J Shoulder Elbow Surg (2019) 28, 1457–1467

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Surgical revision of radial head fractures: a multicenter retrospective analysis of 466 cases

Michael Hackl, MD[a,*], Kilian Wegmann, MD, PhD[a], Boris Hollinger, MD[b], Bilal F. El-Zayat, MD, PhD[c], Dominik Seybold, MD, PhD[d], Thorsten Gühring, MD, PhD[e], Marc Schnetzke, MD[e], Kay Schmidt-Horlohé, MD[f], Stefan Greiner, MD, PhD[g], Helmut Lill, MD, PhD[h], Alexander Ellwein, MD[h], Michael C. Glanzmann, MD[i], Sebastian Siebenlist, MD, PhD[j], Martin Jäger, MD[k], Jörg Weber, MD[l], Lars P. Müller, MD, PhD[a]

[a]*Center for Orthopedic and Trauma Surgery, University Medical Center of Cologne, Cologne, Germany*
[b]*Ellenbogen- und Schulterchirurgie, Arcus Sportklinik, Pforzheim, Germany*
[c]*Center for Orthopaedics and Trauma Surgery, University Hospital Giessen and Marburg, Marburg, Germany*
[d]*Department of General and Trauma Surgery, BG University Hospital Bergmannsheil, Bochum, Germany*
[e]*Department of Trauma and Orthopaedic Surgery, BG Trauma Center Ludwigshafen at the University of Heidelberg, Ludwigshafen, Germany*
[f]*Orthopaedicum Wiesbaden, Wiesbaden, Germany*
[g]*Sporthopaedicum Regensburg, Regensburg, Germany*
[h]*Department of Orthopedics and Traumatology, Diakovere Friederikenstift, Hanover, Germany*
[i]*Upper Extremities Department, Schulthess Clinic, Zürich, Switzerland*
[j]*Department of Orthopaedic Sports Medicine, Klinikum rechts der Isar, Technical University of Münich, Münich, Germany*
[k]*Department of Orthopaedic and Trauma Surgery, University Medical Center Freiburg, Freiburg, Germany*
[l]*Department of Trauma Surgery, Orthopedics and Hand Surgery, Südstadt Hospital Rostock, Rostock, Germany*

Background: Radial head fractures lead to persisting disability in a considerable number of cases. This study aimed to investigate their most common revision causes and procedures.
Methods: This multicenter retrospective study reviewed the cases of 466 adult patients who had undergone surgical revision after operative or nonoperative treatment of a radial head fracture. The initial diagnosis was a Mason type I fracture in 13.0%, Mason type II fracture in 14.6%, Mason type III fracture in 22.8%, Mason type IV fracture in 20.9%, terrible-triad injury in 12.8%, Monteggia-like lesion in 13.1%, and Essex-Lopresti lesion in 2.0%. Initial treatment was nonoperative in 30.2%, open reduction and internal fixation (ORIF) in 44.9%, radial head arthroplasty in 16.6%, radial head resection in 3.7%, sole treatment of concomitant injuries in 2.6%, and fragment excision in 2.0%. Up to 3 revision causes and procedures were recorded per case.

The Institutional Review Board of the Medical Faculty of the University of Cologne approved this study (approval No. 16-461). Investigation performed by the German Society for Shoulder and Elbow Surgery (DVSE).

*Reprint requests: Michael Hackl, MD, Center for Orthopedic and Trauma Surgery, University Medical Center of Cologne, Kerpener Straße 62, Köln D-50937, Germany.
E-mail address: michael.hackl@uk-koeln.de (M. Hackl).

https://doi.org/10.1016/j.jse.2018.11.047

Results: The most common complications were stiffness (67.4%), instability (36.5%), painful osteoarthritis (29.2%), ORIF related (14.8%), nonunion or necrosis (9.2%), radial head arthroplasty related (7.5%), ulnar neuropathy (6.0%), and infection (2.6%). Revision procedures frequently included arthrolysis (42.1%), arthroplasty (24.9%), implant removal (23.6%), ligament repair or reconstruction (23.0%), débridement (14.2%), repeated ORIF (8.2%), and/or radial head resection (7.7%). Mason type I or II fractures were primarily revised because of stiffness and painful osteoarthritis. Complications after Mason type III fractures were predominantly ORIF related. Fracture-dislocations showed a wide range of complications, with instability and stiffness comprising the most common causes of revision.

Conclusions: The complications of radial head fractures are characteristic to their classification. Knowledge of these findings might guide surgeons in treating these injuries and may help counsel patients accordingly.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Radial head fracture; surgical treatment; nonsurgical treatment; complications; revision; salvage procedures

The radial head is vital to the biomechanics of the elbow joint. It provides a bony constraint against posterolateral rotation as well as valgus distortion of the elbow and plays a major role in axial load transmission along the forearm.[33,34,44] Fractures of the radial head are the most common elbow fractures in adults, with a reported incidence of 55 per 100,000 persons per year, and usually result from a fall on an outstretched arm.[12] With a mean age at the time of injury of 43 years, this pathology commonly affects young and active patients who rely on physiological elbow function for everyday activities.[13,37]

Rather than occurring as an isolated injury, radial head fractures are typically accompanied by concomitant fractures and/or soft-tissue lesions. These additional injuries include, among others, collateral ligament tears, dislocations, and fractures of the proximal ulna and the capitulum, as well as disruptions of the interosseous membrane.[24,25,31,35,41,42] The complexity of these osteoligamentous combination injuries may explain the persisting disability frequently encountered after radial head fractures.[9,13,16,23,26,27,29,39] A revision rate of up to 15% has been reported at 2 years after surgical treatment of radial head fractures.[28]

Despite this, we still lack definitive information about both the most common causes of revision after radial head fractures and their associated salvage procedures. We therefore studied the complications of radial head fractures in a retrospective, multicenter investigation to identify the most common causes leading to surgical revision and the most frequently performed revision and salvage procedures.

Materials and methods

This retrospective multicenter investigation was performed by the elbow committee of the German Society of Shoulder and Elbow Surgery (Deutsche Vereinigung für Schulter- und Ellenbogenchirurgie [DVSE]) and the elbow and hand committee of the Society for Arthroscopy and Joint Surgery (Gesellschaft für Arthroskopie und Gelenkchirurgie [AGA]) involving 1 Swiss and 11 German orthopedic and trauma departments. Adult patients who had undergone surgical revision between 2012 and 2016 after conservative or operative treatment of radial head fractures were included in this study by means of a retrospective chart and radiographic review.

Obtained data included the sex and age of patients, as well as the affected side, initial diagnosis, and initial treatment. The time from injury and/or prior surgery to revision, with up to 3 causes of revision and up to 3 revision or salvage procedures per patient, was recorded.

Overall, 466 patients who underwent surgical revision after a radial head fracture were found and included in this investigation. The mean age at the time of revision was 44.5 ± 16.3 years, and 55.7% of patients were men and 44.3% were women. The left side was injured in 65.0% of cases; the right side, in 35.0%. The mean time from injury or prior surgery to revision was 5.7 ± 13.2 years.

The initial diagnosis was available in 438 cases (94.0%; in the remainder, no prior radiographs were available) and predominantly consisted of multifragmentary injuries and fracture-dislocations (Fig. 1). The primary treatment was available for 457 patients (98.1%). Conservative therapy, mainly by temporary immobilization with the precise duration of immobilization infrequently documented, was performed in 138 patients (30.2%), whereas 319 patients (69.8%) were treated surgically (Fig. 2).

