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The management of chronic paediatric Monteggia fracture-dislocation

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ABSTRACT

Background: Monteggia fracture-dislocation is a rare and often missed injury in the paediatric population. The neglected radial head dislocation might go unnoticed for several months, but usually becomes symptomatic at a certain point in time, posing a complex clinical problem. Management strategies for chronic Monteggia lesions have been proposed by many authors. A consensus therapy is nonetheless lacking. In recent years an increasing number of case series reporting the outcomes of various treatment options have been published to gain insight into this challenging pathology. The purpose of this review is to provide a general background on chronic, paediatric Monteggia fracture-dislocation, followed by a systematic analysis and discussion of various management strategies and their outcomes, described in recent outcome studies.
Methods: A literature search was conducted within the online databases PubMed, Cochrane Central, EMBASE and Google Scholar, to identify outcome studies on the management of chronic Monteggia lesions published between January 2015 and April 2020. A total of 23 outcome studies were identified and included in this study.
Results: Obtaining stable radial head reduction can be regarded as the main objective of any management strategy for chronic, paediatric Monteggia fracture-dislocation. In recent literature, many surgical techniques have been put forward to obtain this goal, with the mainstay of most treatment strategies being ulnar osteotomy and open reduction with or without reconstruction of the annular ligament. Watchful neglect is a strategy that got more or less abandoned and is challenged in recent literature.
Conclusions: Due to the complexity of long-standing radial head dislocation and the unpredictability of outcomes in the treatment of chronic Monteggia lesions, early diagnosis and achieving a stable reduction, preferably in the acute setting, are paramount. Because of the tendency to obtain more satisfactory radiological and clinical results in younger patients, with a short injury-to-surgery interval, it is advisable to promptly proceed to surgical treatment when chronic Monteggia fracture-dislocation is diagnosed.

1. Introduction

Monteggia fracture-dislocation was first described in 1814 by Giovanni Batista Monteggia as an ulnar fracture associated with a dissociation of the proximal radioulnar joint and a consequent dislocation of the radiocapitellar (RC) joint.[1] It may present itself as a clinical challenge to the (paediatric) orthopaedic surgeon. Several classification systems were developed to enhance the understanding and management of the Monteggia fracture-dislocation. In 1943, Watson and Jones did introduce their classification relying on the direction of the radial head dislocation (RHD) in relation to the mechanism of injury.[2] In 1962, José Luis Bado devised a classification system based on both the direction of the RHD and the angulation of the ulna fracture. Four different types were described.[3] Letts et al. did identify the Monteggia-equivalent lesion, which specifically occurs in the paediatric population. It is defined as RHD in combination with ulnar bowing. They recognized this subtype gets easily overlooked because of the absence of an apparent fracture of the ulna. Consequently, in 1985, they proposed a new paediatric classification system, which takes the so-called 'Monteggia-equivalent' into consideration. As a result, five fracture-dislocation types were defined within Letts' Classification for paediatric Monteggia injuries. Bado type I was brought under in Letts types A to C. In the Letts classification, Bado type IV has no matching type.[1] Despite its limitation, Bado's classification system is still widely used.[4–7,9–26] One should note that in literature, the term Monteggia-equivalent has been used next to Bado's four fracture-dislocation types to denote an array of different entities, originally referring to Letts type A equivalent lesions,[1] it has more recently

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also been used to define isolated anterior RHD with concomitant radial head (RH)[26] or radial neck[5] fractures (Table 1).

Despite growing awareness for Monteggia lesions in the paediatric population, they can still be overlooked. This applies especially to Letts type A lesions. The unreduced RHD might go unnoticed for several months.[8,15] However, they usually do become symptomatic at a certain point in time. A wide variety of symptoms and complications related to chronic RHD have been described: angular deformity, bony prominence, limited flexion of the elbow, slight to moderate elbow pain, valgus deformity of the elbow, neurological problems (i.e., sensory or motor loss caused by a tardy ulnar nerve palsy or a posterior interosseous nerve palsy), osteoarthritic changes, RH hypertrophy, and elbow instability.[8,14,18,19,21,22,27–29] Especially the radiocapitellar articulation will progressively undergo dysplastic changes due to the lack of joint restraint, leading to long-term consequences.[4,12]

As a result of bad outcomes in untreated and long-standing RHD, a substantial number of outcome studies on different treatment strategies for chronic Monteggia lesions have been published. This does demonstrate the increasing attention paid to this often challenging subject.[4–26] Despite this, so far, there is no consensus regarding the best method of treatment. This might be explained by the relatively low incidence of Monteggia lesions and the small sample sizes in outcome studies.

The purpose of this systematic review was to analyse various management strategies for chronic Monteggia fracture-dislocation and their outcomes, based on recent outcome studies.

2. Materials and methods

A literature search was conducted within the online databases PubMed, Cochrane Central, EMBASE, and Google Scholar to identify outcome studies on the management of chronic Monteggia lesions, published between January 2015 and April 2020. The search queries used were; 'Chronic Monteggia,' 'Neglected Monteggia,' and 'Missed Monteggia.' Only studies written in English and published from January 2015 onward were screened for relevance. No other filters were applied.

To be considered relevant for inclusion in this review, studies had to report on chronic Monteggia fracture-dislocation treatment outcomes. Studies on the management of acute Monteggia lesions and congenital or non-traumatic RHD were excluded. When both acute and chronic Monteggia cases were reported on, in an included study, only data concerning the chronic cases were processed and used.[3,24] Case reports were excluded. A total of 23 outcome studies were identified and included in this study. They do provide the data that are being discussed.

Table 1
Classification systems for Monteggia fracture-dislocation.

Bado Classification for Monteggia injuries[3]		Letts Classification for paediatric Monteggia injuries[1]	
Type	Description	Type	Description
Type I	Anterior radial head dislocation and diaphyseal ulna fracture with anterior angulation	Type A	Anterior radial head dislocation and apex anterior ulnar bending (plastic deformation)
Type II	Posterior or posterolateral radial head dislocation and diaphyseal ulna fracture with posterior angulation	Type B	Anterior radial head dislocation and apex anterior greenstick ulnar fracture
Type III	Lateral or anterolateral radial head dislocation and proximal metaphyseal ulna fracture	Type C	Anterior radial head dislocation and complete apex anterior ulnar fracture
Type IV	Anterior radial head dislocation, proximal 1/3 diaphyseal fracture of both radius and ulna	Type D	Posterior radial head dislocation and apex posterior ulnar fracture
		Type E	Lateral radial head dislocation and greenstick fracture of the ulna

3. Results

Spread across the 23 included outcome studies, a total of 352 children (219 boys vs. 133 girls) were treated for chronic Monteggia fracture-dislocation. The sample sizes did range from 4 to 33 patients. The mean age of patients was 7.43 years (range 2–16 years). The overall mean injury-to-surgery interval was 12.39 months. While in most outcome studies, included within our data, the minimum injury-to-surgery interval was set at 4 weeks, there were two exceptions. He et al. included Monteggia lesions with an injury-to-surgery interval of minimum 2 weeks in their 'neglected' series.[18] Yuan et al. set the cut-off at an injury-to-surgery interval of 3 weeks.[24] Five studies did include some patients with an injury-to-surgery interval exceeding 10 years.[6,14–16,25] Roughly 80% percent of the chronic Monteggia lesions did consist of Bado type I lesions (Table 2).

