, a loss of reduction was more frequently seen in such cases. Among the implants, the use of plate and intramedullary nail was associated with more complications than Kirschner wires.

The optimal position of the forearm is influenced by culture and custom in various countries [18]. In Asian countries, the food plate is held in supination by the nondominant hand and chopstick or forks are used in the near neutral position by the dominant hand. In western countries, the use of forks and knives in both hands does not require full supination. Basic activities of daily life such as washing one's face require hand in supination. Also, note that activities that require pronation can still be performed by a supinated forearm by internal rotation, flexion and abduction at the shoulder. Considering the above factors, the ideal position is thought to be a pronation of 0–20 degrees in the dominant hand and a supination of 0–20 degrees in the nondominant hand [18,23].

Loss of correction and neurovascular complications in the form of transient and permanent palsies were the most common complications across the studies [5,10,16,17,19]. Loss of reduction, as mentioned before, was noted frequently in studies where hardware had not been used

and immobilization was achieved by casting. In contrast, neurovascular complications were observed in studies using plates or intramedullary nails. Interestingly, recurrent cases (loss of correction and recurrence) had longer follow-up compared to nonrecurrent cases (109 vs. 67 months). With the numbers available, this was independent by the surgical technique; nonetheless, we recommend to evaluate the surgical result close to skeletal maturity.

A significant correlation was observed between age at surgery and major complications. It seems that performing surgery >7 years of age may lead to more severe complications. This was particularly important for proximal derotation osteotomies. Moreover, the gain of correction correlated with complications. According to our analysis, >65–70° of correction was detrimental with regard to the occurrence of problems. In contrast, no significant correlation was noted between preoperative fixed deformity and complications. Based on these observations, corrections of >70° should either be done as two-stage procedures or be accompanied by a prophylactic cubital nerve release and/or prophylactic fasciotomy, as suggested by Simcock *et al.* [30].

The limitation of this review is that all the studies included were of level 4 evidence. There were no comparative studies, either prospective or retrospective. Study subject's allocation was not sufficiently described. The mean Newcastle-Ottawa and modified Coleman scores of 3.3 and 32.4, respectively, indicated inherent systematic deficiencies of the studies due to poor study quality. Overall, no information about potential predictive factors has been reported. Additionally, many studies had a small sample size, which precluded any statistical tests. We lastly acknowledge that the aims of motion-preserving surgeries vs. rotational osteotomies are not the same; however, we decided to include motion-preserving surgeries in this report to provide a comprehensive overview of all existing techniques in the literature.

To conclude, each type of surgery and osteotomy is associated with complications, along with the respective hardware being used. However, caution is warranted in interpreting these results in view of the inherent limitations of the included studies. There is a need for well-designed RCTs comparing the different modalities of treatment and usage of patient-reported outcome measures to improve future clinical practice.

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Conflicts of interest

S.F. has received honoraria from Orthofix SRL (Verona, IT) outside the submitted work. All other authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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