Results

Overall revision causes and procedures

Overall, the most common causes of revision among the 466 patients were stiffness (314 cases, 67.4%), instability (170 cases, 36.5%), and post-traumatic osteoarthritis (136 cases, 29.2%). Of the 170 cases of revision with instability, 65 (38.2%) had posterolateral rotatory instability of stage II to III, 38 (22.4%) had valgus instability, 28 (16.5%) had multidirectional instability, 19 (11.2%) had varus posteromedial rotatory instability, 9 (5.3%) had longitudinal forearm instability, 9 (5.3%) had persisting elbow dislocation, and 2 (1.1%) had proximal radioulnar instability; 38 of these revisions (22.4%) were associated with concomitant coronoid fractures. Less frequently, we observed complications directly related to open reduction and internal fixation (ORIF) (69 cases, 14.8%), symptomatic nonunion or (partial) necrosis of the radial head (43 cases, 9.2%), complications related to radial

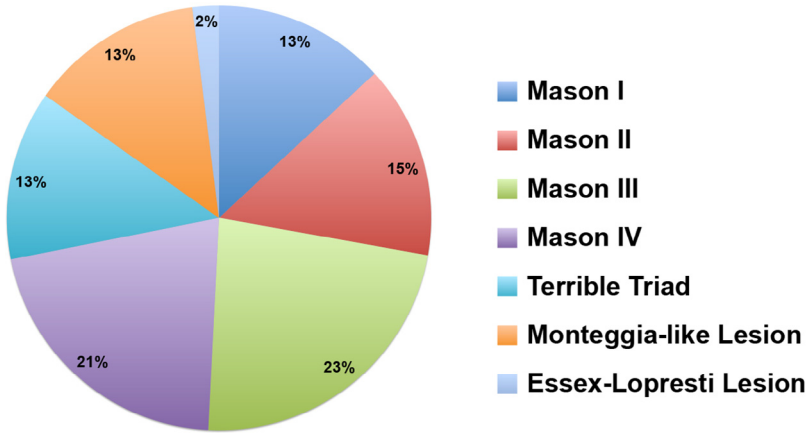

Figure 1 Initial diagnosis in study population (n = 438).

Table I Most common revision procedures after radial head fractures

Revision procedure	n	%
Arthrolysis	196	42.1
Open	104	22.3
Arthroscopic	92	19.8
Arthroplasty	116	24.9
RHA	76	16.3
Revision RHA	24	5.2
RCA	3	0.6
TEA	13	2.8
Implant removal	110	23.6
Removal of hardware	83	17.8
Removal of radial head implant	27	5.8
Ligament repair or reconstruction	107	23.0
LCL repair	17	3.6
UCL repair	4	0.9
Bilateral repair	7	1.5
LUCL reconstruction	55	11.8
UCL reconstruction	14	3.0
Box-loop reconstruction[14,18]	4	0.9
Central band or IOM reconstruction	4	0.9
Annular ligament reconstruction	2	0.4
Joint débridement	66	14.2
With microfracturing	38	8.2
With loose body removal	24	5.2
With plica resection	14	3.0
With joint lavage	12	2.6
Repeated ORIF	38	8.2
Radial head resection	36	7.7
With interposition arthroplasty	8	1.7
Ulnar nerve release	28	6.0
With anterior transposition	20	4.3
Hinged external fixator	11	2.4
Coronoid reconstruction	5	1.1

n, number of cases; *RHA*, radial head arthroplasty; *RCA*, radiocapitellar arthroplasty; *TEA*, total elbow arthroplasty; *LCL*, lateral collateral ligament; *UCL*, ulnar collateral ligament; *LUCL*, lateral ulnar collateral ligament; *IOM*, interosseous membrane; *ORIF*, open reduction and internal fixation.

head arthroplasty (35 cases, 7.5%), ulnar neuropathy (28 cases, 6.0%), and infection (12 cases, 2.6%).

The most common revision procedures comprised arthrolysis (42.1%), arthroplasty (24.9%), implant removal (23.6%), and ligament repair or reconstruction (23.0%).[14,18] Other common revision procedures included joint débridement (14.2%), repeated ORIF (8.2%), radial head resection (7.7%), and ulnar nerve release (6.0%) (Table I).

Revision causes depending on fracture classification

For Mason type I and type II injuries, the main revision causes were stiffness and symptomatic osteoarthritis (Figs. 3 and 4). For Mason type III fractures, however, apart from elbow stiffness, surgical revision was performed predominantly because of nonunion or necrosis and/or loss of reduction (Fig. 5). For fracture-dislocations (Mason type IV fractures, terrible-triad injuries, and Monteggia-like injuries), we observed a broad variety of complications, with instability and stiffness presenting the main reasons for revision (Figs. 6, 7, and 8).

Revision causes depending on initial treatment

The most common complications after conservative therapy were stiffness, symptomatic osteoarthritis, instability, and secondary fracture displacement (Fig. 9). After ORIF, revisions were performed mainly because of stiffness, instability, loss of reduction, symptomatic osteoarthritis, radial head necrosis, and plate and/or screw impingement (Fig. 10). Radial head arthroplasty commonly resulted in surgical revision for stiffness, overlengthening, symptomatic osteoarthritis, instability, ulnar neuropathy and mal-tracking, loosening, breakage, and/or disassembly of the radial head implant (Fig. 11).

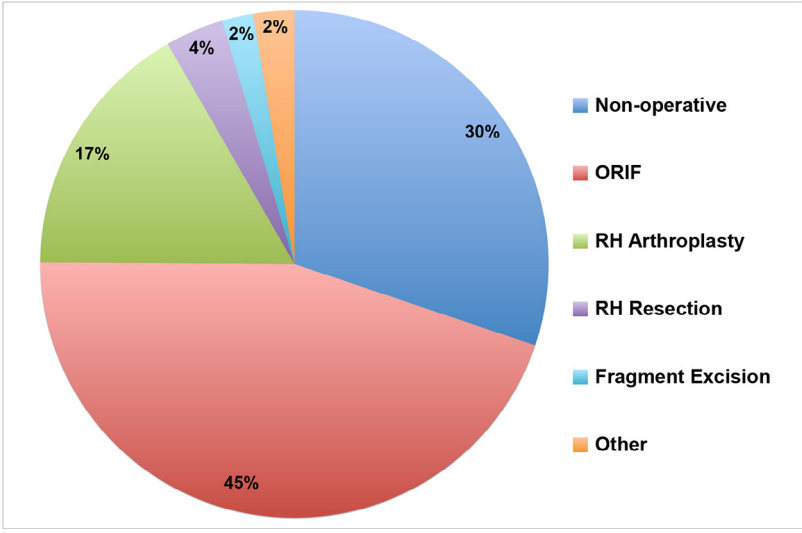

Figure 2 Initial treatment in study population (n = 457). *ORIF*, open reduction and internal fixation; *RH*, radial head.

