Radial Head Fractures and the Role of Radial Head Prosthetic Replacement: Current Update

William P. Cooney, MD

Abstract

Radial head fractures are often secondary to a direct axial force, such as that involved in motor vehicle accidents and falls on an outstretched hand. The Hotchkiss-modified Mason classification is an excellent assessment tool in that it provides commonly accepted direction regarding treatment. For more unstable, comminuted displaced radial head fractures that cannot be reconstructed, replacement of the radial head is warranted. The surgeon should attempt open reduction and internal fixation with restoration of the radial head in anatomical alignment for most type II and some type III fractures, and this treatment is recommended over radial head resection without replacement, as the latter is associated with both elbow and forearm instability over the long term and should be avoided. New radial head replacement designs, including bipolar designs and radial head and capitellar replacements, are available but have limited reported clinical results.

Fractures of the radial head are either simple, straightforward isolated fractures or more complex fractures associated with elbow and forearm instability.[1-3] The elbow is a basic hinge joint, wherein the radial head has an important role as a stabilizer on the lateral aspect of the elbow and is important in elbow and forearm motion as a key component of the radiocapitellar joint. The radial head works in concert with essential anatomical stabilizers of the elbow. These structures include not only the radial head, but the capitellum, coronoid process, ulnohumeral joint, and associated lateral ulnohumeral ligament, medial ulnohumeral ligament, and olecranon.[4] The proximal radioulnar joint is stabilized by the lateral ulnohumeral ligament and the annular ligament (Figure 1). When a "simple" radial head fracture is associated with one or more of these key essential functional components of the elbow—in particular, with the coronoid process or the medial or lateral ulnohumeral ligament—it assumes a different personality and ultimately requires a different type of treatment.[3,5-8]

Radial head fractures were classified by Mason[9] in 1954 and modified by Hotchkiss[1] in 1997 (Figure 2; Table). This classification provides a reasonable approach to diagnosing and treating radial head fractures.

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Type I radial head fractures (minimally displaced) are usually simple, straightforward fractures secondary to a longitudinal compressive force, and usually they are not associated with injuries to the other essential anatomical support structures.

Type II radial head fractures (moderately displaced) are articular fractures of the radial head or angulated fractures of the radial head and proximal shaft or neck area (Figure 3). These are often caused by a combination of axial and rotational forces and may be most commonly associated with a fall on the outstretched hand and a resulting wrist injury. With type II injuries, it is important to check not only for injuries of the essential anatomical structures (eg, coronoid process), but also
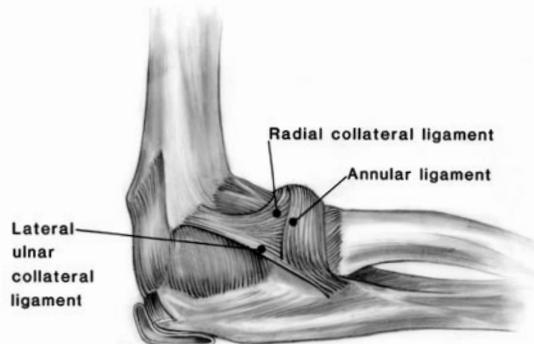
Figure 1. Anatomy of ligament support of elbow; lateral collateral ligament complex. Reprinted from: Morrey BF. "Anatomy of elbow." In: *The Elbow and Its Disorders.* 3rd ed. Philadelphia, PA: W. B. Saunders; 2000:figure 2-28. Copyrighted and used with permission from Mayo Foundation for Medical Education and Research.
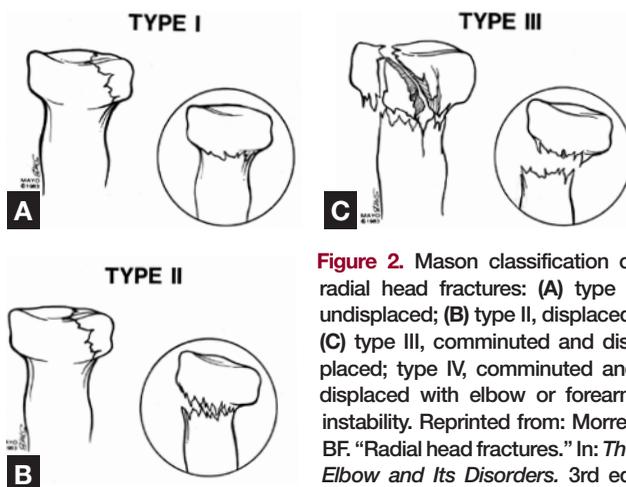
Figure 2. Mason classification of radial head fractures: **(A)** type I, undisplaced; **(B)** type II, displaced; **(C)** type III, comminuted and displaced; type IV, comminuted and displaced with elbow or forearm instability. Reprinted from: Morrey BF. "Radial head fractures." In: *The Elbow and Its Disorders.* 3rd ed. Philadelphia, PA: W. B. Saunders; 2000:figure 25-4. Copyrighted and used with permission from Mayo Foundation for Medical Education and Research.

