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A salvage procedure: Radial head excision in children and adolescents—short-to-midterm outcomes and overview of the literature

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Abstract

Purpose: Purpose of the study was to report the outcomes after radial head excision in children and adolescents in addition with a review of the current literature.

Methods: We report a series of five children and adolescents, who had undergone a post-traumatic radial head excision. Clinical outcomes were evaluated in terms of elbow/wrist range of motion, stability, deformity and discomforts or restrictions at two follow-up points. Radiographic changes were evaluated.

Results: Patient's age at time of the radial head excision averaged 14.6 (13–16) years. Mean time from the injury to the radial head excision was 3.6 (0–9) years. Follow-up I averaged 4.4 (1–8) years and follow-up II 8.5 (7–10) years. At follow-up I, patients showed an average elbow range of motion of 0-10-120° Ext/Flex and 90-0-80° Pro/Sup. Two patients reported discomfort or pain at the elbow. Four (80%) patients had a symptomatic wrist with pain or crepitation at the distal radio ulnar joint. In three (60%) of them, an ulna plus at the wrist was present. Two patients required ulna shortening and autograft stabilization of the interosseous membrane. At final follow-up, all patients reported full functioning with daily activities. Restrictions were present with sport activities.

Conclusion: Functional results at the elbow joint might be improved and pain syndromes lessen due to the radial head excision. Problems at the wrist are likely secondary to the procedure. A critical analysis of other options should be performed ahead of the procedure and a careless application should be avoided by all means.

Level of evidence: IV

Keywords: Radial head excision, children, pseudarthrosis, radial head, salvage procedure

Background

Injuries to the proximal radius may likely result in complications such as radial head overgrowth, nonunion, cross-union or osteonecrosis and following limitations in the elbow range of motion is a common problem.[1,2] Some patients may present with a combination of a painful elbow and significantly limited range of motion. Further intervention may be necessary to restore their elbow function and lessen their pain. In selected patients, radial head resection is performed, which in general is not recommended before skeletal maturity and not as an initial fracture treatment in pediatric patients, if other treatments

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fail and limited range of motion persists.[2,3] It has been described by few authors in small patient populations.[4–10] Dreaded complications after radial head excision are proximal migration of the radius which leads to relative ulna positive variance increase at the wrist, regrowth of the radial head, cross-union, valgus deformity or instability of the elbow, which has been mainly described after resection of the radial head in congenital[11–15] resulting in poor outcomes.[5]

The purpose of the study was to evaluate clinical and radiographic outcomes after radial head resection for post-traumatic disorders in children and adolescents in addition to a review of the literature.

Methods

The study was accepted by the institutional ethic committee of the Ruhr-University Bochum (17-6121-BR). Between 2000 and 2018, all children and adolescents, up to the age of 17 years, who had undergone a post-traumatic radial head excision were identified. A retrospective chart review and review of all available radiographic data were performed. Demographics, initial diagnosis, treatments, and reasons for radial head resections were evaluated. To determine skeletal maturity, we differentiated open or closed distal and proximal radius physes at the time of radial head resections on plain anterior-posterior (AP) and lateral radiographs. We were able to include five patients, who had a follow-up >12 months with an average of 4.4 years (1–8 years, SD 2.7) and reached 4 of them by phone for in a second follow-up with an average of 8.5 years (7–10 years, SD 1.3). Verbal consent was obtained from the study participants or legally authorized representatives to report individual cases. The clinical outcomes were evaluated at follow-up I and II in terms of elbow and wrist range of motion, elbow and wrist stability, elbow deformity such as cubitus valgus, pain, pain medication and discomforts or restrictions with daily and sport activities. The within-the-charts documented range of motion was used to establish differences during the follow-up and calculate the mean range of motion.

Radial head resections were performed via a lateral Kocher approach. According to the records, except of one case with additional refixation of the coronoidal process, at the time of the radial resection no additional stabilizing procedures, then suture of the annular ligament, if possible and capsula followed by a layered wound closure, were performed and all elbows were reported to be stable at this time.