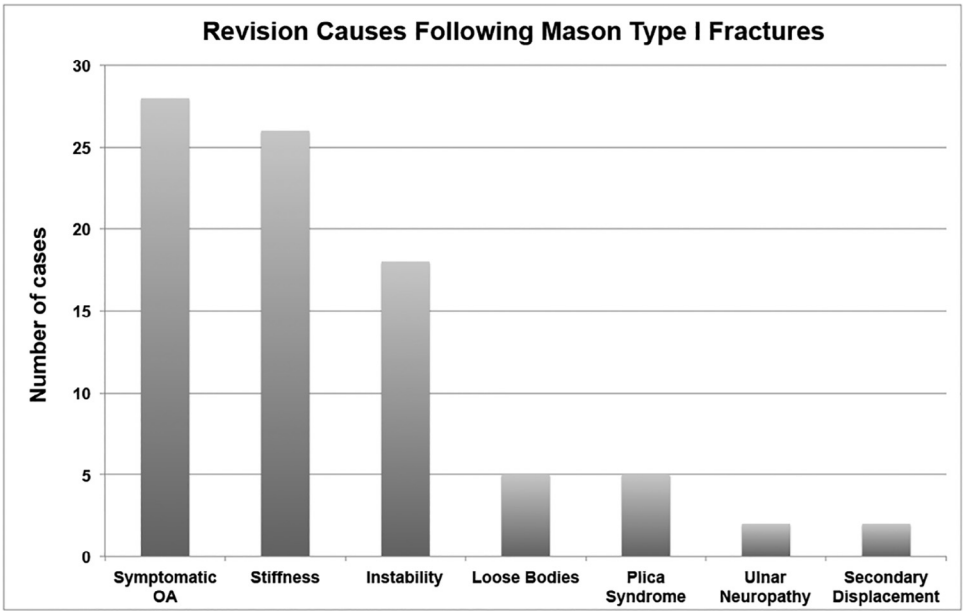

Figure 3 Surgical revision causes after Mason type I fractures (n = 57). *OA*, osteoarthritis.

Discussion

Disability persists in a considerable proportion of patients who have had radial head fractures, especially those with concomitant osteoligamentous injuries. Patients can be counseled that stiffness, instability, and painful osteoarthritis present the most frequently observed sequelae and that arthrolysis, partial or total joint replacement, hardware removal, and collateral ligament repair or reconstruction are the most common surgical revision procedures.

A broad array of complications accompany fracture-dislocations, the most common of which are instability and stiffness. In contrast, causes of surgical revision after isolated 2-part fractures of the radial head (Mason types I and II) primarily comprised painful osteoarthritis and stiffness. Although detailed information on specific conservative treatment regimens was not conclusively retrievable in this retrospective analysis, immobilization of the elbow in a splint for more than 2 weeks was documented in approximately two-thirds of nonoperatively treated cases. This may emphasize the clinical importance of early functional aftercare of conservatively treated nondisplaced or slightly displaced radial head fractures.[19] It has to be considered that Mason type I fractures comprise approximately 74% of all radial head fractures.[12] In our study, only 13% of all revision cases were related to an initial Mason type I injury. Overall, complications

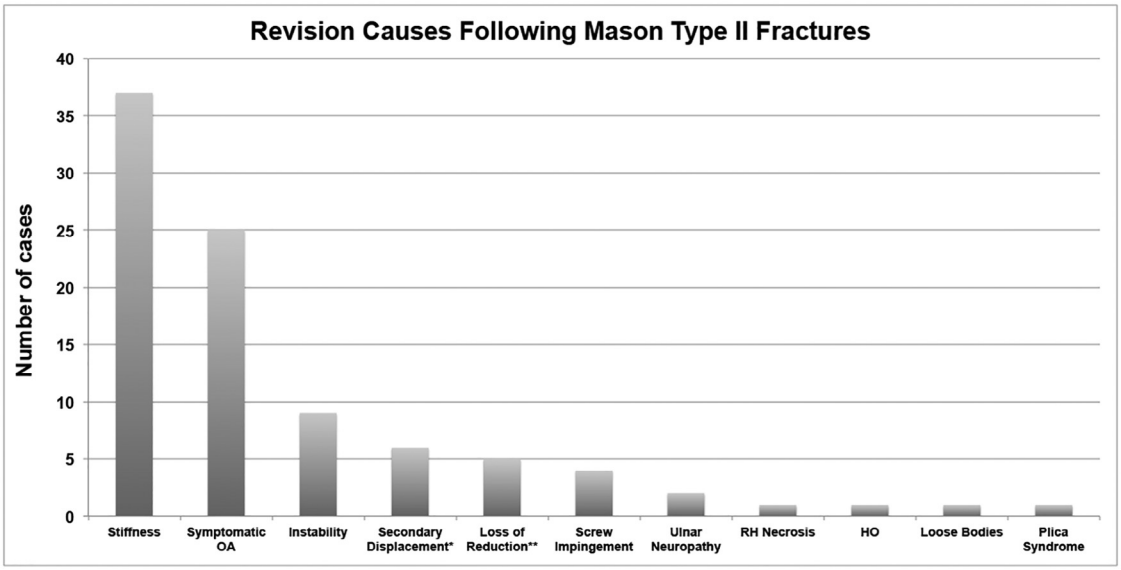

Figure 4 Surgical revision causes after Mason type II fractures (n = 64). *OA*, osteoarthritis; *RH*, radial head; *HO*, heterotopic ossification. *After nonoperative treatment. **After open reduction and internal fixation.

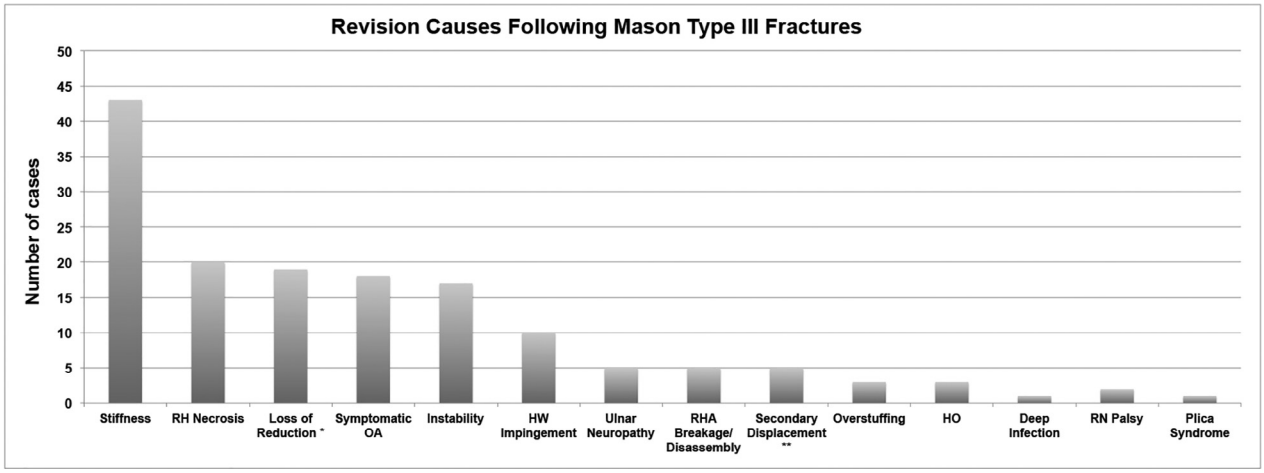

Figure 5 Surgical revision causes after Mason type III fractures (n = 100). *RH*, radial head; *OA*, osteoarthritis; *HW*, hardware; *RHA*, radial head arthroplasty; *HO*, heterotopic ossification; *RN*, radial nerve. *After open reduction and internal fixation. **After nonoperative treatment.

rarely occur after Mason type I injuries—even though the absolute number of revision cases presented in this investigation is rather high owing to its multicenter design.

