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

Keywords: Cleary-Omer, congenital radioulnar synostosis, derotation osteotomy, pronation

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].
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 of all various surgical procedures described for CRUS so far, is to derive any correlation between various influencing factors, outcomes and complications.

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 ≥30°, 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 et al. (1996) [8] | IV 3                  | 35                               |
| Dal Monte et al. (1987) [22] | IV 2                 | 22                               |
| El-adl (2007) [26]  | IV 1.6                  | 30                               |
| Fujimoto et al. (2005) [2] | IV 1.2                | 29                               |
| Green and Mital (1979) [14] | IV 2.8               | 26                               |
| Horii et al. (2014) [16] | IV 4                  | 36                               |
| Hung (2008) [20]   | IV 3                    | 44                               |
| Hwang et al. (2015) [25] | IV 3                 | 38                               |
| Kanaya et al. (1998) [9] | IV 2                 | 32                               |
| Kanaya et al. (2016) [23] | IV 3                | 48                               |
| Khalil Vukelely (1993) [21] | IV 2.3             | 17                               |
| Lin et al. (1995) [18] | IV 5                  | 35                               |
| Miura et al. (1984) [17] | IV 1                  | 10                               |
| Murase et al. (2003) [27] | IV 3                  | 27                               |
| Ogin et al. (1987) [10] | IV 5                  | 29                               |
| Pin et al. (2019) [5] | IV 5                  | 59                               |
| Ramachandran et al. (2005) [28] | IV 3              | 29                               |
| Rubin et al. (2013) [29] | IV 3                  | 35                               |
| Sakamoto et al. (2014) [24] | IV 5                  | 22                               |
| Satake et al. (2018) [18] | IV 3                 | 48                               |
| Simcock et al. (2015) [30] | IV 5                  | 32                               |
| Simmons et al. (1983) [19] | IV 5                  | 29                               |
Table 2 Demographic details of the studies included

| Study | No of cases | Age (years) | Sex | Dominant side | Affected side | Cleary-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 et al. (1996) [8] | 4 | 7 | Not available | 4 right | 1 right, 3 left | 0, 1, 3, 0 | 96 |
| Dal Monte et al. (1997) [22] | 26 | 10 | 6 male, 16 female | Not available | 4 right, 14 left, 4 bilateral | 1, 24, 1, 0 | 5–40 |
| Buhl et al. (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 et al. (2006) [2] | 10 | 6± 0.4 (4.5) | 3 male, 2 female | 2 right, 2 left | Not available | 0, 5, 0 | 21±10 (12–36) |
| Green and Mital (1979) [14] | 13 | 8± 5 (4–18) | 7 male, 6 female | 2 right, 11 left | Not available | Not available | 190±52 (120–306) |
| Horii et al. (2014) [15] | 35 | 5 | Not available | Not available | 9 right, 7 left, 18 bilateral | 0, 6, 28, 18 | 60 |
| Hung (2008) [20] | 52 | 6 | 22 male, 12 female | Not available | 25 dominant, 3 nondominant | 3, 5, 20, 0 | 64 |
| Huang et al. (2015) [25] | 28 | 7 | 21 male, 7 female | Not available | 2 right, 1 left, 4 – NOD | 3 right, 4 left | 4±4±8 (28–53) |
| Kanaya et al. (1998) [9] | 7 | 8± 2 (6–12) | Not available | 2 right, 1 left, 4 – NOD | 3 right, 4 left | 0, 0, 5, 2 | 46±10 (14–73) |
| Kanaya et al. (2016) [23] | 6 | 8± 3 (5–12) | 4 male, 2 female | 2 right, 4 left, 2 – NOD | 5 right, 7 left | Not available | 118±18 (96–144) |
| Khalil and Vizekley (1993) [21] | 10 | 8± 3 (4–13) | 9 male, 1 female | Not available | Not available | Not available | 95±92 (20–174) |
| Lin et al. (1995) [16] | 12 | 6± 4 (2–14) | Not available | Not available | Not available | Not available | 46±26 (14–73) |
| Mura et al. (1984) [17] | 8 | 4± 1 (2–5) | 1 male, 3 female | 4 right | 3 right, 3 left | 1, 0, 0, 5 | 55 |
| Murase et al. (2003) [27] | 4 | 7± 3 (4–13) | 11 male, 2 female | Not available | Not available | Not available | 24 |
| Ogino et al. (1997) [10] | 36 | 5 | 20 male, 11 female | Not available | Not available | Not available | 29 |
| Pei et al. (2019) [5] | 36 | 5 | 20 male, 11 female | Not available | Not available | Not available | 29 |
| Ramachandran et al. (2005) [28] | 6 | 5± 2 (4–8) | 4 male, 2 female | 3 right, 1 left, 4 right | 3 right, 2 left | 0, 0, 4, 0 | 100±15 (85–120) |
| Ruben et al. (2013) [29] | 4 | 11± 1 (9–13) | 2 male, 2 female | 3 right, 1 left | 2 right, 2 left | 9 right, 6 left | 64±38 (13–132) |
| Sakamoto et al. (2014) [24] | 15 | 6± 4 (3–17) | 14 male, 1 female | 14 right | 3 right, 9 left | Not available | 152±56 (55–230) |
| Satake et al. (2015) [30] | 31 | 7 (3–19) | 15 male, 11 female | Not available | Not available | Not available | 46 |
| Simcock et al. (2018) [33] | 28 | 8 | Not available | Not available | Not available | Not available | 150 |