3.1. Treatment strategies

In recent literature, many surgical techniques for treating chronic paediatric Monteggia lesions have been described (Table 3). Ulnar osteotomy and open reduction with or without reconstruction of the annular ligament are the mainstay of most management strategies. More exceptional are the use of radial neck[6] or shaft[13] osteotomy and RH excision.[6] Skilful neglect is a strategy that got more or less abandoned and is challenged more frequently in recent literature.[6] It is of note that none of the identified outcome studies did report on the use of conservative treatment for chronic Monteggia injuries.

3.1.1. Reduction of the radial head

Obtaining stable RH reduction is the main objective in the treatment of chronic Monteggia lesions. It can be achieved either directly or indirectly. The first approach consists of open reduction, while the latter relies on the correction of the ulnar angulation and/or length.[26] A combination of both direct and indirect reduction is used by most authors.[5–26]

According to Çevik et al., who adopted four different management techniques in their case series, the treatment strategy has no significant effect on the results, as long as it provides RH reduction.[26]

He et al. found that closed RH reduction is significantly less successful in treating chronic Monteggia fracture-dislocation when compared to acute Monteggia lesions.[18] During an open reduction, fibrous scar tissue is often observed to surround the RH, which, combined with occasional dysplastic changes of the RC joint, might hinder a closed RH reduction.[5,8,9,13,26] Chen et al. believe that in long-standing Monteggia lesions, it is imperative to remove scar tissue to facilitate RH reduction.[13] This is supported by the failure to achieve closed reduction after ulnar osteotomy, as a first step in some proposed treatment plans. Some authors explicitly describe the need to proceed to an open reduction to obtain proper RH reduction after performing an ulnar osteotomy.[6,16,20,24] Nevertheless, successful closed RH reduction can occasionally be achieved.[6,20,24,26] One closed reduction did show successful 56 months post-injury.[4]

Park et al. tried to perform closed RH reduction under general anaesthesia as a first step in their treatment plan. After failure to obtain closed reduction in all their patients, they performed an open reduction, followed by an ulnar osteotomy in case of insufficient reduction stability. Open RH reduction alone, without ulnar osteotomy, seems to work in select cases. They found a relationship between the amount of maximum ulnar bow (MUB), the MUB location, and the method of surgical treatment. In cases where the MUB was less than 4 mm, and the MUB was situated in the distal 40% of the ulna, they could reduce the RH without ulnar osteotomy. It should be mentioned that the injury-to-surgery interval in the group that did not undergo ulnar osteotomy was significantly shorter. They could not define any definite indication to perform isolated open reduction, but suggest it may be effective in case of minimal bowing of the distal ulna. Therefore, they recommend open

Table 2
Demographic data of all included outcome studies on chronic Monteggia in children.

Study	Number of patients	Sex (M)ale, (F) emale	Mean age (range) at time of surgery/ *injury [in years]	Mean interval injury-surgery (range) [in months]	Bado Classification[3] (I, II, III, IV) & Monteggia equivalents (Me)
Bor[4]	4	(M) 2, (F) 2	9.75 (9–11)	24 (3–56)	I (4)
Kosev[5]	4	(M) 1, (F) 3	6.6 (4.2–9.1)	12 (2–25)	I (2), III (1), Me (1)
Di Gennaro[6]	22	(M) 10, (F) 12	7.2 (4.1–13.6)	15.7 (1–128)	I (20), III (2)
Megahed[7]	16	(M) 7, (F) 9	7.25 (7–12)	11.2 (3–20)	I (11), II (3), III (2)
Lu[8]	23	(M) 16, (F) 7	6 (4–9)	7 (1.5–16)	*NR*
Park[9]	22	(M) 11, (F) 11	7.6 (3.5–14.3)	16.1 (1–84)	I (22)
Xu[10]	5	(M) 3, (F) 2	5.7 (3.4–6.8)	3 (1–4)	I (5)
Ngoc Hung[11]	13	(M) 5, (F) 8	8.6 (6.1–12.7)/7.7 (4.7–12.5)*	12.1 (2–25)	I (9), II (3), III (1)
Agarwal[12]	11	(M) 7, (F) 4	7.8 (6–11.5)	4 (2–11)	I (6), III (2), Me (3)
Chen[13]	20	(M) 11, (F) 9	10.2 (3.5–16.75)	10 (1.2–49)	I (18), III (2)
Eamsobhana[14]	30	(M) 18, (F) 12	7.4 (4–13)	23.4 (6–120)	I (21), II (2), III (7)
Stragier[15]	14	(M) 7, (F) 7	8 (3–17)	26.9 (1–145)	I (4), Me (10)
Take[16]	5	(M) 4, (F) 1	9 (5–14)/6,33 (2–10)*	31 (2–125)	I (5)
Mazhar[17]	7	(M) 6, (F) 1	6.6 (4–1.8)	1.8 (1–3.5)	I (4), III (2) IV (1)
He[18]	17	(M) 13, (F) 4	6.94 (2.08–12.58)	4.82 (0.5–25)	I (16), III (1)
Wang[19]	13	(M) 11, (F) 2	5.66 (2.17–10)	12 (2–36)	I (10), III (3)
Gallone[20]	20	(M) 10, (F) 10	8.1 (5.1–14.2)/6.7 (4–9.7)*	12.7 (3–38)	I (19), III (1)
Liao[21]	33	(M) 27, (F) 6	6.9 (2–12)	7 (1–60)	I (27), III (6)
Soni[22]	6	(M) 4, (F) 2	8.1 (3–14)	6 (1–24)	I (6)
Kumar[23]	17	(M) 11, (F) 6	6.61 (*NR*)	3.52 (3–5)	*NR*
Yuan[24]	11	(M) 8, (F) 3	6.5 (2–12)*	8.5 (*NR*)	I (8), III (3)
Musikachart[25]	21	(M) 15, (F) 6	7.95 (5–12)	27.05 (3–120)	I (21)
Çevik[26]	18	(M) 12, (F) 6	6.9 (2.6–12.2)	2 (1–3.7)	I (7), II (5), III (1), Me (5)
Total or mean†	*352*	*(M) 219, (F) 133*	*7.43 years†*	*12*.39 months†	*I (245), II (13), III (34), IV (1), Me (19)*

reduction as a first surgical step to prevent unnecessary ulnar osteotomy in patients without definite ulnar deformity.[9]

Yuan et al. found a significantly longer injury-to-surgery interval in patients who required open reduction.[24]

In most outcome studies that report on closed RH reduction, an ulnar osteotomy is followed by external fixation (EF) with[4,6,20] or without[24] gradual lengthening. Ulnar osteotomy with a plate or crossed k-wire fixation, in combination with closed reduction is described in one study and yielded good results.[26]

Approaches according to Boyd,[5,7,10,11,16,19,23] Kocher,[6,9,12,13,15,17,20,24] Kaplan[15,22,25] and Henry[8,19,21] are used to perform open RH reductions.