Of 64 patients who underwent surgical revision after a Mason type II fracture, 30 (47%) were initially treated conservatively. However, the conservatively treated group comprised 76% of cases (19 of 25) with painful osteoarthritis after a Mason type II injury. This finding agrees with the results of Lindenhovius et al[30] and Akesson et al,[1] who found post-traumatic degenerative changes in only 12.5% of operatively treated Mason type II fractures whereas 82% of patients undergoing conservative therapy showed signs of osteoarthritis. ORIF of Mason type II fractures may therefore lower the risk of post-traumatic osteoarthritis and could thereby affirm the findings of the systematic review by Kaas et al,[26] who observed a more reliable outcome of surgical treatment (93% successful outcome) compared with nonoperative therapy (80% successful outcome). Considering the minimally invasive treatment options currently available with arthroscopically assisted fracture fixation,[20,32,38] osteosynthesis can thus be recommended to the young and active patient to more likely evade the invasive salvage procedures for painful osteoarthritis.[2,22]

Even lower-grade radial head fractures can be accompanied by—mainly capsuloligamentous—concomitant injuries.[4,24,25] With 27 cases of Mason type I and type II fractures requiring revision surgery owing to ligamentous instability, our investigation underlines this.

When we looked at comminuted radial head fractures (Mason type III) in this case series, a large number of complications were related to ORIF, which was performed in 74 of 100 cases. At first glance, this finding may support the

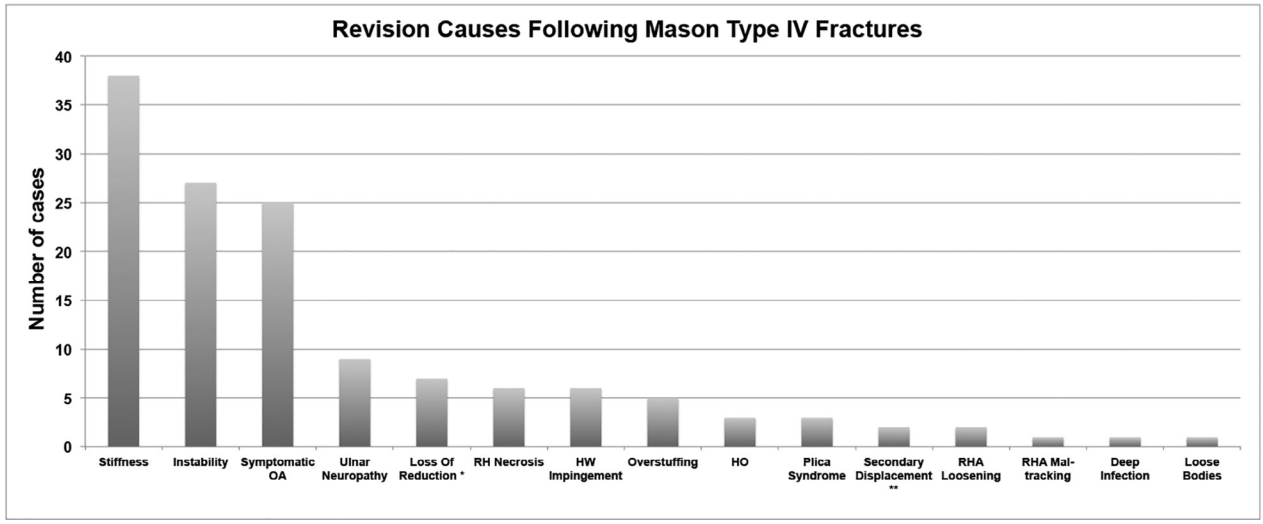

Figure 6 Surgical revision causes after Mason type IV fractures (n = 93). *OA*, osteoarthritis; *RH*, radial head; *HW*, hardware; *HO*, heterotopic ossification; *RHA*, radial head arthroplasty. *After open reduction and internal fixation. **After nonoperative treatment.

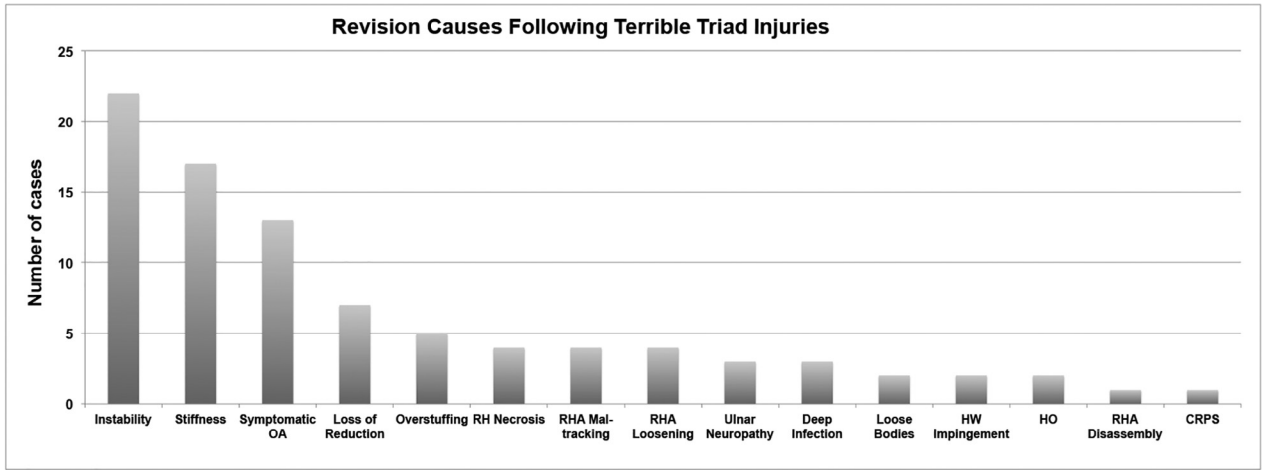

Figure 7 Surgical revision causes after terrible-triad injuries (n = 57). *OA*, osteoarthritis; *RH*, radial head; *RHA*, radial head arthroplasty; *HW*, hardware; *HO*, heterotopic ossification; *CRPS*, complex regional pain syndrome.

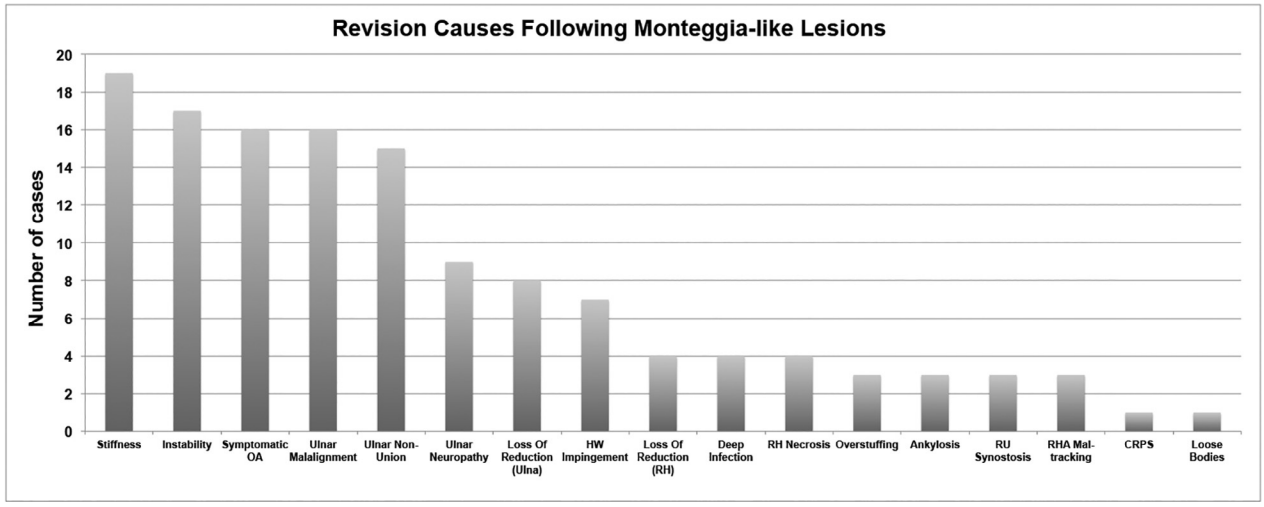

Figure 8 Surgical revision causes after Monteggia-like lesions (n = 58). *OA*, osteoarthritis; *HW*, hardware; *RH*, radial head; *RU*, radioulnar; *RHA*, radial head arthroplasty; *CRPS*, complex regional pain syndrome.