To evaluate the functional outcomes we used the Mayo Elbow Performance Score (MEPS), which comprises four sections, pain intensity, motion, stability and function. Calculations were done online http://www.orthopaedic-score.com/scorepages/mayo_elbow.html. Excellent results were scores >90, good 75–89, fair 60–74 and poor were scores < 60. In addition, the Mayo Wrist Score (MWS) was used to evaluate the wrist pathology subsequent to the radial head resection, which comprises four categories, pain, satisfaction, range of motion, and grip strength. Calculations were done online https://www.orthopaedic-score.com/scorepages/mayo_wrist_score.html. Excellent results were scores 90–100, good 80–89, fair 65–79, and poor were scores < 65. MEPS and MWS were evaluated at follow-ups I and II.

An isokinetic cybex test of both elbows in a Biodex Multi Joint-System 3 to objective the strength of the injured elbow compared to the uninjured elbow was performed in four patients at follow-up I. The isokinetic tests were performed at 60° Ext/Flex and 120° Ext/Flex. The maximum hinge moment in Newton Meter (NM), the hinge moment (NM) at 18 s, the total energy in Joule (J), and the power in Watts were measured. The deficits of the injured elbow compared to the uninjured elbow were calculated in percent for each parameter. Differences > 25% between the extremities were defined as significant.

The radiographic outcomes were evaluated at an AP and lateral view of the elbow and, if available, AP and lateral radiographs of the ipsilateral wrist. Degenerative changes such as joint narrowing, subchondral sclerosis and osteophytes at the elbow and wrist were documented. Radial migration resulting in relative ulna positive variance increase at the wrist was noted. At follow-up I, complete AP and lateral view of the elbow was available in all five patients. In addition, four patients had radiographs of the ipsilateral wrist and in three patients additional radiographs of the contralateral wrist were present. Three patients had clinical photographs with documented range of motion of both elbows.

Results

The patients were two girls and three boys. Underlying injuries were two radial head/neck fractures, one elbow dislocation with radial head/neck fractures and fractures of the coronoid process and two Monteggia-like lesions (Table 1). Age averaged 10.4 years (4–16 years, SD 5.2) at the time of initial injury and 14.6 years (13–16 years, SD 1.5) at the time of radial head resection. The mean time to radial head resection was 3.6 years (0–9 years, SD 4.9). The elbow and wrist physes were closed in three patients, and the wrist physis was still open in two patients at the time of radial head removal. One procedure was primarily performed, because of fracture irreducibility, two within the first year after trauma and two >1 year after trauma. Except of this patient in all other patients, initial fracture treatment was not performed at our institution (Table 1). Two patients required further operative interventions after the radial head resection (Table 2).

All patients showed a good elbow range of motion with follow-up I, averaging 0-10-120° Ext/Flex and 90-0-80°

Table 1. Patient characteristics.

ID	Gender	Diagnosis	Age @ injury (years)	Initial treatment	Reason for resection	Age @ resection (years); physis elbow	Time to resection (years)
2	F	Radial head fracture dislocation	6	Unknown; prox. radial shortening osteotomy with temporare radio-humeral arthrodese (5 years after trauma ex domo)	Radial head overgrowth with complete loss of supination	16; elbow(c), wrist(c)	9 years
5	M	Elbow dislocation, radial head fracture, proc. coronoideus fracture	16	Radial head resection, coronoideal process reconstruction	Comminuted fracture, failed reconstruction	16; elbow(c), wrist(c)	-
6	M	Monteggia-like lesion	4	Plate fixation (ex domo)	Permanent posterior dislocation radial head, Ext/Flex 0-30-110°; Pro/Sup 30-0-0°	13; elbow(c), wrist(o)	9 years
7	M	Monteggia-like lesion	12	1. Non-operative (ex domo); 2. Open arthrolysis	Permanent radial head dislocation; Ext/Flex 0-70-100° Pro/Sup 80-0-10°	13; elbow(c), wrist(o)	9 months
10	F	Radial head fracture dislocation	14	ESIN + screw fixation (ex domo)	Symptomatic nonunion; Ext/Flex 0-15-120°, Pro/Sup 40-0-80°	15; elbow(c), wrist(c)	6 months

(c) = closed physis; (o) = open physis; ESIN = elastic stable intramedullary nailing.