3.1.2. Ulnar osteotomy

The aim of ulnar (over)correction osteotomy can be considered twofold. First, to tighten the interosseous membrane to the point that its intrinsic tension maintains the RH in the correct anatomical position and secondly, at the same time, eliminating any ulnar fulcrum that might force the radius anteriorly when the arm is pronated.[10] Several authors do consider treatment of the ulna key in obtaining and maintaining RH reduction.[13–15,22]

The use of ulnar osteotomy is reported on within all the included series. In some outcome studies however, ulnar osteotomy was only performed when open reduction alone did prove insufficient to maintain RH reduction,[7,9,11] or when positioning of the RH in the innate annular ligament was impossible during open reduction.[8] Four different outcome studies reported on the outcomes of 20 patients in total, treated without ulnar osteotomy.[6,8,9,18]

3.1.2.1. Location of the osteotomy. The ulnar osteotomy is most often carried out at the level of the proximal ulna. Numerous arguments have been laid out to ratify this osteotomy site. The altered bone shape and the resulting scar would be less bothersome, the interosseus membrane gets less disturbed, but more importantly, it is found to reduce the risk of nonunion and delayed union.[6,13,14,20]

Significantly better results and lower complication rates were found by Gallone et al. in patients undergoing osteotomy of the proximal third of the ulna. They recommend performing the osteotomy as proximally as possible or at least within the proximal 47.5% of the ulna.[20] Di Gennaro et al. observed delayed union or nonunion in 25% of their cases, probably owing to having performed their osteotomy beyond the proximal 1/3rd of the ulna in 75% of their patients.[6]

Çevik et al. performed their osteotomies at the junction of distal 2/3 and proximal 1/3 of the ulna if there were both bony union and acceptable angulation at the former fracture site. If a complete union was absent or the angulation at the fracture site was unacceptable, they performed their osteotomy at the level of the callus.[26]

Xu et al. performed centre-of-rotation-angulation (CORA)-based osteotomy in their case series comprising five patients with Bado type I lesions with a relatively short injury-to-surgery interval and reported stable RH reduction and excellent outcomes. They argue that in cases where anterior bowing of the ulna creates a fulcrum that might prevent proper reduction, an osteotomy at the deformity site is justified.[10]

3.1.2.2. Correction versus overcorrection osteotomy. Only one included study did compare the outcomes of corrective versus overcorrection osteotomies. Because of significantly inferior radiologic outcomes and increased incidence of posterior RHD in patients who underwent overcorrection in their series, the authors advise proper consideration when the overcorrection exceeds 10° of dorsal angulation.[25]

The majority of the studies mention the use of posterior bending overcorrection osteotomy, resulting in ulnar lengthening, in the effort to obtain stability of the RC joint.[4–7,11–13,17,19–22,24]

The reported osteotomy angles vary considerably both between and within the included outcome studies and did range up to 40° of dorsal angulation.[25]

The amount of ulnar angulation and elongation applied after the osteotomy is often determined intra-operatively depending on the tension of the interosseous membrane and the induced stability of the RH reduction.[5,7,9,10,14,15,17,19,21,22,26]

Chen et al. mapped the correction angle and ulnar osteotomy site, using a preoperative template, to more accurately assess the theoretically optimal ulnar osteotomy site and angular correction needed to achieve RH reduction. They argue it might facilitate the procedure and might help prevent making major surgical mistakes.[13]

Transverse opening wedge osteotomies were most frequently performed. Two authors report the use of an oblique osteotomy.[12,19] A sagittal V-shaped osteotomy was proposed by Megahed et al. arguing that it might provide greater intrinsic stability due to a larger contact

Table 3
Overview surgical information of the included outcome studies on chronic Monteggia fracture-dislocation in children.

Study	Procedure	Approach	Ulnar osteotomy site	Type of ulnar osteotomy fixation	Transcapitellar wire	Annular ligament reconstruction / repair	Type of ulnar correction	Bone grafting	Post-operative cast
Bor[4]	UO + CR + gradual lengthening with EF	Directly over osteotomy site	Proximal methaphysis	Single half ring hinged Ilizarov EF (2 proximal + 2 distal threaded pins) Mean time in frame 3.5 mo (2.75-4.5 mo)	No	No	Dorsal osteotomy + gradual angulation (mean 26° (20-35°) and lengthening (mean 2cm (1.6-2.5cm) in Ilizarov frame (after latency of 1 week)	No	NR
Kosev[5]	UO + OR	Boyd	Proximal ulna (5cm below olecranon)	prebent one-third tubular plate	No	Repositioning RH in intact AL (2)	Transverse distraction and angulation osteotomy guided by RH reduction stability	Wedge-shaped tricortical bone graft	4-6 weeks LAE
Di Gennaro[6]	OR + ALR (repair (7) / Bell Tawse (2)) (+ TP (8)) *Or* UO + gradual lengthening with EF (9) (+ OR (8) + ALR (8) + TP (6) at time EF removal) *Or* UO + gradual lengthening with EF + OR + Radial neck osteotomy + ALR + TP (1) *Or* OR + UO + plate + ALR (Bell Tawse) (2) *Or* Radial head excision (1)	Kocher	Middle third ulna (5) Between proximal and middle third (3) Between middle and distal third (1) Proximal third (3)	External fixator (10) /plate (2)	Yes - Kirschner wire (16)	Repair (16) / Bell Tawse (4)	Posterior bending elongation and angulation osteotomy (+gradual lengthening and angulation using EF (10)/ plate (2))	Yes (2) < Dalayed union*	± 4 weeks LAE, 90° elbow flexion + neutral rotation (19) / none (2)
Megahed[7]	OR + UO + ALR + TP (+ temporary oblique radioulnar pin)	Boyd + dorsal approach	Proximal ulna ("i.e., the site of malunion orplastic deformity")	Dynamic compression plate or reconstruction plate	Yes- Kirschner wire (16)	Repair / reconstruction with lateral slip triceps	Sagittal oriented V-shaped lengthening (mean 7mm (5-10)) and angulation osteotomy guided by RH reduction stability	No	6 weeks LAE, 90° elbow flexion + full supination
Lu[8]	OR (+ reduction in innate AL after dissection) (5) *or in case of residual RH-instability* OR (+ reduction in innate AL after dissection) + UO (18)	Anterior Henry approach	Proximal ulna	Plate	Yes – Kirschner wire (1) (removal at 3 weeks)	Repostioning RH in innate AL (20) Repair (3)	*NR*	*NR*	3 weeks LAE, 90° elbow flexion + neutral rotation
Park[9]	OR (5) UO + OR (17)	Kocher approach	Site of maximum deformity / proximal third of the ulna if no apparent deformity	Bent plate	*NR*	Repair / resection	Corrective/ dorsal angulation osteotomy guided by RH reduction stability	No	6 weeks LAE, 90° elbow flexion + neutral rotation
Xu[10]	OR + CORA-based UO	Boyd + directly over pre-determinded CORA	CORA	Bent 5- or 6-hole reconstruction plate	No	No	Transverse dorsal open wedge angulation (mean 15.8° (13-20°)) osteotomy guided by RH reduction stability	No	6 weeks LAE