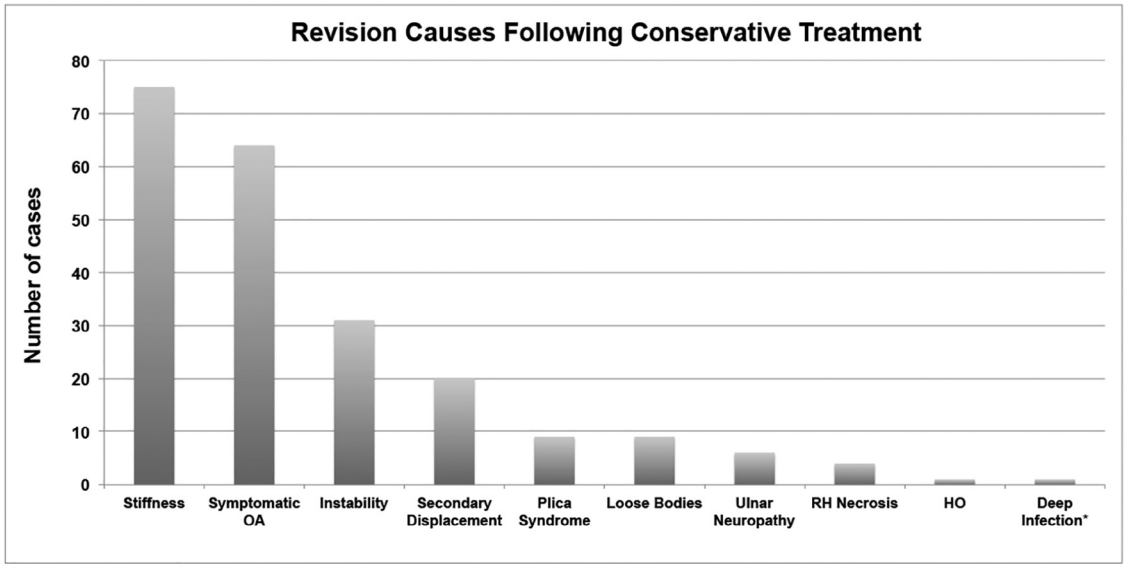

Figure 9 Surgical revision causes after conservative treatment of radial head fractures (n = 138). *OA*, osteoarthritis; *RH*, radial head; *HO*, heterotopic ossification. *After aspiration of hematoma and/or effusion.

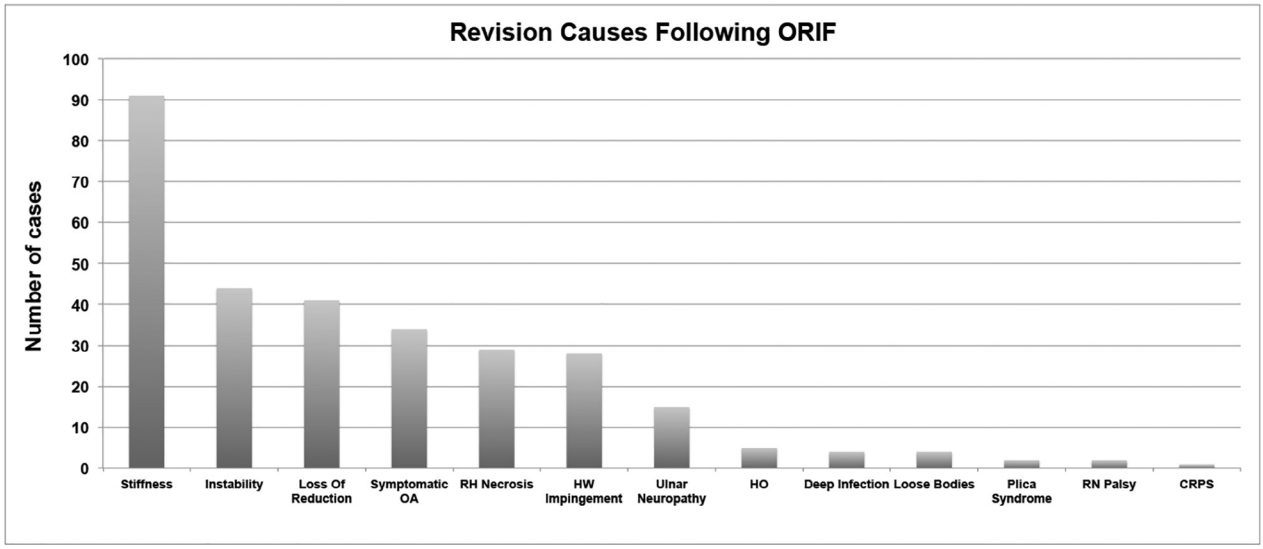

Figure 10 Surgical revision causes after open reduction and internal fixation (*ORIF*) of radial head fractures (n = 205). *OA*, osteoarthritis; *RH*, radial head; *HW*, hardware; *HO*, heterotopic ossification; *RN*, radial nerve; *CRPS*, complex regional pain syndrome.

statement of Ring et al,[36] who in 2002 recommended radial head replacement whenever 3 or more articular fragments are present. However, in most cases in this study, ORIF of the radial head was performed with hand plates (Fig. 12) rather than precontoured radial head locking plates, which have recently shown promising results for the treatment of comminuted radial head fractures.[5,10] This could also explain why short-term to midterm revision rates after ORIF of the radial head in terrible-triad injuries are considerably higher when compared with radial head replacement because relevant comparative studies have not included anatomically pre-shaped radial head plates.[29,43] Given the imperfect biomechanical properties[7,8,21,40,44] and the subsequent mediocre midterm to long-term results of radial head arthroplasty,[6,9,13] its indication should be considered carefully in light of potentially disastrous and at times unsalvageable complications.[11,17,23]

In fracture-dislocations, however, restoring joint stability is of primary concern and can only be sufficiently obtained by replacement of the radial head if ORIF is not feasible.[3] This is supported by our investigation, in which extensive revision surgery with radial head replacement, collateral ligament (and coronoid) repair or reconstruction, and—if necessary—a temporary hinged external fixator were required whenever primary radial head resection was performed for fracture-dislocations (n = 14) (Fig. 13).[15] Of those 14 cases, 3 could