Table 2. Clinical outcomes.

ID	FU I (years)	FU II (years)	Elbow ROM	Symptomatic elbow?	Symptomatic wrist?	Cubitus valgus?	Secondary operative procedures?
2	8	—	Ext/Flex 0-0-120° Pro/Sup 90-0-70°	Pain after sport activities	Pain while pulling weights	30°	No
5	1	8	Ext/Flex 0-25-110° Pro/Sup 90-0-90°	No	No	No	No
6	4	7	Ext/Flex 0-0-130° Pro/Sup 90-0-50°	No	DRUJ: radio-carpal impingement, Pain with weight lifting, sports, screw driving, ulna plus (radiographic)	No	An ulna shortening osteotomy with gracilis tendon membrane stabilization 3 years after radial head removal
7	3	10	Ext/Flex 0-5-120° Pro/Sup 90-0-90°	No	Pain with weight lifting, mild instability DRUJ, ulna plus (radiographic)	No	No
10	6	9	Ext/Flex 0-0-130° Pro/Sup 90-0-90°	Crepitation, humero-ulnar	Crepitation wrist with weight lifting, no pain; ulna plus (radiographic)	No	Anconeus interposition arthroplasty at the elbow 4 years after radial head removal ulna shortening osteotomy with gracilis tendon membrane stabilization 6 months later

FU: follow-up; ROM: range of motion; Ext: extension; Flex: flexion; Pro: pronation; Sup: supination; DRUJ: distal radio ulnar joint.

Pro/Sup (Table 2). Two patients reported discomfort or pain at the elbow. In one woman (ID 10) an anconeus interposition arthroplasty was performed 4 years after radial head excision, 6 months later she underwent an ulna shortening osteotomy with plate fixation and autograft stabilization of the interosseous membrane. One cubitus valgus was present. Four patients had a symptomatic wrist with pain or crepitation at the distal radio ulnar joint (DRUJ). In three of them, radiographic relative ulna positive variance increase at the wrist was present. In one other patient (ID 6), an ulna shortening osteotomy with a membrane stabilization using a gracilis tendon was performed 3 years after radial head resection, because of his symptomatic wrist (Table 2). Except for one patient all presented an excellent outcome score for the injured elbow after radial head resection. Despite this, the outcome at the wrist was

Table 3. Outcome scores.

ID	Mayo wrist score		Mayo elbow performance score	
	FU I	FU II	FU I	FU II
2	70	—	90	—
5	80	95	95	95
6	60	55	95	80
7	75	90	95	95
10	60	80	70	85

Mayo Elbow Performance Score: Excellent > 90, good 75–89, fair 60–74, poor < 60; Mayo Wrist Score: Excellent 90–100, good 80–89, fair 65–79, poor < 65. FU: follow-up.

Table 4. Isokinetic tests showing strength deficits in percent (%) compared to the uninjured side.

ID	Ext 60°/s	Flex 60°/s	Ext 120°/s	Flex 120°/s	Dominant arm injured?
2	Max. HM: 39.7% HM@18s: 0.0% Total energy: 49.6% Power: 37.5%	Max. HM: 54.1% HM@18s: 44.9% Total energy: 69.1% Power: 66.5%	Max. HM: 35.2% HM@18s: 14.1% Total energy: 42.8% Power: 43.8%	Max. HM: 40.9% HM@18s: 17.9% Total energy: 67.5% Power: 69.4%	No
5	Max. HM: 38.5% HM@18s: 35.4% Total energy: 42.6% Power: 41.1%	Max. HM: 52.7% HM@18s: 55.2% Total energy: 58.8% Power: 56.8%	Max. HM: 33.7% HM@18s: 35.0% Total energy: 39.5% Power: 40.9%	Max. HM: 46.6% HM@18s: 60.3% Total energy: 53.5% Power: 53.3%	No
6	Max. HM: 41.4% HM@18s: 22.9% Total energy: 36.2% Power: 41.3%	Max. HM: 58.6% HMt@18s: 72.4% Total energy (J): 70.9% Power (Watt): 74.8%	Max. HM: 75.3% HM@18s: 65.9% Total energy (J): 83.1% Power (Watt): 85.6%	Max. HM: 54.1% HM@18s: 56.4% Total energy (J): 78.6% Power (Watt): 84.2%	Yes
7	Max. HM: 6.7% HM@18s: −6.7% Total energy: 9.2% Power: 4.2%	Max. HM: −10.2% HM@18s: −19.3% Total energy: 21.7% Power: 19.0%	Max. HM: 17.7% HM@18s: 10.3% Total energy: 17.5% Power: 22.4%	Max. HM: 24.9% HM@18s: −8.8% Total energy: 36.2% Power: 36.9%	No
10	—	—	—	—	—