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Table 3 (*continued*)

Study	Procedure	Approach	Ulnar osteotomy site	Type of ulnar osteotomy fixation	Transcapitellar wire	Annular ligament reconstruction / repair	Type of ulnar correction	Bone grafting	Post-operative cast
Ngoc Hung[11]	OR + UO + ALR + TP (+ temporary oblique radioulnar pin)	Boyd + dorsal approach	Proximal diaphyseal-metaphyseal junction	Pre-bent one third tubular	Yes - Kirschner wire (removal at 2 weeks)	Fascia lata	Straight distraction (mean 0.86 cm (0.5-1.8 cm)) and angulation (mean 21.3° (16-25°)) osteotomy	Yes (1) < Nonunion*	6 weeks LAE, 90° elbow flexion + supination
Agarwal[12]	OR + UO (+ TP)	Kocher	Site of malunion or proximal metaphysis	Dynamic compression plate or reconstruction plate	Yes - Kirschner wire (1) (removal at 3 weeks)	No	Oblique angulation (mean 16.2° (range 10–30°)) and distraction (mean 6.9mm (range 4–15mm)) osteotomy	*NR*	6 weeks LAE, 90° elbow flexion + neutral rotation
Chen[13]	OR + UO (+ TP) (18) *Or* OR + OU + radial shaft shortening osteotomy (+ TP) (2)	Kocher + medial directly over proximal ulna	Proximal diaphyseal-metaphyseal junction of ulna	Pre-bent four-to five-hole compression plate	Yes (5) – K-wire (removal at 4 weeks)	No	Dorsal angulation (mean angle 18.9° (range 8-33°)) and elongation (mean 5.6mm (range 0.1-16.9mm)) osteotomy	Bone substitute or allograft if substantial gap	6 weeks LAE, 90° elbow flexion + full supination
Eamsobhana[14]	OR + UO (8) *or* OR + UO + ALR (+ TP) (22)	Extended posterolateral reaching to midshaft ulna	Proximal ulna	Four-to seven hole compression plate	Yes – 2mm Kirschner wire (7) (removal at 6 weeks)	Triceps fascia (22) – No (8)	Transverse overcorrection osteotomy guided by RH reduction stability	No	6 weeks LAE, 90° elbow flexion + supination
Stragier[15]	OR + UO (+ TP) (12) *or* OR + UO + ALR +TP (2)	Kaplan (13) – Extended Kocher (1)	Proximal ulna (5 cm below olecranon)	Plate and screws	Yes 1.6mm Kirschner wire (12) (removal at 4-6 weeks)	Bell Tawse (1) / repair (1)	Dorsal opening wedge osteotomy guided by RH reduction stability	Autologous bone graft (2)	4-6 weeks LAE, 90° elbow flexion + neutral rotation
Take[16]	OR + UO	Boyd + directly over proximal ulna	Proximal ulna	Ilizarov mini-EF Mean time in EF 10w (8-13w)	No	No	Opening wedge angulation osteotomy	No	*NR*
Mazhar[17]	OR + UO + ALR (+ TP)	Kocher	Proximal ulnar metaphysis	3.5mm reconstruction plate	Yes (1)	Repair (5) / reconstruction with triceps fascia (2)	Angulation and distraction osteotomy guided by RH reduction stability	*NR*	2 weeks LAE, 90° elbow flexion + neutral rotation
He[18]	OR + cast (1) *Or* OR + UO (10) *or* OR + UO + ALR (6)	*NR*	*NR*	LCP (15) / EF (1)	*NR*	Repair (5) / reconstruction (1)	*NR*	*NR*	*NR*
Wang[19]	OR + temporary-EF-assisted UO (+ TP)	Boyd (3) – Henry approach with proximal ulnar dorsal incision (10)	Proximal ulna	Temporary unilateral external fixator (2 proximal and 2 distal Kirschner wires) + 2.7mm LCP	Yes – Kirschner wire (1)	No	Oblique osteotomy with posterior (Bado type I)/ posteromedial (Bado type III) angulation (mean 28° (20-30°)) and lenghtening (mean 0.7mm (0.5 – 1.2mm)) guided by RH reduction stability	'Allograft bone graft substitute'	6 weeks LAE, 90° elbow flexion + supination
Gallone[20]	UO + gradual distraction and angulation using EF until RH reduction is obtained (9) + *UPON failure to achieve reduction at time of EF removal:* + OR + ALR + TP (11)	Directly over osteotomy site / Kocher (OR)	Site of maximum deformity / as proximally as possible / proximal third	External fixator, 2 proximal and 2 distal pins	Yes - Kirschner (11) (removal at 2-3 weeks)	Repair (7) / Bell Tawse (4)	Linear distraction (1mm/ day from day 3 PO onward, mean 11mm (3-37mm)) and angulation (mean correction 16°) osteotomy with EF	Yes < aseptic nonunion* (3)	3 weeks once EF was removed
Liao[21]	OR + UO (+ TP)	Anterior Henry's + posterior approach	Proximal ulna	Bent plate (removal when clinical and radiographic evidence of union (6-12 mo))	Yes - Kirschner wire (10)	No	Transverse dorsal angulation and lengthening osteotomy guided by RH reduction stability	Iliac graft 'if necessary'	4-6 weeks LAE, 90° elbow flexion + neutral rotation or mild supination

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Table 3 (*continued*)

Study	Procedure	Approach	Ulnar osteotomy site	Type of ulnar osteotomy fixation	Transcapitellar wire	Annular ligament reconstruction / repair	Type of ulnar correction	Bone grafting	Post-operative cast
Soni[22]	UO + OR + temporary TP	Extended lateral approach	Proximal ulna	Straight plate (2,7-3,5mm)	Yes – temporary during surgery	No	Transverse angulation and lengthening osteotomy guided by RH reduction stability	*NR*	4 weeks LAE, 90° elbow flexion + neutral rotation
Kumar[23]	OR + UO + ALR	Boyd approach	Apex of the deformity	Pre-bent 3.5mm 5-hole dynamic compression plate	No	Bell Tawse	Dorsal angulation (10-30°) open wedge osteotomy (no lengthening or distraction)	No	5 weeks LAE, 90° elbow flexion + neutral rotation
Yuan[24]	UO + CR (adjustment EF until stable reduction RH) (5) *or UPON failure to reduce RH* UO + OR (+ALR) (6)	Posterior approach + modified Kocher (OR)	Proximal ulna	EF (5-6 pins, 2 or 3 proximal and 2 distal of the osteotomy)	NR	Repair if possible	Transverse lengthening and dorsal angulation (mean 25.6 ±7.7) osteotomy	*NR*	None
Musikachart[25]	OR + UO (overcorrection (10) / anatomical (11)) (+ ALR + TP)	Extended lateral approach	Proximal ulna	Plate and screws	Yes – 2mm Kirschner wire (removal at 6 weeks)	Triceps fascia (8) – No (13)	Transverse overcorrection (10) (mean 28.37° (12-40°)) osteotomy (10) OR correction (mean 6.09° (3-9°)) osteotomy (11)	*NR*	6 weeks over the elbow, 90° flexion + supination
Çevik[26]	OR + UO (plate) + TP + ALR (6) *Or* UO (cross k-wire) + CR + TP (5) \ *or* OR + UO (intramedullary k-wire) + TP + "radial head fixation with k-wire" (2) *Or* UO (plate) + CR (5)	Not specified	Junction proximal third and distal two thirds of the ulna or fracture site if no bony bridging	Plate (11) – Crossed k-wire (5) – intramedullary k-wire (2)	Yes - Kirschner wire (13) (removal at 6 weeks)	Yes (6) – technique not specified	Overcorrection osteotomy guided by RH reduction stability	No	6 weeks LAE (in case of TP)