Complications

Outcomes were assessed in 17.9% (67/374) of the cases reviewed (Table 3). Loss of correction and neurovascular complications were the most common complications across the studies [5,10,14,17,19,22,27,29,30]. The only article that reported loss of correction in the studies after surgery was reviewed [18,25]. The outcomes used in these studies were the Liverpool Elbow Score, Failla classification system, and quick disability of the arm, shoulder, and hand (QDASH) [5,18,25]. These studies noted a significant improvement in the objective scores assessed.

Outcomes were assessed subjectively in three of the studies [9,23,24]. The mean fixed deformity noted in supination and pronation was 10° (range, 0–35 degrees) has been indicated as the best position to hand dominance has been used in the studies reviewed (Table 3). The forearm that did not use any implants in 29% (105/362) of the cases. Moreover, the suggestion for the best forearm position according to hand dominance has been discussed in various studies. In the study by Sakamoto et al., the mean arch of pronation and supination was 53°.

Deformity

The mean preoperative deformity of the forearm was 64.8° (range, 75° supination to 110° supination) in pronation (range, 4–8 weeks). The forearms were immobilized for a mean of 6.7 weeks. Immobilization and consolidation times ranged from 4–8 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 8.1 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 8.1 weeks as compared to 4–6 weeks for forearms where any implant was used.
| Reference                  | 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                                                              | Intramedullary nail    | 7                           | 7                           | No                               | 0                             |
| Dal Monte et al. 1987 [22] | Not available                     | 2 ± 9P (12S–14P)                 | Proximal osteotomy                                                                  | K wire                | Not available               | Not available               | Shortening of forearm           | 1                             |
| Eladi et al. 2007 [28]     | 76 ± 7P (65P–85P)                | 11 ± 25P (30S–30P)               | Distal osteotomy                                                                     | No implant             | 8                           | 6                           | No                               | 0                             |
| Fujimoto et al. 2005 [2]   | 76 ± 8P (70P–85P)                | 7 ± 17S (35S–30P)                | Proximal osteotomy                                                                  | No implant             | 8 ± 1 (6–9)                 | 11 ± 8 (6–20)                | Delayed union                    | 1                             |
| Green and Mital 1979 [14]  | Not available                     | 10 ± 2P (10S–20P)                | Double level osteotomy                                                              | K wire                | Not available               | Not available               | Compartment syndrome            | 1                             |
| Horii et al. 2014 [15]     | 72P                               | 0                                | Proximal osteotomy distal to synostosis                                             | No implant             | 6                           | Not available               | Loss of correction              | 1                             |
| Hung et al. 2008 [20]      | 82P in dominant                   | 6P in dominant                   | Distal osteotomy                                                                     | Intramedullary nail    | 6                           | 7                           | Loss of correction              | 1                             |
| Hwang et al. 2015 [25]     | 14 ± 9P (0–25P)                  | 13 ± 8S (50S–25P)                | Distal osteotomy                                                                     | Intramedullary nail    | 6                           | 7                           | No                               | 0                             |