Figure 3. Clinical example of Mason type II fracture.

Figure 4. Clinical example of Mason type III/IV fracture.

Figure 5. (A) Displaced type II radial head fracture with failed closed reduction. (B) Open reduction and compression-screw fixation along with proximal radius plate.
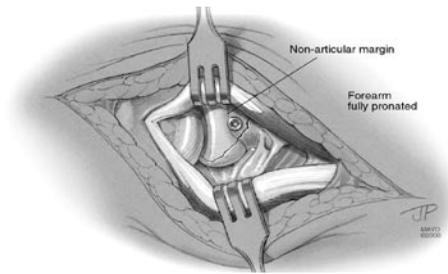

Figure 6. Preparation for internal fixation with provision of Kirschner wire and countersunk drill followed by screw insertion. Reprinted from: Morrey BF. "Radial head fractures." In: *The Elbow and Its Disorders.* 3rd ed. Philadelphia, PA: W. B. Saunders; 2000: figure 25- 17. Copyrighted and used with permission from Mayo Foundation for Medical Education and Research.

for wrist or forearm injuries associated with the axial directed force, particularly injuries to the distal radioulnar joint.[10-16]

Type III radial head fractures, comminuted fractures of the radial head, are often associated with injury to the other essential anatomical support elements of the elbow (medial collateral ligament, coronoid process, capitellum) (Figure 4). With type III fractures, usually the elbow (and the forearm) is determined to be stable.

Type IV radial head fractures involve a comminuted radial head fracture and elements of elbow and/or forearm instability.[1,9,17] Careful examination of the elbow, for example, will demonstrate instability often associated with dislocation of the elbow and a radial head fracture. One or more of the essential elements is often injured. These complex radial head fractures require different treatment recommendations. Again, it is essential to examine the elbow as well as the wrist and forearm for associated injuries at the elbow—in particular, for olecranon fractures, coronoid process fractures, and medial or lateral collateral ligament injuries.

DIAGNOSIS

Clinical examination of the elbow and wrist is essential when there is a history of a substantial force or fall on the outstretched hand or forearm, and it provides the initial key to diagnosis. Tenderness, swelling over the lateral aspect of the elbow, and painful forearm or elbow motion are often present. Motion of the forearm and elbow may be limited. The interosseous membrane within the midforearm may demonstrate tenderness. The essential anatomical structures about the elbow should be carefully examined for, specifically, stability in extension and flexion (medial and lateral ulnohumeral ligaments) and tenderness (along the olecranon

and over the radial head and ulnohumeral joint). Gentle stress testing of the elbow for instability (particularly valgus instability) should be performed. Forearm range-of-motion (ROM) and rotation limitations caused by pain should be noted. Wrist examination includes careful assessment of the distal radioulnar joint for fracture and/or instability.

Imaging assessment includes plain anteroposterior and lateral radiographs along with varus and valgus stress films. Radiographs of the forearm and distal radioulnar joint and wrist should be included as well. Tomogram radiographs of the elbow are becoming increasingly important in determining degree of displacement of a radial head fracture and any associated injuries, particularly of the coronoid process, capitellum, or proximal ulna.[1,3,7,18-20] Fractures of the coronoid process, for example, are classified into 3 types based on degree of injury seen on lateral tomogram radiographs. Three-dimensional tomographic reconstruction has provided an even clearer view of the degree of injury and potential instability of the elbow associated with radial head fractures.