NR (=Not Reported), RH (=Radial Head), AL (=Annular Ligament), LAE (=Long Above Elbow cast), EF (External Fixator), CORA (=Center Of Rotation Angulation) [Open Reduction (OR), Closed Reduction (CR), Ulnar Osteotomy (UO), Annular Ligament Repair/Reconstruction (ALR), Transcapitellar Pinning (TP)]
*postoperative complication

surface of the ulna's proximal and distal parts.[7]

3.1.2.3. Fixation technique. Both plate and screw, and EF are commonly used stabilization techniques. Seven authors mention using an external fixator to stabilize the ulna after osteotomy in either all their cases[4,16,19,20,24] or some of them.[6,18] All other authors report the use of plate and screw fixation. The use of crossed k-wires and intramedullary k-wire fixation is evaluated in only one study.[26]

It is argued that plate and screw osteosynthesis offers greater stability and less loss of the obtained reduction than most alternative fixation methods.[22] Elastic stable intramedullary nailing only provides relative stability. It has been reasoned to be insufficient to maintain the ulnar length and the angulation after correction osteotomy leading to recurrent RHD.[30] According to He et al. minimally invasive techniques can only be relied upon in acute cases.[18]

Plates offer the advantage that they can be bent to match the desired correction angle of the ulna and allow for carrying out the correction in one procedure.[22] In contrast, EF allows for progressive correction, but often requires multiple sessions in the operating theatre.[6] On the other hand, plate fixation is more invasive than the use of an external fixator and disrupts the ulnar periosteum's blood supply. Plate removal in children requires general anaesthesia while removal of an external fixator can usually be done in the ambulatory setting.[16]

The gradual lengthening and angulation technique, making use of an external fixator in an attempt to obtain closed RH reduction over time, in a minimally invasive way, by overcoming soft tissue contractures, did prove little successful in the series of both Di Gennaro et al. and Gallone et al. The majority of their patients did require an open RH reduction with annular ligament repair (ALR) and transcapitellar pinning at the time of external fixator removal to obtain a desirable result.[6,20] Bor et al. on the other hand, reported good outcomes with the same technique. By using an Ilizarov external fixator, gradual ulnar correction can be carried out without the need for multiple general anaesthesia sessions.[4] An external fixator, without gradual correction, is used as an alternative for plate fixation in other series.[16,18,24] Mentioned disadvantages of EF are pin tract infection, inconvenience for the patient, and the operating surgeon's required technical proficiency. An infection might cause mechanical pin loosening and nonunion of the ulna.[4,20] No difference in delayed union rate could be demonstrated when comparing EF with plate fixation.[6]

Wang et al. carried out external fixator-assisted osteotomies in their patient group. According to the authors, temporary stabilization with an external fixator facilitates an effective operative performance by aiding to achieve the transected ulna's optimal positioning prior to plate fixation. By temporarily fixating the ulna after osteotomy, joint stability testing is possible without losing the ulna's angulation and/or distraction without the need to fix the plate in position immediately. As such, this technique relies on the advantages of the perioperative flexibility of an external fixator and the stability of internal fixation.[19]

3.1.2.4. Bone grafting. Some authors mention the use of bone grafts either at initial surgery[5,13,15,19,21] or at the time of revision because of a nonunion[11,20] or a delayed union.[6]

3.1.3. Annular ligament reconstruction/repair (ALR)

Whether or not reconstruction or repair of the annular ligament should be carried out remains controversial. The annular ligament is often torn and irreversibly altered after sustaining a Monteggia fracture-dislocation. Still, observation learns this is not always the case, especially in relatively recent injuries, the ligament might remain intact.[5,8,9] If found intact, repositioning of the RH in the annular ligament during open reduction is a feasible option and provides long-term stability. Careful examination of the annular ligament is therefore advisable when performing open reduction since accurate reconstruction proves harder than repositioning of the RH in an intact native annular ligament.[8]

ALR with remnants of the native ligament, on the other hand, may prove difficult in long-standing lesions because of incurred dysplastic changes. Upon surgical exploration of the RC joint, remnants of the annular ligament are often attenuated, trapped between radius and humerus and might be hard to recognize.[13,14] If possible, some authors tried to repair the ligament with remnants of the native structure.[6,9,17,18,20,24] Others deliberately did not perform annular ligament reconstruction nor repair,[13,22] while some only performed annular ligament reconstruction in case of persisting intraoperative RH instability once an osteotomy was carried out.[14,25] A last group always aimed at repairing or reconstructing the annular ligament.[7,11,23] The Bell Tawse technique[31] or its variations to reconstruct the torn annular ligament with a slip of triceps aponeurosis still have widespread use.[6,7,14,15,17,20,23,25] Alternatively, a fascia lata graft can be used to reconstruct the ligament.[11] During ALR, care should be given to avoid excessive tensioning of the reconstructed or repaired annular ligament to avoid complications.[23] Graft harvest adds complexity and morbidity because of additional skin incisions and soft tissue dissection.[13] Potential risks of ALR have been suggested, such as elbow stiffness, osteolytic changes, avascular necrosis, synostosis, heterotopic ossification, narrowing or growth disturbance of the radial neck, and restriction of pronation.[4] Concerning the latter, significant limitations in the post-operative range of motion (ROM) after ALR could not be demonstrated in recent studies.[7,14]

A significant outcome benefit of ALR in the management of missed Monteggia fracture-dislocation could not be demonstrated[26] and open reduction with ulnar osteotomy is often sufficient in providing stability of the RH, without ALR or transcapitellar pinning being performed.[5,10,12–14,16,18,19,21,22,25]

3.1.4. Transcapitellar pinning

Some authors report the use of transcapitellar pinning in all cases.[7,11] Others consider transcapitellar pinning essential when RH stability is lacking once the reduction is achieved, following ulnar osteotomy and open reduction.[8,12–15,17,19,25]

Breakage of the Kirschner wire (1.6 mm) is a reported complication.[15] To minimize the risk of breakage, an above the elbow cast is applied until the time of K-wire removal.[13,26] Furthermore, the use of a K-wire with a minimum thickness of 2 mm is recommended.[6]