Max. hinge moment = NM (Newton Meter); Hinge Moment@18s = NM (Newton Meter); Total energy = Joule; Power = Watt; − = (negative) the injured side has a higher value than the uninjured side. s: seconds; Max.: maximum; HM: hinge moment.

poor in two patients, fair in another two patients and good in one patient (Table 3). Three patients had significant strength deficits at the isokinetic testing compared to the uninjured side. In two of them the non-dominant arm was injured (Table 4). Degenerative changes were seen in one patient at the humero-ulna joint at the time of follow-up I. This patient had an additional injury to the coronoid process and required a reconstruction.

None of the patients required pain medication on a regular basis. All of them reported full functioning with daily activities. Restrictions were present with sport activities, pulling or pushing weights. All patients presented a stable elbow joint, one patient showed a mild instability at the DRUJ. At follow-up II, two patients presented still excellent with MEPS, one changed from excellent to good and one from fair to good. For MWS one patient remained with poor outcome while one improved from poor to good and two of them improved to excellent from either good and fair at follow-up I (Table 3). In Figures 1–3, we present the course of one patient for illustration as an example.

Discussion

Even though injuries to the proximal radius are rare in the pediatric population, they may result in poor outcomes and long-time disabilities with restricted elbow range of motion or pain due to multifaceted post-traumatic changes such as radial head overgrowth, malangulation, nonunion, osteonecrosis, or cross-union.[1,2,7,16] As these complications are more often associated by multiple reduction maneuver, open reduction or open osteosyntheses, in general, closed reduction or percutaneous procedures are recommended.[1,12]

We acknowledge that different initial treatments of the injuries in the present study may have led to different outcomes without the necessity for further intervention. Since initial intervention in four of the patients was not

Figure 1. The CT scan shows the symptomatic nonunion in a 15 years old female 6 months after ESIN (ID 10). The lateral radiographs document the radial head resection.

performed in our institution, we will not focus on the controversy about correct initial treatment in this article. In acute, subacute, or chronic situations, careful analysis of the underlying complexity of the previous injury should be performed and preserving treatment techniques preferred. Especially in patients with missed Monteggia-like-lesions with chronic radial head dislocations other options such as radial head distalization, open reduction of the radial head as well as internal or external ulna osteotomies should be discussed.[17–20]

The present discussion will focus on the outcomes after radial head removal as a salvage procedure if treatment of a proximal radial fracture has failed and surgeons are confronted to a symptomatic, painful elbow with significant restriction of the range of motion in a young adolescent or even a child.

Radial head removal has been described as a treatment option for congenital radial head dislocation[11,21–24] and congenital radio-ulnar synostosis[25] in children. Some authors have mentioned radial head resection as a salvage procedure for post-traumatic disorders at the proximal radius (Table 5).[4,6,7,10,27,28,32] Weise et al.[33] mentioned radial head resection if functional impairment and pain persist after radial head fracture after skeletal maturity.

In our series, all patients showed improved range of elbow motion and all but one had an excellent Mayo Elbow

Figure 2. The right X-rays show an AP lateral view of the wrist with an ulnar plus and the lateral view of the elbow of this patient 4 years later an anconeus interposition arthroplasty at the elbow was performed. She further developed a symptomatic wrist and required an ulna shortening osteotomy with stabilization of the interosseous membrane. The left X-rays show an AP and lateral view of the forearm after the ulna shortening osteotomy and stabilization of the interosseous membrane 6 months afterward.