TREATMENT

Treatment of radial head fractures fits well with the Mason–Hotchkiss classification and is recommended. Nondisplaced or minimally displaced Mason type I radial head fractures may be treated with supportive splinting and early ROM.[1,7,20,21] Aspiration of the elbow hematoma may be beneficial, along with an injection of analgesic medication, such as lidocaine or bupivacaine. With the assistance of therapy, assisted ROM can be performed, but any evidence of instability should be carefully considered.
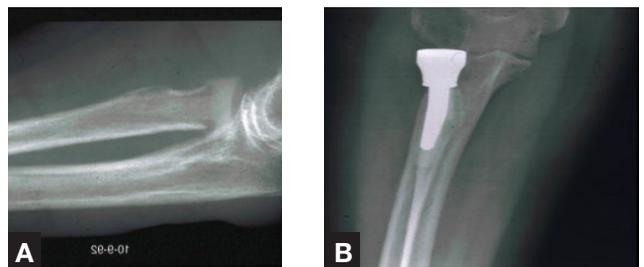
Figure 7. (A) Silicone implant with stem loosening and early silicone synovitis. (B) Monoblock radial head replacement with long stem and bone cement.

Table. Mason Classification as Modified by Hotchkiss[1]

| Type	Description
I	Minimally displaced fracture, no mechanical block to forearm rotation, intra-articular displacement less than 2 mm
II	Fracture displaced more than 2 mm or angulated, possible mechanical block to forearm rotation
III	Severely comminuted fracture, mechanical block to motion
IV[22]	Radial fracture with associated elbow dislocation

Type II radial head fractures include displacement of the radial head and are treated by open reduction and internal fixation (Figure 5). Current recommended treatment is lateral Kocher approach to the elbow, exposure of the radial head, placement of stabilizing Kirschner wires (K-wires), and placement of cannulated screws over the K-wires[1,7,20,22,23] (Figure 6). Headless screws (preferred) are countersunk in the radial head and exiting proximal to the proximal radioulnar joint,[10,24] which prevents injury and subsequent arthritis of the proximal radioulnar joint from a prominent radial head screw. However, if it is necessary to have the screw cross the radial head transversely, care must be taken to avoid penetration of the far cortex.[23] Laterally placed small plates may be considered, but these are often associated with loss of forearm rotation and inability to repair the annular ligament.[1,22,23] Several recently developed small, low-profile plates may be of benefit, but these have not been presented in any type of clinical series. For type II injuries, the lateral approach is usually preferred; a recently described posterior approach allows for more direct access to associated structures about the elbow. This approach, described by King[25] and Ring

and King,[2] helps prevent indirect injury to the lateral ulnohumeral ligament and provides options for repair of that structure when it is associated with radial head fractures.

Mason type III radial head fractures are comminuted fractures that usually require excision or, preferably, radial head replacement. Studies have demonstrated that, after resection of the radial head, these fractures cause long-term axial instabilities because of lack of support on the lateral aspect of the elbow.[10,11,15,25-27] The radial head serves as a secondary stabilizer of the elbow and also of the forearm. Loss of the radial head leads to unstable forearm force transmission and an altered center of rotation for the forearm. Current options for radial head replacement include silicone spacers and metallic implants (metallic implants can be spacers or true anatomical radial head replacements).[2,7,8,12,28-34] Currently, there is less indication or recommendation for use of a silicone implant because of problems with silicone synovitis[8] (Figure 7). We therefore recommend a radial head implant that can be either cemented or left uncemented in place depending on the technique used. Both monoblock and bipolar prostheses are available[2,7,28,29,32-34] (Figures 8–9). There is no clinical series showing a preference for monoblock over bipolar. With a bipolar prosthesis (Figure 8), it is argued that the radial head can seat itself more anatomically on the capitellum, but if a monoblock prosthesis of appropriate size is used for a radial head replacement, particularly in acute trauma, and there is minimal associated lateral collateral ligament injury, one can anticipate satisfactory long-term results. The debate over cemented versus uncemented/free-floating radial head implants has not been resolved. It has been suggested that free-floating implants (Figure 9) also allow better seating with the capitellum.[12,32,35]