Temporary intraoperative transcapitellar pinning following open RH reduction, with pin removal once the plate is in situ, is used in one study.[22]

The interval between surgery and k-wire removal ranges from 2 up to 6 weeks.[8,11,13–15,20,25,26]

3.1.5. Radial osteotomy and radial head excision

Osteotomy of the proximal radius was performed in two studies.[6,13] Chen et al. came across two longer existing (>2y) injuries that required radial shaft shortening osteotomy to facilitate RH reduction. The excess bone was used as grafting material at the ulnar osteotomy site.[13] Di Gennaro reported a radial neck osteotomy in one patient. Additionally, in their series, a patient with an injury-to-surgery interval of 10 years underwent RH excision, associated with long-term morbidity at long term follow-up.[6]

3.1.6. Postoperative casting or splinting

Cast immobilisation is commonly applied in the postoperative management of chronic Monteggia lesions. Recommendations in this respect vary amongst authors. Immobilisation with an above the elbow cast in 90° of flexion is widely accepted in recent literature. Whether the arm should be immobilized in neutral rotation or supination does remain controversial. Splinting of the forearm in neutral rotation[6,8,9,12,15,17,22,23] is reported slightly more often than immobilisation with the forearm in supination.[7,11,13,14,19,25]

If applied, the adopted time of immobilisation varies from 2[17] up to 6 weeks, with most authors reporting postoperative cast immobilisation for a period of 4–6 weeks.[5–7,9–15,19,21–23,25,26] In one study, patients received a cast for three weeks after external fixator removal.[20]

Physiotherapy is seldomly reported as necessary to regain ROM following cast removal.[12,13] Some authors did explicitly mention that specific physiotherapy was not prescribed.[5,8,14,17]

3.2. Outcomes

Follow-up ranged widely between studies (3[17]–292[6]months). With a mean follow-up time of 132 months, Stragier et al. had the longest overall follow up.[15] Outcomes of the included studies are listed in Table 4.

3.2.1. Subjective outcomes

Satisfaction levels were reported by some authors and were found to be good.[7,13,15,22,24] Stragier et al. used a standard elbow questionnaire to assess potential subjective improvement and satisfaction induced by the treatment. All patients reported to be satisfied with the treatment. Patients who had an injury-to-surgery interval greater than 6 months all reported some pain on a visual analogue scale while only one out of six patients with less than 6 months between injury and surgery reported pain.[15] Di Gennaro also recorded persisting pain after the treatment in five out of twenty-two patients.[6] In the study of Yuan et al. ten out of eleven patients complained about the appearance of the upper extremity, particularly about the bowing of the proximal ulna.[24]

3.2.2. Functional and clinical outcomes

Functional outcomes were evaluated using the Kim[32] Elbow Performance Score (KEPS),[5,6,8,9,11,14,16,17,19,20,25] Mayo Elbow Performance Index (MEPI),[7,9,13,18,23,33] Quick DASH,[24] Oxford Elbow Score (OES)[26] or the Broberg & Morrey Rating System[10] and are summarized in Table 4.

3.2.3. Radiological outcomes

Radiological outcomes are generally classified into 3 different categories. The radiological outcome is considered good when complete reduction can be seen (radiocapitellar line (RCL) crossing middle third of capitellum), and no osteoarthritic changes are noticeable. A fair result is defined by either subluxation (RCL does not intersect the middle third of the capitellum, but partial contact of the joint surface is preserved) or the presence of ostheoarthritic changes in the RC joint. A poor result means there is a complete radiocapitellar dislocation.[29]

Overall, good radiographical results were seen in 298 cases, fair results in 37 cases, and poor results in 16 patients. One patient underwent RH resection.[6] Of those with a fair radiological outcome, 26 patients had residual RH subluxation, 9 had osteoarthritic changes at the RC joint, and 2 patients had both RH subluxation and osteoarthritic changes at the RC joint.

3.3. Outcome determinants

Chen et al. found in their series that patients who underwent surgery within the first year after sustaining the injury had better functional outcomes than those who underwent surgery more than one year after the injury. Differences in pronation, supination, extension, and MEPI scores differed significantly between both groups. Despite not performing ALR, an overall pronation loss was noted.[13]

Stragier et al. found a significant difference in flexion-extension arc improvement and pronation loss when comparing patients with an injury-to-treatment interval of less than 6 months, to those who received treatment over 6 months after injury. Patients in the first group had a greater improvement of flexion-extension and less loss of pronation than the latter group. They also found a significant difference in radiological outcomes between both groups. Also, patients under the age of six at the time of surgery all had a good radiological outcome, compared to only 50% of patients receiving surgery after the age of six.[15]

Splinting of the forearm in neutral rotation rather than in supination did not prevent the occurrence of postoperative pronation deficits.[22]

K-wire fixation or ALR did not influence the radiographic outcome in the series of Çevik et al., who compared four different management techniques. They could not demonstrate a statistically significant relationship between the loss of ROM, OES, surgical strategy, injury-to-surgery interval, age at the time of surgery, and Bado type. Open reduction with ALR seemed to cause the most loss in both supination and pronation compared to the three other applied strategies in their study. Two patients in their series developed RH hypertrophy; they both sustained a RH fracture at the time of injury.[26]

In the study of Gallone et al. nonunion and delayed union after osteotomy was significantly correlated to the osteotomy site and the postoperative loss of angulation. Children undergoing distal ulnar osteotomy showed a significantly higher rate of delayed union or nonunion, reduced angulation of the osteotomy correction, and an inferior shift of the RH. Nonunion and delayed union only occurred when the osteotomy was performed on the distal 52.5% of the ulna. Noteworthy is the fact that they lengthened the ulna considerably, up to 37 mm in one case.[20] Di Gennaro et al. also reported a nonunion in one patient who underwent an osteotomy in the distal third of the ulna, and delayed union occurred in two patients with an osteotomy at the middle third of the ulna.[6]

Osteoarthritic changes at the RC joint level do not seldomly occur, especially in longer existing chronic Monteggia lesions. Eamsobhana et al. could not determine any factor, through univariate analysis, that was significantly associated with a fair or poor radiological outcome. Their patients who developed osteoarthritic changes were either >11 years old and/or got treatment more than 2 years after the initial injury. In three of those cases, the RH stayed completely reduced. None of the patients who underwent surgery <24 months after incurring the injury developed osteoarthritic changes or RH hypertrophy.[14] Deformation of the RH at the time of Monteggia fracture-dislocation diagnosis might compromise successful treatment because of the lack of joint congruity, mobility limitations and potential associated pain.[22] Despite the occurrence of dysplastic changes in a long-standing RHD in children, it is argued that young patients have a high remodelling and restauration potential that might improve joint congruency once RH reduction is achieved.[4]