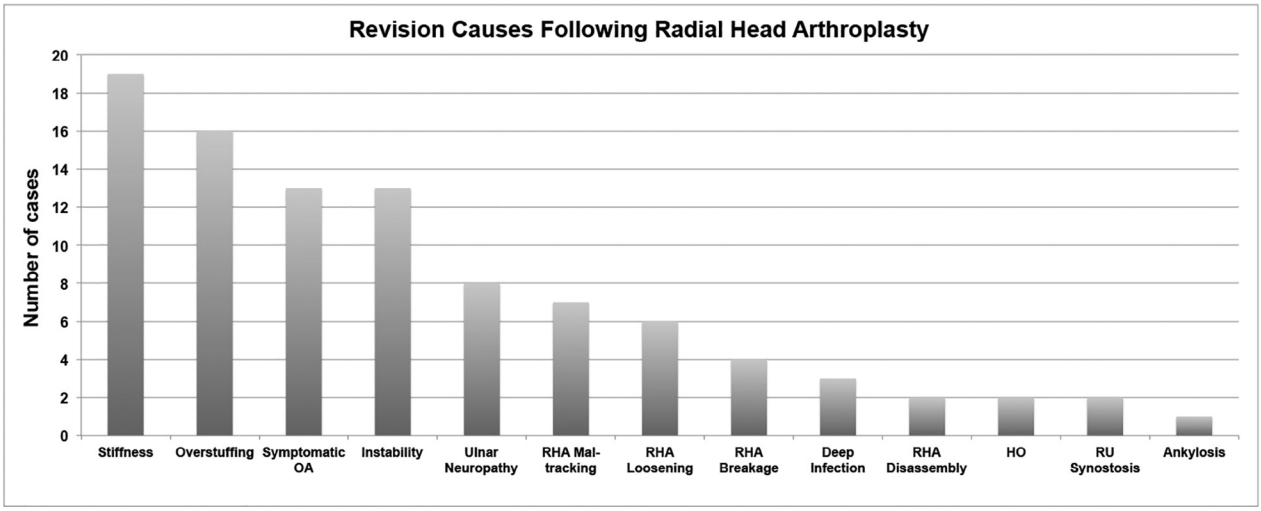

Figure 11 Surgical revision causes after radial head arthroplasty (n = 76). *OA*, osteoarthritis; *RHA*, radial head arthroplasty; *HO*, heterotopic ossification; *RU*, radioulnar.

only be salvaged by total elbow arthroplasty, which emphasizes the importance of primary restoration of elbow stability to avoid debilitating fracture sequelae.

This study is limited by its retrospective design. Another limitation of this work is the fact that the indications for revision surgery and the choice of revision procedure (or procedures) were left to the discretion of the respective surgeons rather than being set by uniformly observed, predefined criteria. Although this could create a certain degree of bias, the study's multicenter design also reflects the broad-based reality of surgical revision of radial head fractures. Finally, the results of this investigation are limited by the circumstance that the total number of radial head fractures, out of which this cohort with surgically relevant complications was extracted, is unknown. This is because most cases were primarily treated in other hospitals and referred to one of the participating institutions in this study once a complication occurred. Therefore, these results cannot inform us about overall complication rates. Nevertheless, this study reveals the most common causes of revision seen in clinical practice.

Conclusion

Stiffness, instability, and painful osteoarthritis are the most frequently encountered causes of revision after radial head fractures. Lower-grade radial head fractures primarily lead to revision for stiffness and painful osteoarthritis. Complications in comminuted radial head fractures are predominantly ORIF related; however, modern precontoured locking radial head plates have only been used in a small number of these cases. A broad spectrum of complications is seen in fracture-dislocations, with instability and stiffness being the most common. Patients can be counseled that arthrolysis, partial or total joint replacement, hardware removal, and ligament repair or reconstruction are the most frequently performed revision procedures.

Acknowledgments

The authors thank Marleen Mathiowetz for her contribution to this work.

Disclaimer

Michael Hackl received a travel grant from Wright/Tornier and research support from Arthrex and Medartis.

Kilian Wegmann received a travel grant from Wright/Tornier and research support from Arthrex and Medartis and is a consultant for Arthrex, Medartis, and Wright/Tornier.

Boris Hollinger is a consultant for Arthrex and Zimmer Biomet.

Bilal F. El-Zayat is a consultant for ConMed and Smith & Nephew.

Helmut Lill is a consultant for Arthrex and DePuy Synthes.

Jörg Weber is a consultant for Arthrex.

Lars P. Müller received research support from Arthrex and Medartis and is a consultant for Arthrex, Medartis, and Wright/Tornier.

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

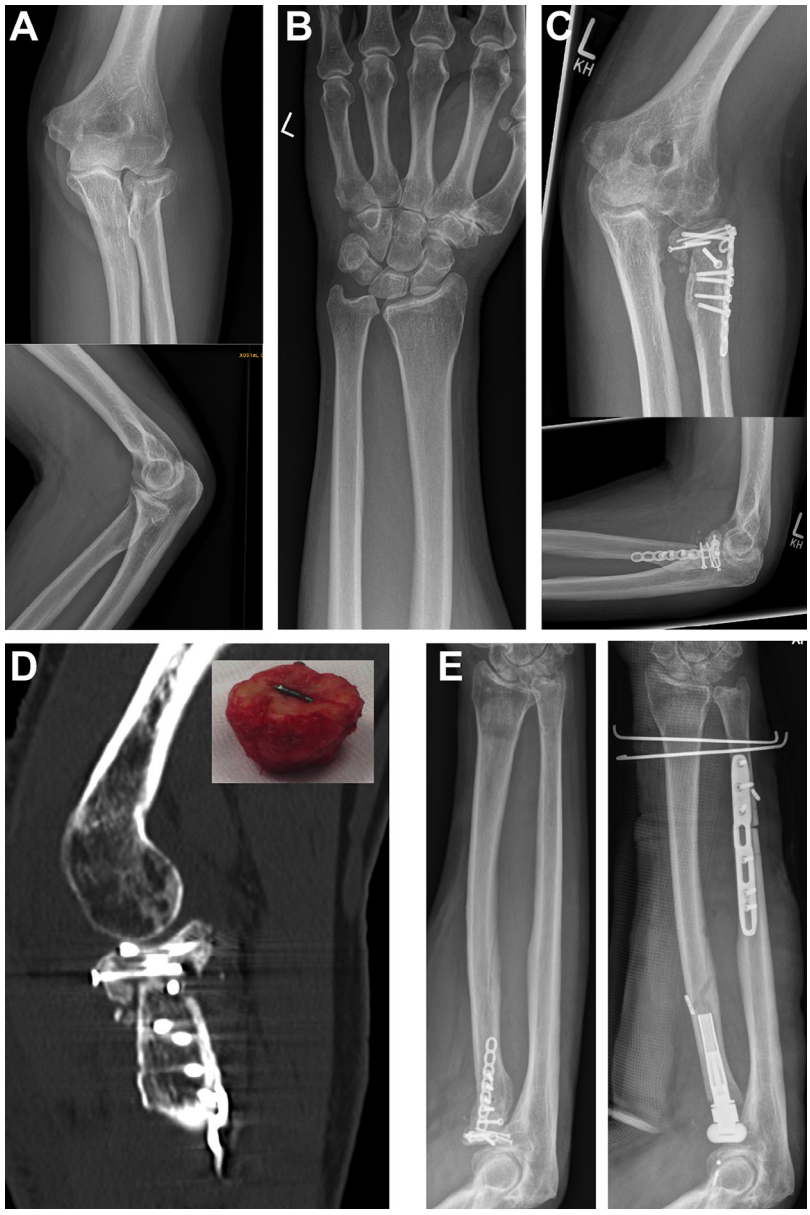

Figure 12 Case of a Mason type III fracture. **(A, B)** Conventional radiographs after trauma in a 63-year-old male patient with concomitant dissociation of the distal radioulnar joint, that is, an Essex-Lopresti lesion. The patient was referred 6 months after open reduction and internal fixation of the radial head with a hand plate (*L*, left). **(C)** Conventional radiographs revealed loss of reduction with bending of the plate, which could not withstand axial loading with longitudinal forearm instability. **(D)** The unstable fixation led to necrosis with screw perforation into the joint. Surgical revision was performed with radial head replacement, ulna shortening osteotomy, and central band reconstruction with temporary arthrodesis of the distal radioulnar joint. **(E)** Conventional radiographs before and after revision.