The Essex-Lopresti lesion is an axial forearm instability usually associated with comminuted and displaced radial head fractures. This lesion is classified as a Mason type IV injury,[12,15] which is an unstable fracture associated with elbow instability or axial forearm instability. Mason type IV injuries commonly present as complex elbow injuries, often described as a terrible triad
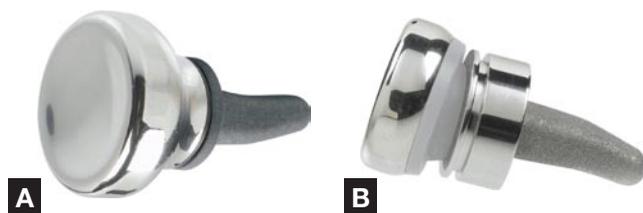
Figure 8. (A) Monoblock modular design and (B) bipolar radial head implant design (Small Bone Innovations, Morrisville, PA).

Figure 9. Evolve modular, monoblock radial head design. Photo provided by Wright Medical Technology, Inc.
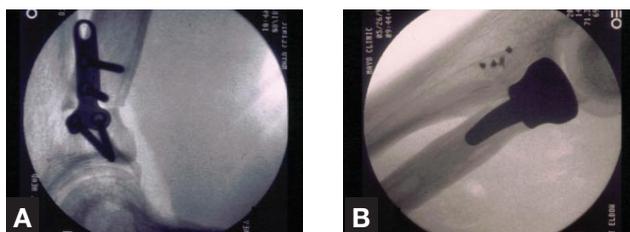
Figure 10. (A) Failed internal fixation plate of proximal radius fracture and (B) radial head replacement with repair of ulnar humeral ligament with Mitek anchors.

of injury to the medial collateral ligament, the coronoid process, and the radial head. With these fractures, a posterior approach is recommended, along with repair of the medial collateral ligament, repair of the coronoid process, and replacement of the radial head.[5,13,22,27,29] Radial head implants provide a secondary stabilizer to the elbow and are recommended in the treatment of instability of the elbow associated with radial head fractures.

SURGICAL TECHNIQUE

With radial head fractures, plate fixation or prosthetic replacement is performed from a lateral approach between the anconeus and the extensor carpi ulnaris.[36] This approach can be extended 5 to 6 cm more proximally along the lateral column of the elbow, which allows for better visualization and release of the anterior and posterior capsules. With this approach, the extensor carpi radialis longus and brevis muscles are released and retracted anteriorly while the extensor carpi ulnaris and anconeus muscles are reflected posteriorly from the lateral epicondyle. The lateral collateral ligament is reflected from the lateral epicondyle with important preservation of the lateral ulnohumeral ligament. For radial head replacement, the radial head is excised at the level of the radial neck, preserving the annular ligament. We recommend using an alignment guide. After division across the radial neck, the radial head is excised and used as a template for the size of the radial head implant. The proximal radius is then broached and the radial stem inserted along the intramedullary canal prepared by the broach. The radial implant is then placed on the stem; a firm fit is obtained with most of the implants. Lateral closure is performed in layers repairing the annular ligament and lateral collateral ligaments. Radiographic confirmation of alignment and position of the radial head implant with respect to the capitellum in flexion, extension, and pronosupination is important to ensure proper contact with the capitellum and overall alignment. (Surgical technique details: http://www.totalsmallbone.com/us/pdfs/rHead_RadialSurgical.pdf.)

LATE ELBOW INSTABILITY

With radial head fractures, late presentation of elbow instability also requires consideration of radial head replacement.[34] Alternatives for radial instability have in the past included fascial or muscle interposition arthroplasties, such as the anconeus muscle or a silicone implant (Figure 7A). Today, we more commonly recommend a radial head implant with either a bipolar or monoblock radial head replacement. When there are late problems of arthritis or osteopenia of the capitellum caused by unloading, radial head capitellar replacement may be considered in addition to radial head replacement.

PERILS AND PITFALLS

In the treatment of radial head fractures, the surgeon should consider several potential problems. First, all bone and soft-tissue stabilizers of the elbow—including the radial head capitellum, the coronoid process, the olecranon, and the medial and lateral collateral ligaments—should be considered part of the injury.[6,14,19,27] With careful clinical and radiographic examination, injuries to these stabilizers can be confirmed. The second consideration is that radial head repair may fail and that radial

head replacement is a viable option in such cases (Figure 10). It is also essential to repair the coronoid process and the olecranon in anatomical alignment and in combination with repair or replacement of the radial head.