Gallone et al. could not identify any correlation between the patient's age at the time of surgery, the shape of the RH at the time of surgery, the surgeon's experience, open reduction, K-wire stabilization of the RC joint, and annular ligament repair or reconstruction, and the clinical and radiological outcomes. They noted that excessive lengthening of the ulna did not contribute to the relocation of the RH and was associated with a reduced pronosupination arc.[20]

Patients treated earlier had a greater postoperative ROM than those who had a longer injury-to-surgery interval in the series of Ngoc Hung et al.[11]

According to Di Gennaro et al., K-wire pinning did not have a limiting effect on postoperative ROM.[6]

3.4. Complications

Commonly reported complications are loss of pronation, loss of supination, subluxation, redislocation, osteoarthritic changes of the RC joint, delayed union and nonunion.[5–9,11,13–21,23,25] Pin tract infection was observed in two series.[4,24] Three authors reported postoperative elbow contracture.[13,17,21] Other mentioned complications are dysesthesiasis,[24] hypertrophic scar,[23] cubitus valgus,[11,19] heterotopic ossification,[17] K-wire breakage,[15] and transient posterior interosseus nerve palsy.[6]

Chen et al. encountered one transient postoperative compartment syndrome in the case in their series with the highest ulnar dorsal angulation (24.8°) that led to a loss of 20° ROM in supination and a mild degree of Volkmann contracture. They attributed the occurrence of the

Table 4
Overview reported outcomes and complications of the included outcome studies on chronic Monteggia in children.

Study	Follow-up time [months]	Radiological outcome†	Functional scoring ‡	Clinical outcome Mean (F)lexion / (E)xtension at final follow-up (range or ±SD)	Clinical outcome Mean (P)ronation / (S)upination at final follow-up (range or ±SD)	Recorded complications
Bor[4]	42 (24-72)	Good (4)	*NR*	(F) 150° (E) 0°	(P) 90° (S) 85° (-70-90°)	Pin tract infection (1)
Kosev[5]	48 (30-66)	Good (3) Fair (1*)	KEPS Excellent (3) Good (1)	(F) 141.25° (135-150°) (E) -2.5° (-10-5°)	(P) 67.5° (50-85°) (S) 86.25° (75-90°)	Mild residual subluxation (1)
Di Gennaro[6]	66 (12-292)	Good (15) Fair (5*) Poor (1) Excised RH (1) *(RH deformity (11))*	KEPS Excellent (14) Good (4) Fair (4) PostOP mean 91 (65-100)	(F) 134.32° (110-140°) (E) 5° (0-15°)	(P) 83.86° (60-90°) (S) 74.55° (-45-90°)	Transient posterior interosseus nerve palsy (1) Nonunion ulna (1) Delayed union (3) Residual subluxation (5) Redislocation (1)
Megahed[7]	19.5 (12-26)	Good (14) Fair (2*)	MEPI Excellent (8) Good (5) Fair (3)	Flexion-extension arc: mean 129° (110-145°)	Pronation-supination arc: mean 154° (140-170°)	Residual subluxation (2)
Lu[8]	18 (8-36)	Good (23)	KEPS\ PreOP mean 85 (75-95) PostOP mean 90 (70-100)	(F) 135° (130-145°) (E) 5° (0-10°)	(P) 70° (65-80°) (S) 80° (70-90°)	None observed
Park[9]	45.6 (12-168)	Good (21) Poor (1)	MEPI PreOP mean 81.1 (±9.4) PostOP mean 89.5 (±8.3) KEPS PreOP mean 80 (±8.2) PostOP mean 86.6 (±8.2)	(F) 135° (130-140°) (E) 4° (0-10°)	(P) 81° (60-80°) § (S) 71° (70-90°)	Anterior radial head dislocation (1) Delayed union (2) Cosmetic (1)
Xu[10]	10 (6-17)	Good (5)	Broberg & Morrey Rate Index Excellent (5)	(F) 142° (140-145°) (E) -1° (-5-0°)	(P) 62° (60-70°) (S) 95° (90-110°)	None observed
Ngoc Hung[11]	40.8 (24-61)	Good (12) Fair (1*)	KEPS Excellent (9) Good (3) Fair (1) PreOP mean 75.38 PostOP mean 93.07	Flexion-extension arc: mean 127.7° (120-140°)	(P) 67.69° (50-75°) (S) 70° (40-80°)	Nonunion ulna (1) Cubitus valgus (2) Anterior subluxation (1)
Agarwal[12]	13 (7-21)	Good (11)	*NR*	Mean increase in flexion 20° (10°-40°) *Extension NR*	Mean increase supination: 1.8° (-20°-30°) *Pronation NR*	NR
Chen[13]	21 (15-49)	Good (17) Fair (2*+1**)	MEPI PreOP mean 80 (70-90) PostOP mean 94 (70-98)	(F) 124° (100-140°) (E) -4.5° (-25-0°)	(P) 65° (50-90°) (S) 77° (45-90°)	Mild persistent radial head subluxation (2) Osteoarthritis (1) Transient post-operative compartment syndrome (1)
Eamsobhana[14]	42.2 (15-120)	Good (22) Fair (2*+4**) Poor (2)	KEPS Excellent (23) Good (3) Fair (2) Poor (2)	(F) 126.21° (100-140°) (E) -2.83° (-30-0°)	(P) 71.55° (45-80°) (S) 73,28° (45-85°)	Subluxation (2) Complete dislocation (2) Mild osteoarthritis (4)
Stragier[15]	132 (67-206)	Good (9) Fair (2*&**+3**)	*NR*	(F) 146.1° (140-155°) (E) -5° (-30-0°)	(P) 74.2° (45-90°) (S) 89.6° (70-100°)	K-wire breakage (1) Postoperative infection (1) Subluxation: anterior (1) & posterior (1) Osteoarthritic changes (5)

(*continued on next page*)

Table 4 (*continued*)