| Khalil and Vakeley 1993 [21]| 53 ± 22P (10P–80P)               | 10 ± 23P (10S–80P)               | Bar resection                                                                       | K wire in 5 cases      | 6                           | Not available               | Radial head redislocation       | 3                             |
| Lin et al. 1995 [16]       | 65 ± 47P (75S–90P)               | 3 ± 20S (40S–30P)                | Distal osteotomy                                                                     | No implant             | 9                           | Not available               | Residual radial head dislocation | 3                             |
| Murae et al. 1998 [17]     | 78 ± 5P (70P–85P)                | 8 ± 10P (0–20P)                  | Double level osteotomy                                                              | K wire                | 5                           | 8 ± 0.4 (7,8)               | Transient radial nerve palsy    | 1                             |
| Ogino et al. 1987 [10]     | 66 ± 23P (30P–110P)              | 4 ± 19S (20S–10P)                | Proximal osteotomy                                                                  | Modification of tension band wiring | 6                           | Not available               | Transient radial nerve palsy    | 1                             |
| Pei et al. 2019 [5]        | 14 ± 9P (0–25P)                  | 13 ± 8S (50S–25P)                | Soft tissue interposition + Proximal osteotomy                                      | Plate                 | 3                           | Not available               | Transient nerve palsy           | 3                             |
| Ramachandran et al. 2005 [28]| 68 ± 16P (40P–80P)              | 10S                               | Distal osteotomy                                                                     | Intramedullary nail    | 6 ± 1 (6–8)                 | 6 ± 1 (6–8)                 | Transient nerve palsy           | 1                             |
| Rubin et al. 2013 [29]     | 100 ± 8P (90P–110P)              | 15 ± 12S (30S–0)                 | Distal osteotomy                                                                     | External fixation      | 9 ± 1 (8,10)                | 9 ± 1 (8,10)                | Transient nerve palsy           | 1                             |
| Sakamoto et al. 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 et al. 2018 [18]    | 51 ± 21P (30P–90P)               | 4 ± 14S (30S–20P)                | Distal osteotomy                                                                     | (2) No implant         | 9                           | 6                           | No                               | 1                             |
| Simmons et al. 1983 [19]   | 82P                               | 8P                               | Distal osteotomy                                                                     | (1) K wire             | 15                          | Not available               | Loss of correction              | 3                             |

**Table 3 Operative details and complications noted in the studies included**

*Notes:*
- Complications include shortening of forearm, neurovascular complications, median nerve palsy, compartment syndrome, delayed union, recurrence of synostosis, deep vein thrombosis, flap congestion, superficial infection, transient radial nerve palsy, anterior interosseous nerve palsy, radial nerve palsy, compartment syndrome, and transient nerve palsy.*
mean loss of correction of $3^\circ$ (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.

Acknowledgements

Open Access publication was supported by Exzellenzfeld Orthopädie der Vinzenz Gruppe. S.F., G.G., P.Z., G.T. and G.D. designed the study. Material preparation and data collection were performed by G.G. and P.Z. Data analysis was performed by S.B. and S.F. The first draft of the manuscript was written by S.B., S.F., G.G. and P.Z. All authors revised the manuscript and approved the final draft.
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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