With radial head implants, it is important not to "overstuff" the lateral side of the elbow with the radial head implant, as doing so can place excessive pressure on the radiocapitellar joint. The radial head implant should match the level of articulation of the proximal ulna with the distal humerus. In an acute fracture, the radial head implant should be sized to match the excised radial head. Length of the radial head should be judged by normal anatomy and proximal displacement when the distal radius is forcefully loaded from a distal direction to a proximal direction. When there is a question, a smaller rather than a larger radial head implant should be selected. Options for the radial head implant include bone fixation, bone cement, and free-floating radial head stem. We prefer an osteointegration implant system.

Use of a hinged brace or an external fixator[37] may be necessary in certain unstable elbow dislocations associated with a radial head fracture and injury to the medial collateral ligament and coronoid process. In such cases, early elbow ROM can be initiated using an anatomically aligned external fixator.

TREATMENT RESULTS

In 1981, Swanson and colleagues[17] reported results from their study of silicone radial head implants. Twelve patients with late silicone replacement of the radial head and 6 patients with acute replacement (follow-up, 3.8 years) demonstrated the value of radial head replacement in providing elbow stability after both acute and chronic cases of radial head fracture. The value of a secondary stabilizer with good radiocapitellar contact and ability to prevent radial shortening was noted. However, results from later studies of silicone radial head replacement showed problems of implant instability and silicone synovitis.

Radial head metal implants soon replaced silicone implants. In 2001, Moro and colleagues[14] reported their experience with a metallic radial head implant in 24 consecutive patients with unreconstructible fractures of the radial head. Described patients had Mason type III and IV injuries, usually associated with other injuries, including coronoid and collateral ligament injuries. As graded on the Mayo Elbow Performance Index (MEPI), there were 17 good to excellent, 5 fair, and 3 poor results. Disabilities of Arm, Shoulder, and Hand scores were 17±19, and Short Form–36 Health-Related Quality of Life scores were 47±10. Fair and poor results were associated with concomitant associated injuries, work compensation issues, and litigation. Results from objective studies showed elbow motion of 9° to 140°, forearm pronation of 78°, and supination of 68°. With use of a modular, free-floating intramedullary stem, Moro and colleagues noted asymptomatic loosening around the implant in 17 of 25 elbows. They concluded that a metal radial head implant for severely comminuted radial head fractures was safe and effective but resulted in mild to moderate physical limitations of the elbow.

In 2004, Ashwood and colleagues[28] reported their experience with a titanium prosthesis for Mason type III radial head fractures. Sixteen patients had titanium prosthetic replacement alone or with medial collateral ligament repair. There were 8 excel-

lent, 5 good, and 3 fair Mayo Elbow scores. The patients treated acutely fared better than those treated with late reconstruction. Elbow motion was restored along with elbow and forearm stability, with slight loss of elbow extension and forearm rotation. Ashwood and colleagues concluded that monoblock radial head replacement along with soft-tissue reconstruction helped restore stability, and they emphasized early mobilization.

Longer term evaluation of radial head implants was performed by Shore and colleagues[34] in a review of 32 metallic radial head implants. Indications for replacement were delayed union and nonunion of radial head fractures, elbow instability, failed radial head excision, and silicone radial head implants. There were 17 excellent and 8 good results (64%) and 7 fair and 4 poor results; mean MEPI score was 83 points on a 0-to-100 scale (100 being ideal). Patients had less motion and strength in the affected elbow than in the unaffected elbow. No prosthesis required revision, but 74% showed some degree of posttraumatic arthritis. Metallic implants appear to be safe and durable at 8-year follow-up, but longer term outcomes are guarded.

Delayed treatment of chronic longitudinal radioulnar dissociation associated with comminuted radial head fractures was reviewed by Hejink and colleagues.[12] Eight patients had chronic axial or longitudinal deficiency treated with a metal radial head implant. Four patients were doing well a mean of 6 years (range, 4.4-7.4 years) after primary implantation; the other 4 patients showed mild evidence of aseptic loosening (1 metal radial head was revised to a bipolar implant). Mild degenerative changes in the capitellum were found in 2 patients, and another 2 patients required capitellum replacement. Mean Mayo Wrist score was 70 points, and mean MEPI score was 78.8 points (out of 100) with 2 excellent, 2 good, 3 fair, and 1 poor overall final results. The good and excellent results were associated with a bipolar prosthetic design and the fair and poor results with a monoblock radial head implant.