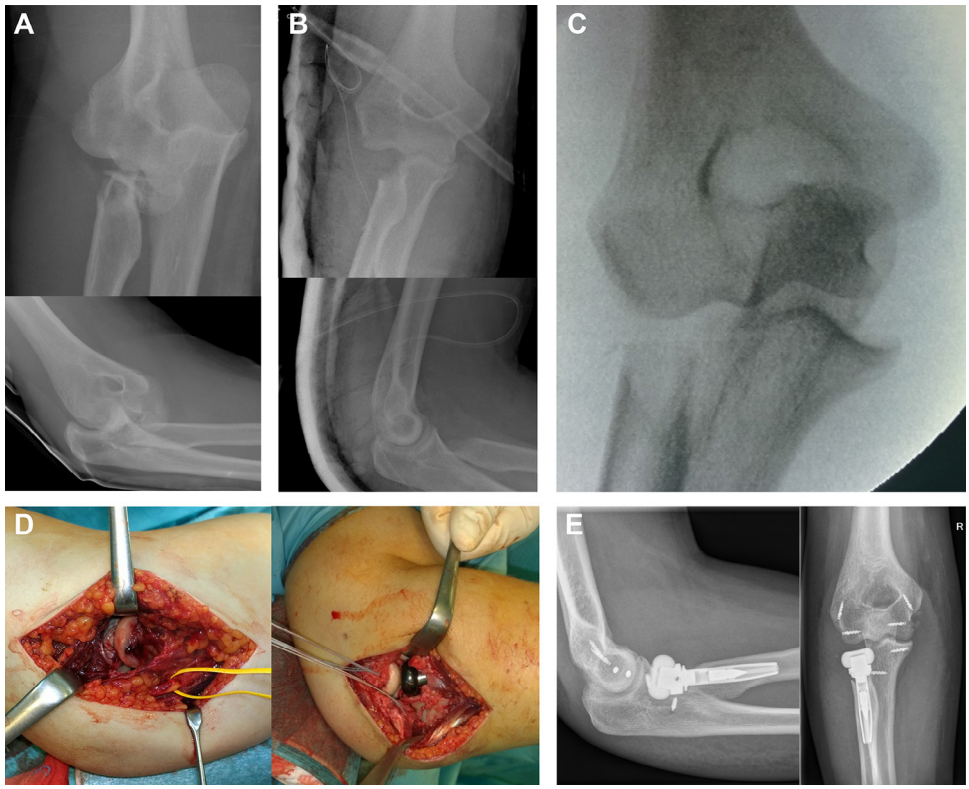

Figure 13 Case of a Mason type IV fracture in a 22-year-old female patient. **(A)** Radiographs after trauma revealing posterior elbow dislocation along with a comminuted radial head fracture. **(B)** Postoperative radiographs after radial head resection. **(C)** The patient was referred after she sustained multiple redislocations. Preoperative fluoroscopy revealed gross instability on slight valgus stress. **(D)** Surgical revision was performed with radial head arthroplasty and bilateral ligament repair and augmentation (*right*). The ulnar collateral ligament and the common flexor tendons were completely detached from their humeral origin (*left*). **(E)** Follow-up radiographs (*R*, right).

References

1. Akesson T, Herbertsson P, Josefsson PO, Hasserius R, Besjakov J, Karlsson MK. Primary nonoperative treatment of moderately displaced two-part fractures of the radial head. J Bone Joint Surg Am 2006;88:1909-14. http://dx.doi.org/10.2106/JBJS.E.01052
2. Baghdadi YM, Morrey BF, Sanchez-Sotelo J. Anconeus interposition arthroplasty: mid- to long-term results. Clin Orthop Relat Res 2014;472:2151-61. http://dx.doi.org/10.1007/s11999-014-3629-3
3. Beingessner DM, Dunning CE, Gordon KD, Johnson JA, King GJ. The effect of radial head excision and arthroplasty on elbow kinematics and stability. J Bone Joint Surg Am 2004;86:1730-9.
4. Burkhart KJ, Franke S, Wegmann K, Ries C, Dehlinger F, Müller LP, et al. [Mason I fracture—a simple injury?]. Unfallchirurg 2015;118:9-17 [in German]. http://dx.doi.org/10.1007/s00113-013-2532-9
5. Burkhart KJ, Gruszka D, Frohn S, Wegmann K, Rommens PM, Eicker CM, et al. [Locking plate osteosynthesis of the radial head fractures: clinical and radiological results]. Unfallchirurg 2015;118:949-56 [in German]. http://dx.doi.org/10.1007/s00113-014-2562-y
6. Burkhart KJ, Mattyasovszky SG, Runkel M, Schwarz C, Küchle R, Hessmann MH, et al. Mid- to long-term results after bipolar radial head arthroplasty. J Shoulder Elbow Surg 2010;19:965-72. http://dx.doi.org/10.1016/j.jse.2010.05.022
7. Chanlalit C, Shukla DR, Fitzsimmons JS, An KN, O'Driscoll SW. Influence of prosthetic design on radiocapitellar concavity-compression stability. J Shoulder Elbow Surg 2011;20:885-90. http://dx.doi.org/10.1016/j.jse.2011.03.009
8. Chytas ID, Antonopoulos C, Cheva A, Givissis P. Capitellar erosion after radial head arthroplasty: a comparative biomechanical study of operated radial head fractures on cadaveric specimen. Orthop Traumatol Surg Res 2018;104:853-7. http://dx.doi.org/10.1016/j.otsr.2018.02.007
9. Contreras-Joya M, Jiménez-Martín A, Santos-Yubero FJ, Navarro-Martínez S, Najarro-Cid FJ, Sánchez-Sotelo J, et al. Radial head arthroplasty, 11 years experience: a series of 82 patients. Rev Esp Cir Ortop Traumatol 2015;59:307-17. http://dx.doi.org/10.1016/j.recot.2015.02.001
10. Cronlein M, Zyskowski M, Beirer M, Imhoff FB, Pforringer D, Sandmann GH, et al. Using an anatomically preshaped low-profile locking plate system leads to reliable results in comminuted radial head fractures. Arch Orthop Trauma Surg 2017;137:789-95. http://dx.doi.org/10.1007/s00402-017-2693-z
11. Delclaux S, Lebon J, Faraud A, Toulemonde J, Bonnevialle N, Coulet B, et al. Complications of radial head prostheses. Int Orthop 2015;39:907-13. http://dx.doi.org/10.1007/s00264-015-2689-7
12. Duckworth AD, Clement ND, Jenkins PJ, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of radial head and neck fractures. J Hand Surg Am 2012;37:112-9. http://dx.doi.org/10.1016/j.jhsa.2011.09.034
13. Duckworth AD, Wickramasinghe NR, Clement ND, Court-Brown CM, McQueen MM. Radial head replacement for acute complex fractures: what are the rate and risks factors for revision or removal? Clin Orthop Relat Res 2014;472:2136-43. http://dx.doi.org/10.1007/s11999-014-3516-y