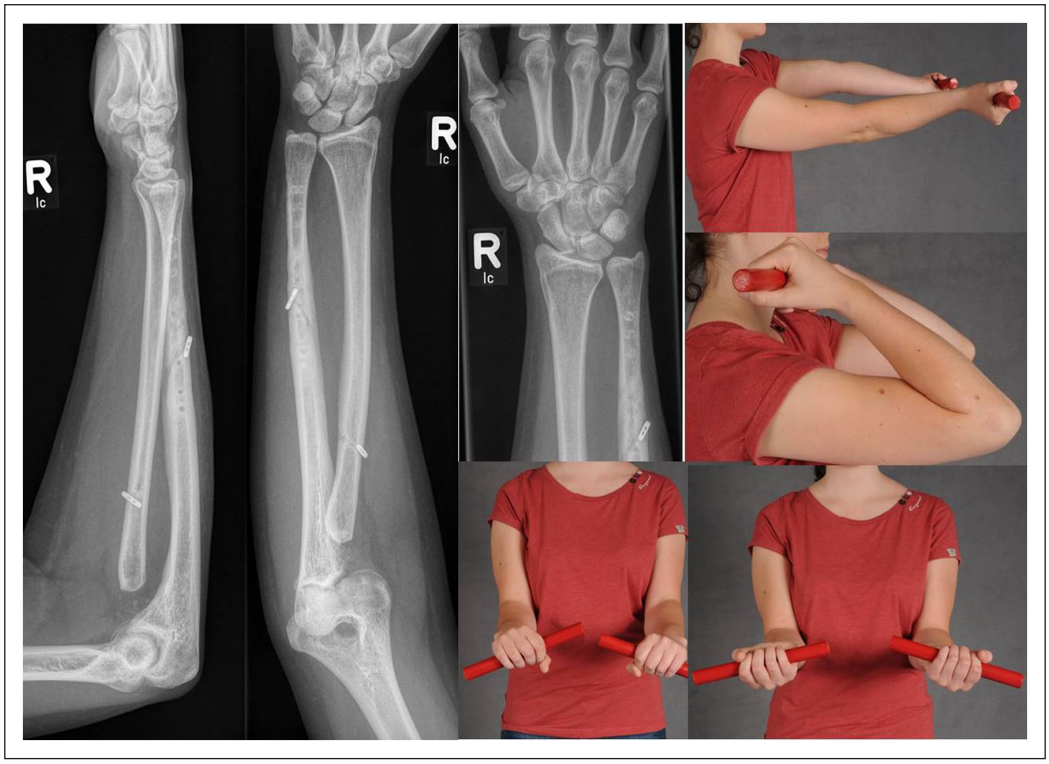

Figure 3. AP and lateral view of the forearm and AP view of the wrist show the follow-up I, 2 years later as well as the functional results with limited extension and pronation. The patient had still discomfort in her wrist.

Table 5. Literature of post-traumatic radial head removal.