SUMMARY

Radial head fractures are often secondary to a direct axial force, such as that involved in motor vehicle accidents and falls on an outstretched hand. The Hotchkiss-modified Mason classification is an excellent assessment tool in that it provides commonly accepted direction regarding treatment. For more unstable, comminuted displaced radial head fractures that cannot be reconstructed, replacement of the radial head is warranted. The surgeon should attempt open reduction and internal fixation with restoration of the radial head in anatomical alignment for most type II and some type III fractures, and this treatment is recommended over radial head resection without replacement, as the latter is associated with both elbow and forearm instability over the long term and should be avoided. New radial head replacement designs, including bipolar designs and radial head and capitellar replacements, are available but have limited reported clinical results.

AUTHOR'S DISCLOSURE STATEMENT

The author wishes to note that he has a consulting contract with Small Bone Innovations and receives royalties through the Mayo Clinic. He also wishes to note that he shares a patent with the Mayo Clinic related to the Small Bone Innovations radial head implant.

REFERENCES

1. Hotchkiss RN. Displaced fractures of the radial head: internal fixation or excision? *J Am Acad Orthop Surg*. 1997;5(1):1-10.
2. Ring D, King G. Radial head arthroplasty with a modular metal spacer to treat acute traumatic elbow instability. Surgical technique. *J Bone Joint Surg Am*. 2008;90(suppl 2):63-73.
3. Sotereanos DG, Darlis NA, Wright TW, Goitz RJ, King GJ. Unstable fracture-dislocations of the elbow. *Instr Course Lect*. 2007;56:369-376.
4. Van Riet RP, Morrey BF, O'Driscoll SW, Van Glabbeek F. Associated injuries complicating radial head fractures: a demographic study. *Clin Orthop*. 2005;(441):351-355.
5. Charalambous CP, Stanley JK, Siddique I, Powell E, Ramamurthy C, Gagey O. Radial head fracture in the medial collateral ligament deficient elbow; biomechanical comparison of fixation, replacement and excision in human cadavers. *Injury*. 2006;37(9):849-853.
6. Doornberg JN, Ring DC. Fractures of the anteromedial facet of the coronoid process. *J Bone Joint Surgery Am*. 2006;88(10):2216-2224.
7. Jackson JD, Steinmann SP. Radial head fractures. *Hand Clin*. 2007;23(2):185-193.
8. Morrey BF, Askew L, Chao EY. Silastic prosthetic replacement for the radial head. *J Bone Joint Surg Am*. 1981;63(3):454-458.
9. Mason ML. Some observations on fractures of the head of the radius with a review of one hundred cases. *Br J Surg*. 1954;42(172):123-132.
10. Broberg MA, Morrey BF. Results of delayed excision of the radial head after fracture. *J Bone Joint Surg Am*. 1986;68(5):669-674.
11. Essex-Lopresti P. Fractures of the radial head with distal radio-ulnar dislocation; report of two cases. *J Bone Joint Surg Br*. 1951;33(2):244-247.
12. Heijink A, Cooney WP, Morrey BF. Metal radial head replacement for chronic longitudinal radio-ulnar disassociation. *J Shoulder Elbow Surg*. In press.
13. Calfee R, Madom I, Weiss AP. Radial head arthroplasty. *J Hand Surg Am*. 2006;31(2):314-321.
14. Moro JK, Werier J, MacDermid JC, Patterson SD, King GJ. Arthroplasty with a metal radial head for unreconstructible fractures of the radial head. *J Bone Joint Surg Am*. 2001;83(8):1201-1211.
15. Rozental TD, Beredjiklian PK, Bozentka DJ. Longitudinal radioulnar dissociation. *J Am Acad Orthop Surg*. 2003;11(1):68-73.
16. Van Riet RP, Van Glabbeek F, Neale PG, et al. Anatomical considerations of the radius. *Clin Anat*. 2004;17(7):564-569.