14. Finkbone PR, O'Driscoll SW. Box-loop ligament reconstruction of the elbow for medial and lateral instability. J Shoulder Elbow Surg 2015;24:647-54. http://dx.doi.org/10.1016/j.jse.2014.12.008
15. Geßmann J, Königshausen M, von Glinski A, Rausch V, Schildhauer TA, Seybold D. [Chronic elbow decentration]. Obere Extremität 2016;11:218-27 [in German]. http://dx.doi.org/10.1007/s11678-016-0379-8
16. Gupta A, Barei D, Khwaja A, Beingessner D. Single-staged treatment using a standardized protocol results in functional motion in the majority of patients with a terrible triad elbow injury. Clin Orthop Relat Res 2014;472:2075-83. http://dx.doi.org/10.1007/s11999-014-3475-3
17. Hackl M, Burkhart KJ, Wegmann K, Hollinger B, Lichtenberg S, Müller LP. From radial head to radiocapitellar to total elbow replacement: a case report. Int J Surg Case Rep 2015;15:35-8. http://dx.doi.org/10.1016/j.ijscr.2015.08.015
18. Hackl M, Heinze N, Wegmann K, Lappen S, Leschinger T, Burkhart KJ, et al. The circumferential graft technique for treatment of multidirectional elbow instability: a comparative biomechanical evaluation. J Shoulder Elbow Surg 2016;25:127-35. http://dx.doi.org/10.1016/j.jse.2015.07.016
19. Hackl M, Leschinger T, Uschok S, Müller LP, Wegmann K. Rehabilitation of elbow fractures and dislocations. Obere Extremität 2017;12:201-7. http://dx.doi.org/10.1007/s11678-017-0425-1
20. Hackl M, Müller LP, Wegmann K. [Arthroscopically assisted fracture fixation of the elbow]. Obere Extremität 2018;13:14-22 [in German]. http://dx.doi.org/10.1007/s11678-017-0435-z
21. Hackl M, Wegmann K, Helf C, Neiss WF, Müller LP, Burkhart KJ. [Accuracy of fit of monopolar radial head prostheses in the proximal radioulnar joint]. Obere Extremität 2015;10:246-51 [in German]. http://dx.doi.org/10.1007/s11678-015-0337-x
22. Hackl M, Wegmann K, Kahmann SL, Heinze N, Staat M, Neiss WF, et al. Radial shortening osteotomy reduces radiocapitellar contact pressures while preserving valgus stability of the elbow. Knee Surg Sports Traumatol Arthrosc 2017;25:2280-8. http://dx.doi.org/10.1007/s00167-017-4468-z
23. Hackl M, Wegmann K, Koslowsky TC, Zeifang F, Schoierer O, Müller LP. Rare implant-specific complications of the MoPyC radial head prosthesis. J Shoulder Elbow Surg 2017;26:830-7. http://dx.doi.org/10.1016/j.jse.2016.11.004
24. Hausmann JT, Vekszler G, Breitenseher M, Braunsteiner T, Vecsei V, Gabler C. Mason type-I radial head fractures and interosseous membrane lesions—a prospective study. J Trauma 2009;66:457-61. http://dx.doi.org/10.1097/TA.0b013e31817fdedd
25. Itamura J, Roidis N, Mirzayan R, Vaishnav S, Learch T, Shean C. Radial head fractures: MRI evaluation of associated injuries. J Shoulder Elbow Surg 2005;14:421-4. http://dx.doi.org/10.1016/j.jse.2004.11.003
26. Kaas L, Struijs PA, Ring D, van Dijk CN, Eygendaal D. Treatment of Mason type II radial head fractures without associated fractures or elbow dislocation: a systematic review. J Hand Surg Am 2012;37:1416-21. http://dx.doi.org/10.1016/j.jhsa.2012.03.042
27. Konrad GG, Kundel K, Kreuz PC, Oberst M, Sudkamp NP. Monteggia fractures in adults: long-term results and prognostic factors. J Bone Joint Surg Br 2007;89:354-60. http://dx.doi.org/10.1302/0301-620X.89B3.18199
28. Kupperman ES, Kupperman AI, Mitchell SA. Treatment of radial head fractures and need for revision procedures at 1 and 2 years. J Hand Surg Am 2018;43:241-7. http://dx.doi.org/10.1016/j.jhsa.2017.10.022
29. Leigh WB, Ball CM. Radial head reconstruction versus replacement in the treatment of terrible triad injuries of the elbow. J Shoulder Elbow Surg 2012;21:1336-41. http://dx.doi.org/10.1016/j.jse.2012.03.005
30. Lindenhovius AL, Felsch Q, Ring D, Kloen P. The long-term outcome of open reduction and internal fixation of stable displaced isolated partial articular fractures of the radial head. J Trauma 2009;67:143-6. http://dx.doi.org/10.1097/TA.0b013e31818234d6
31. McGinley JC, Gold G, Cheung E, Yao J. MRI detection of forearm soft tissue injuries with radial head fractures. Hand (N Y) 2014;9:87-92. http://dx.doi.org/10.1007/s11552-013-9561-2
32. Michels F, Pouliart N, Handelberg F. Arthroscopic management of Mason type 2 radial head fractures. Knee Surg Sports Traumatol Arthrosc 2007;15:1244-50. http://dx.doi.org/10.1007/s00167-007-0378-9
33. Morrey BF, An KN, Stormont TJ. Force transmission through the radial head. J Bone Joint Surg Am 1988;70:250-6.
34. Morrey BF, Tanaka S, An KN. Valgus stability of the elbow. A definition of primary and secondary constraints. Clin Orthop Relat Res 1991;(265):187-95.
35. Nalbantoglu U, Gereli A, Kocaoglu B, Aktas S, Turkmen M. Capitellar cartilage injuries concomitant with radial head fractures. J Hand Surg Am 2008;33:1602-7. http://dx.doi.org/10.1016/j.jhsa.2008.05.016
36. Ring D, Quintero J, Jupiter JB. Open reduction and internal fixation of fractures of the radial head. J Bone Joint Surg Am 2002;84:1811-5.
37. Sardelli M, Tashjian RZ, MacWilliams BA. Functional elbow range of motion for contemporary tasks. J Bone Joint Surg Am 2011;93:471-7. http://dx.doi.org/10.2106/JBJS.I.01633
38. Shetty SK, Shetty A, Balan B, Ballal A, Rai HR, Hegde A. Excision versus fixation of the radial head: a comparative study of the functional outcomes of the two techniques. J Clin Diagn Res 2017;11:RC1-3. http://dx.doi.org/10.7860/JCDR/2017/22051.9379
39. Trousdale RT, Amadio PC, Cooney WP, Morrey BF. Radio-ulnar dissociation. A review of twenty cases. J Bone Joint Surg Am 1992;74:1486-97.
40. Van Glabbeek F, Van Riet RP, Baumfeld JA, Neale PG, O'Driscoll SW, Morrey BF, et al. Detrimental effects of overstuffing or understuffing with a radial head replacement in the medial collateral-ligament deficient elbow. J Bone Joint Surg Am 2004;86:2629-35.
41. van Riet RP, Morrey BF. Documentation of associated injuries occurring with radial head fracture. Clin Orthop Relat Res 2008;466:130-4. http://dx.doi.org/10.1007/s11999-007-0064-8
42. Vavken P, Vavken J, Demarmels S, Rikli D. [Associated injuries in radial head fractures]. Z Orthop Unfall 2017;155:220-5 [in German]. http://dx.doi.org/10.1055/s-0042-118960
43. Watters TS, Garrigues GE, Ring D, Ruch DS. Fixation versus replacement of radial head in terrible triad: is there a difference in elbow stability and prognosis? Clin Orthop Relat Res 2014;472:2128-35. http://dx.doi.org/10.1007/s11999-013-3331-x
44. Wegmann K, Hain MK, Ries C, Neiss WF, Müller LP, Burkhart KJ. Do the radial head prosthesis components fit with the anatomical structures of the proximal radioulnar joint? Surg Radiol Anat 2015;37:743-7. http://dx.doi.org/10.1007/s00276-014-1407-2