Author/journal/year	Injury	Age @ resection	Follow-up	Ext/flex	Pro/sup	Pain	Cubitus valgus	Instability	Ulna plus	Overall result
Stoll et al.,[4] JBJS [Br]	Missed Monteggia	13:8 late resection 15:7 early resection	3.3 years	0-5-145° 5-0-130°	45-0-70° 80-10-0°	Yes No	Yes No	No Yes	—	—
Vince and Miller,[26] JBJS	Radial neck/head/elbow luxation (cross-union) Radial head/neck Monteggia	? +prosthesis +prosthesis	14 months 60 months 41 months	Cross-union recurrence? Cross-union recurrence	Cross-union recurrence Arc 70° Cross-union recurrence	—	—	—	—	—
Young et al.,[27] JPO	Avascular necrosis	Approx.12, +prosthesis secondary Approx.12 Approx.18	5.5 years 11 years 7 years	Decreased Limited 10-0-120°	Decreased Limited 40-0-85°	Yes — —	— Varus—	— —	— —	Continuous pain, decreased ROM Continuous limited ROM —
Hresko et al.,[6] JPO	12 Patients with post-traumatic changes proximal radius	12.3–17.8	3.6–13.4 years	Flexion arc 105–145°	Rotation arc 140–170	None: 4 Minimal: 6 Severe: 1 Moderate: 1	—	—	3–5 mm: 6 7–8 mm: 5 –2 mm: 1	Excellent: 1 Good: 6 Fair: 2 Poor: 3
Di Gennaro et al.,[28] MS	Missed Monteggia (Bado I)	13.7	24.3 years	0-10-130	75-0-80	Yes	Yes	Yes	—	—
King,[29] JBJS	Fracture dislocation Radial head fracture Fracture dislocation	14 14 + 19 (reoperation because of bony formation) 13	6 years 5 years 18 years	0-0-140 — —	75-0-90 20-0-80 Fixed at 25°supin	Yes Yes	Yes No	Yes No	—	Fair Fair Poor/cross-union
Waters and Stewart,[7] JPO	Radial neck nonunion	15	12 years	—	—	No	No	Mild	—	Pain-free, no restrictions with activity
Tay and Mahadev,[30] AAMS	Traumatic fracture dislocation prox. radius	10	3 years	Free	None	None	—	—	—	Regrowth prox. radius
Wegmann et al.,[9] JSES	Post-traumatic dislocation, post-traumatic synostosis	11	47.9 months	Non-significant improvement	Significant improvement ($p = 0.018$)	—	Yes (3×)	—	Yes (1×)	Mean DASH score 16.1; Mayo Elbow score 88
Nagda et al.,[31] IJO	Chondral shear fracture of the capitellum	12	12 months	10-0-140	Full ROM	No	—	No	—	—
Factor et al.,[10] SE	Congenitalradial head subluxation Prior Monteggia fracture Prior supracondylar fracture Prior Monteggia fracture	12 12 14 15	25 months 25 months 23 months 20 months	5–140 0–140 15–135 0–130	90–70 85–60 80–80 80–70	No Yes No No	— — — —	— — — —	No Yes Yes Yes	Mean DASH score 11.5; Mayo Elbow score 92.5; VAS 2
Farr et al.,[32] 2020	Intraarticular epiphyseal radial head fracture Subluxated radial head and bilateral olecranon pseudarthrosis of unknown origin Fishtail deformity several years after a supracondylar humerus fracture	13–16	2.5 years 12 months 16 months	0-15-140 0-15-115 0-3-130	60-0-60 Unlimited 70-0-60	No Minor No	— — —	— — —	No No No	DASH score 3.3; MEPS 100, Timmermann–Andrews Score 165 DASH score 6.7, MEPS 80, Timmermann–Andrews Score 150 DASH score 0, MEPS 95, Timmermann–Andrews Score 145

ROM: range of motion; MEPS: Mayo Elbow Performance Score; DASH: Disability of the Shoulder and Arm-Score; VAS: Visual Analog Scale.

Performance Score with follow-up I. Improved ROM was also described by Nagda et al.[31] at 1-year follow-up after radial head excision in a 12-year-old boy due to a late diagnosed chondral shear fracture of the Capitellum. Wegmann et al. reported radial head excision in five patients with post-traumatic dislocation or synostoses with an average MEPS of 88. They also stated a significant improvement of pronation/supination postoperatively compared with the pre-operative ROM, but with a significant lower strength of pronation, compared to the non-affected side.[9] In our patients, the elbow strength was also significantly lower on the injured arm in three of four patients. In two of them, the non-dominant side was affected. Di Gennaro et al. reported one 13.7-year-old child treated with resection of the radial head for radial head dislocation after a missed Monteggia lesion. At follow-up, 24 years, later the patient presented cubitus valgus deformity, elbow instability, ulnar nerve palsy, and elbow and wrist pain.[28] Two other cases of radial head excisions for a missed Monteggia fracture were described by Stoll et al.[4] One of the children presented with elbow pain and cubitus valgus.