17. Swanson AB, Jaeger SH, La Rochelle D. Comminuted fractures of the radial head. The role of silicone-implant replacement arthroplasty. *J Bone Joint Surg Am*. 1981;63(7):1039-1049.
18. Caputo AE, Burton KJ, Cohen MS, King GJ. Articular cartilage injuries of the capitellum interposed in radial head fractures: a report of ten cases. *J Shoulder Elbow Surg*. 2006;15(6):716-720.
19. Ring D. Fractures of the coronoid process of the ulna. *J Hand Surg Am*. 2006;31(10):1679-1689.
20. Tejwani NC, Mehta H. Fractures of the radial head and neck: current concepts in management. *J Am Acad Orthop Surg*. 2007;15(7):380-387.
21. Wysocki RW, Cohen MS. Surgical management of radial head fractures. *Am J Orthop*. 2007;36(2):62-66.
22. Lindenhovius AL, Felsch Q, Doornberg JN, Ring D, Kloen P. Open reduction and internal fixation compared with excision for unstable displaced fractures of the radial head. *J Hand Surg Am*. 2007;32(5):630-636.
23. McArthur RA. Herbert screw fixation of fracture of the head of the radius. *Clin Orthop*. 1987;(224):79-87.
24. Bunker TD, Newman JH. The Herbert differential pitch bone screw in displaced radial head fractures. *Injury*. 1985;16(9):621-624.
25. King GJ. Management of comminuted radial head fractures with replacement arthroplasty. *Hand Clin*. 2004;20(4):429-441.
26. Cebesoy O, Baltaci ET, Isik M. Importance of radial head on elbow kinematics: radial head prosthesis. *Arch Orthop Trauma Surg*. 2006;126(7):501.
27. Harrington IJ, Tountas AA. Replacement of the radial head in the treatment of unstable elbow fractures. *Injury*. 1981;12(5):405-412.
28. Ashwood N, Bain GI, Unni R. Management of Mason type-III radial head fractures with a titanium prosthesis, ligament repair, and early mobilization. *J Bone Joint Surg Am*. 2004;86(2):274-280.
29. Bain GI, Ashwood N, Baird R, Unni R. Management of Mason type-III radial head fractures with a titanium prosthesis, ligament repair, and early mobilization. Surgical technique. *J Bone Joint Surg Am*. 2005;87(suppl 1, pt 1):136-147.
30. Brinkman JM, Rahusen FT, de Vos MJ, Eygendaal D. Treatment of sequelae of radial head fractures with a bipolar radial head prosthesis: good outcome after 1-4 years follow-up in 11 patients. *Acta Orthop*. 2005;76(6):867-872.
31. Chapman CB, Su BW, Sinicropi SM, Bruno R, Strauch RJ, Rosenwasser MP. Vitallium radial head prosthesis for acute and chronic elbow fractures and fracture-dislocations involving the radial head. *J Shoulder Elbow Surg*. 2006;15(4):463-473.
32. Dotzis A, Cochu G, Mabit C, Charissoux JL, Arnaud JP. Comminuted fractures of the radial head treated by the Judet floating radial head prosthesis. *J Bone Joint Surg Br*. 2006;88(6):760-764.
33. Grewal R, MacDermid JC, Faber KJ, Drosdowech DS, King GJ. Comminuted radial head fractures treated with a modular metallic radial head arthroplasty. Study of outcomes. *J Bone Joint Surg Am*. 2006;88(10):2192-2200.
34. Shore BJ, Mozzon JB, MacDermid JC, Faber KJ, King GJ. Chronic posttraumatic elbow disorders treated with metallic radial head arthroplasty. *J Bone Joint Surg Am*. 2008;90(2):271-280.
35. Judet T, Garreau de Loubresse C, Piriou P, Charnley G. A floating prosthesis for radial-head fractures. *J Bone Joint Surg Br*. 1996;78(2):244-249.
36. Mansat P, Morrey BF. The column procedure: a limited lateral approach for extrinsic contracture of the elbow. *J Bone Joint Surg Am*. 1998;80(11):1603-1615.
37. De Llano Temboury AQ, Arévalo RL, Queipo de Llano Jiménez FL. ARM: a modular hinged joint for the AO tubular external fixator. *Tech Hand Up Extrem Surg*. 2006;10(1):14-24.