Study	Follow-up time [months]	Radiological outcome†	Functional scoring ‡	Clinical outcome Mean (F)lexion / (E)xtension at final follow-up (range or ±SD)	Clinical outcome Mean (P)ronation / (S)upination at final follow-up (range or ±SD)	Recorded complications
Take[16]	12 (11-120)	Good (3) Fair (2*)	KEPS Excellent (4) Good (1) PreOP mean 65 (50-75) PostOP mean 94 (80-100)	(F) 140° (135-150°) (E) 2° (0-10°)	(P) 81° (60-90°) (S) 84° (50-100°)	Subluxation: anterior (1) & posterior (1)
Mazhar[17]	30.8 (3-70)	Good (7)	KEPS Excellent (6) Good (1) PostOP mean 96.4 (85-100)	Flexion-extension arc: mean 137.9° (130- 150°)	(P) 65.7° (30-85°) (S) 72.1° (30- 90°)	Flexion contracture (-10°, -35°) (2) Nonunion ulna (1) Heterotopic ossification (1)
He[18]	> 12 months	Good (14) Poor (3)	MEPI Excellent (10) Good (4) Fair (3) PostOP mean 92.1 (±2.7)	*NR*	*NR*	Redislocation RH (3)
Wang[19]	27 (16-44)	Good (13)	KEPS Excellent (10) Good (3) PostOP mean 93.5 (80-100)	Loss of extention (3) (20°, 30° & 35°)	"No rotational limitations"	Delayed union ulnar osteotomy (3) Cubitus valgus (1) Skin irritation (< protruding plate) (1)
Gallone[20]	36 (12-132)	Good (8) Fair (6*) Poor (6)	KEPS Excellent (14) Good (3) Fair (2) Poor (1) PostOP mean 88.7 (35-100)	(F) 133.25° (100-140°) (E) 3.75° (0-15°)	(P) 78.5° (5-90°) (S) 73.25° (-45-90°)	Aseptic nonunion ulna (3) Delayed union (1) Residual subluxation (6) Complete dislocation (6)
Liao[21]	33.8 (8-87)	Good (30) Fair (2*) Poor (1)	Mayor Elbow Score PreOP mean 79.4 (±7.6) PostOp mean 97.7 (±2.8)	(F) 135.94° (±9.39°) (E) 0° (-5-1.5°)	(P) 79.27° (±7.02°) (S) 83.39° (±7.3°)	Redislocation (1) Subluxation (2) Mild ischemic contracture with recovery (1) Compartment syndrome with full recovery (1)
Soni[22]	36 (12-72)	Good (6)	*NR*	(F) 140° (E) 0°	(P) 80.83° (70-90°) (S) 87.5° (75-90°)	None observed
Kumar[23]	16.2 (14-24)	Good (16) Fair (1*)	MEPI PreOP mean 76.76 (±1.71) PostOP mean 91.11 (±1.11) KEPS PreOP mean 76.94 (±2.24) PostOP mean 91.35 (±1.27)	"full ROM" (16) Terminal flexion restriction (1)	"Full ROM"	Mild subluxation (1) Hypertrophic scar (10)
Yuan[24]	25.9 (13-41)	Good (11)	Quick DASH 0 (10) >1 (1) PostOP mean 1.24 (0-13.6)	Comparable to not-injured side (8) Not comparable to not-injured side (3)	Comparable to not-injured side (8) Not comparable to not-injured side (3)	Immediate post-op redislocation (1) Pin tract infection (1) Dysesthesiasis radial nerve territory (1)
Musikachart[25]	29.90 (12-84)	Good (17) Fair (2*) Poor (2)	KEPS Excellent/ good (19) Fair/ poor (2)	(F) 135.71° (100-150°) (E) 4.29° (0-40°)	(P) 73.10° (45-85°) (S) 73.81° (30-90°)	Posterior dislocation (2) Subluxation (2)
Çevik[26]	62 (48-85)	Good (17) Fair (1**)	OES Mean funct. score 90Mean sociopsych. score 85 Average pain score 86	(F) 130.8° (120-155°) (E)-0.8° (-30-10°)	(P) 77.5° (45-90°) (S) 72° (0-90°)	Mild osteoarthritic changes (1)

† Good = Complete reduction radial head, no osteoarthritic changes, Fair = Radial head subluxation* or presence of osteoarthritic changes**, Poor = Radial head dislocation[29]
‡ KEPS = Kim Elbow Performance Score, MEPI = Mayo Elbow Performance Index, OES = Oxford Elbow Score - [Postoperative values if not specified]
NR (=Not Reported), RH (=Radial Head), § = not reliable reported value

compartment syndrome to the amount of distraction at the osteotomy site.[13]

Wang et al. observed three cases of delayed union in their study, which might be caused by excessive lengthening of the ulna. Therefore, they suggest the use of an autologous bone graft in cases requiring lengthening of more than 10 mm.[19]

3.5. Revisions

Both Gallone et al. and Di Gennaro et al. performed secondary open RH reduction with ALR in respectively eleven out of twenty cases and eight out of twenty-two cases, because of improper reduction at the time of external fixator removal.[6,20]

Revision surgery because of delayed union or nonunion, necessitating bone-grafting, is reported by three authors.[6,11,20]

Two patients in the series of Eamsobhana et al. underwent revision surgery because of persisting complete dislocation of the RH. They underwent an open reduction and radius shortening in one case, and open reduction with rotational osteotomy in the other. In both cases, the RH redislocated, possibly due to abnormalities of the configuration of the distal humerus and proximal radioulnar joint. When joint incongruity is a cause of failure, they do not recommend further reduction attempts.[14]

In the series of Stragier et al. one patient had persisting RH protrusion and pain. The RH was eventually resected, and an open Outerbridge-Kashiwagi procedure was performed because of elbow blockage. In another case, arthrolysis was performed because of functional impairment and osteoarthritic changes of the RC joint.[15]

4. Discussion

A standardized treatment of chronic Monteggia fracture-dislocation in children could not be established to date. The lack of consensus might be attributed to the variable presentation of chronic Monteggia lesions, their relative rarity, and consequently the limited number of patients being eligible to be included in prospective comparative treatment studies. None of the recent outcome studies aimed at directly comparing outcomes of different management strategies. Some authors reported outcomes of a series that included different management strategies.[6,9,14,18,25,26] While most studies reported outcomes of a single pre-defined management technique in the management of chronic Monteggia.[4,5,7,8,10–13,15–17,19–24]

Small sample sizes, the retrospective nature of most outcome studies, variable presentation of the fracture-dislocation, and the lack of randomization make it hard to compare outcomes of different management strategies within the studies. Also, comparing outcomes between case series that report on alternative techniques is difficult for several reasons. First of all, outcomes are not reported according to a standardized protocol. Many outcome parameters are similar, but not exactly the same, leaving room for interpretation. Furthermore, outcome differences between studies must be interpreted with caution, since interobserver variability might affect the recorded outcome data. Lastly, patient demographics, injury-to-surgery intervals and follow-up time wildly vary both within and among the included studies.

In none of the studies a clear distinction was made regarding the treatment of the distinct Monteggia types. Different lesion types might require a different approach.

Small sample-size series are indicative, but there is a need for further prospective, randomized studies to evaluate the best treatment option for chronic Monteggia fracture-dislocation.

5. Conclusion

Due to the complexity of long-standing RHD and the unpredictability of outcomes in treating chronic Monteggia lesions, early diagnosis, and achieving a stable reduction, preferably in the acute setting, are paramount. Once the chronic stage is entered, a consensus management strategy is currently lacking. Nonetheless, in recent literature, surgical management became the mainstay of treatment. Obtaining stable RH reduction can be regarded as the main objective of any management strategy, regardless of the Monteggia type. Many different techniques have been described in recent literature to achieve this. Proximal ulnar, overcorrection osteotomy is key in many proposed treatment protocols and yields good overall results. Indications for annular ligament repair or reconstruction and/or transcapitellar pinning are undetermined, and their added value remains controversial. Because of the tendency to obtain more satisfactory radiological and clinical results in younger patients, with a short injury-to-surgery interval, it is advisable to promptly proceed to surgical treatment once chronic Monteggia fracture-dislocation is diagnosed.

List of contributions

Tom Gryson, MD (Contribution: study design, manuscript preparation).

Alexander Van Tongel, MD PhD (Contribution: manuscript preparation).

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