At the time of radial head excision, no additional interposition or stabilization procedure was performed. Two patients underwent additional interposition or membrane stabilization procedures 3–4 years later. Farr et al. reported about three patients with initial corium interposition arthroplasty with radial head resection for radial head arthrosis with good clinical results and without complications. No proximal migration of the radius had occurred at the final follow-up after 19 months.[32] Factor et al. reported four patients (one congenital, three post-traumatic) after radial head excision followed by Achilles allograft interposition arthroplasty with averaged MEPS of 92.5 and improved ROM at 2 years follow-up. In all patients, proximal migration of the radius occurred despite the allograft interposition.[10]

We also saw problems at the wrist associated to the procedure in almost all patients. They were similar to the previously reported problems with pain at the DRUJ, ulna plus variance and instability and secondary procedures followed in two patients with ulnar shortening osteotomy with gracilis membrane stabilization. In theory, an additional distal epiphysiodesis or waiting until closure of the growth plate to evade the ulna plus may also have been a treatment option, which should be part of the decision plan. Hresko et al.[6] reported a secondary operation rate of 50% in patients with post-traumatic radial head excision. Coleman et al.[34] described degenerative changes in four of 17 adult patients with an average follow-up of 20 years. We were not able to correlate this to any other variables. In patients with post-traumatic growth arrest of the radius or non-traumatic ulna plus variance improvement of the Mayo wrist score after ulna shortening or ulna epiphysiodesis has been described.[35,36] Both patients in our series had ongoing problems at the wrist at follow-up I and were likely to require further operative intervention in the future.

Most authors suggest radial head excision not before skeletal maturity has reached and the distal radial physis is closed.[2,4,14] Nevertheless no altered results after skeletal maturity were indicated by Hresko et al. who reported beneficial results in 70% of their patients treated with radial head excision for a stiff, painful elbow joint with a mean follow-up of 7.8 years. 12 of 25 patients in their study populations had post-traumatic disorders. They concluded that waiting until skeletal maturity is not necessary in patients with sufficient symptoms.[6] All patients in our study had closed physis at the proximal radius, some showed open physes at the wrist at the time of radial head excisions. We were not able to show differences between those patients because of the limited number of patients. Radial head prosthesis as an alternative salvage procedure may be part of the decision-making process especially in adolescents as well, but the outcome data is limited in young patients. Rotman et al. reported a case series of five adolescent patients with different pathologies at the proximal radius requiring intervention, who were treated with a radial head prosthesis at a mean age of 14 years. The reported improving pain and axial forearm stability with an average follow-up of 8 years.[37]

Due to the retrospective design and the small patient numbers, a number of limitations apply for this study. Retrospectively, we are not able to perform a proper analysis of the initial treatment and the potential failures which may have caused the ongoing problems at the radial head. Furthermore, given the design, we are unable to clarify if any other treatment besides the radial head resection would have been possible or not. In addition, given the inhomogen underlying injuries in this study, the results of the patients may not be fully comparable with each other. Larger series are required to draw reliable conclusion and patients need to be observed for further 10 to 20 years to estimate the full amount of complications after this procedure. However, we were able to follow-up four out of five patients 8.5 years after radial head excision and 10.8 years after injury.

Conclusion

Considering our results and our literature review, radial head excision presents a salvage procedure for post-traumatic proximal radial changes in selected patients with a painful, symptomatic, elbow joint with significant limited range of motion. Decreasing of pain and improvement of the elbow range of motion might be achieved. The possibility of alternative treatment methods, depending on the underlying injury, should be carefully evaluated and discussed. But patients and parents must be carefully and completely informed about the procedure and it's likelihood of secondary wrist disorders, which might result in restrictions,

pain, and requirement of additional procedures. All pros and cons need to be reflected and discussed previously to the procedure and a wide, careless application of the procedure for all certain issues of the proximal radial head is to avoid by all means.

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Author contributions

CK: study design, analysis, writing; AB: data acquisition, writing; JC: data acquisition, writing; CC: data acquising, analysis; MK: analysis, critical revision; TAS: analysis, critical revision; MD: study design, critical revision. All authors have read and approved the manuscript.

Availability of data and materials

The authors confirm that the data supporting the findings of this study are available within the article or its supplementary materials.

Declaration of conflicting interests

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Ethics approval and consent to participate

The study was approved by the ethical committee of the Ruhr-University Bochum (17-6121-BR).

Consent for publication

Verbal consent was obtained from the study participants, and this study was approved by the ethics committee of the Ruhr-University Bochum.

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