Comminuted Radial Head Fractures Treated with a Modular Metallic Radial Head Arthroplasty

STUDY OF OUTCOMES

By Ruby Grewal, MD, FRCSC, Joy C. MacDermid, BScPT, MSC, PhD, Kenneth J. Faber, MD, FRCSC, Darren S. Drosdowech, MD, FRCSC, and Graham J.W. King, MD, MSC, FRCSC

Investigation performed at the Hand and Upper Limb Center, Division of Orthopedic Surgery, St. Joseph’s Health Care, University of Western Ontario, London, Ontario, Canada

Background: Comminuted fractures of the radial head are challenging to treat with open reduction and internal fixation. Radial head arthroplasty is an alternative treatment with results that compare favorably with those reported after open reduction and internal fixation of similar fractures. The purpose of this study was to evaluate the two-year outcomes and the rate of recovery of a closely followed cohort of patients in whom an unreconstructible radial head fracture had been treated with a modular metallic prosthesis.

Methods: Twenty-six patients (seventeen female and nine male; mean age, fifty-four years) with an unreconstructible comminuted radial head fracture and associated elbow injuries were treated with a modular metallic radial head arthroplasty. Patients who had presented more than four weeks following the injury or had had the radial head arthroplasty as a second-stage or salvage procedure were excluded. Of the twenty-six patients, twenty-two had an associated elbow dislocation, and thirteen of them also had an associated fracture of the coronoid process. Patients were prospectively followed at three, six, twelve, and twenty-four months. Self-reported limb function, general health, range of motion, and isometric strength were assessed by an independent observer.

Results: Following treatment of the injury, significant decreases in self-reported and measured impairments were noted over time, with the majority of the recovery occurring by six months and little further recovery noted between six and twenty-four months. There were slight-to-moderate deficits in the range of motion and strength compared with the values on the contralateral, unaffected side. Patient satisfaction was high at three months and remained high at two years. All elbow joints remained stable, no implant required revision, and there was no evidence of overstuffing of the joint. Mild osteoarthritis was seen in five (19%) of the twenty-six patients.

Conclusions: An arthroplasty with a modular metallic radial head is a safe and effective option for the treatment of unreconstructible radial head fractures associated with other elbow injuries. Recovery primarily occurs by six months, with minimal additional improvements over the next eighteen months.

Level of Evidence: Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

Radial head fractures account for 33% of all elbow fractures1. When these fractures are associated with other osseous or ligamentous injuries, the radial head becomes the primary stabilizer against valgus and axial forces across the elbow, and accurate management of the radial head fracture becomes essential2:3.

Open reduction and internal fixation has yielded good results when used for displaced radial head fractures with a simple fracture pattern4. However, treatment of comminuted radial head fractures with open reduction and internal fixation has resulted in a high number of complications5. Radial head excision was advocated for the treatment of displaced radial head fractures in the past, but it has fallen out of favor as a result of complications such as valgus elbow instability, elbow stiffness, and proximal migration of the radius6:7.

Radial head arthroplasty has been advocated for the treatment of unreconstructible radial head fractures with concomitant medial collateral ligament injury, interosseous
Biomechanical studies have shown that metallic radial head implants restore elbow and forearm stability to levels approaching those of the native radial head\textsuperscript{3,5,21}. Clinical experience with metallic radial head implants, although limited, has been favorable\textsuperscript{23-25}. Traditional metal implants have had a monoblock design, which has made it difficult to correctly size the head diameter, head thickness, and stem diameter, as these anatomic features are poorly correlated with one another\textsuperscript{24}. Component modularity allows the surgeon to alter the height and diameter of the head as well as the height and diameter of the stem to optimize implant sizing without the risk of overstuffing the radiocapitellar joint, which can lead to increased pain, restricted flexion, and early degenerative disease\textsuperscript{27-29}.

The modular radial head prosthesis employed in this study has a smooth stem that is implanted with a loose press-fit into the radial neck. The implant acts as a spacer, allowing the soft tissues and ligaments to heal. While early clinical experience with this modular metallic implant has been favorable, we are not aware of any reports of short-term results\textsuperscript{23}. The purpose of this study was to evaluate the short-term outcomes and the rate of recovery of a closely followed cohort of patients in whom an unreconstructible radial head fracture was treated with a modular prosthesis.

Materials and Methods

Over a three-year period, from December 1999 to January 2003, twenty-eight consecutive patients in whom an unreconstructible Hotchkiss type-III\textsuperscript{30} radial head fracture had been treated with replacement of the radial head with a modular metallic radial head implant (Evolve; Wright Medical Technology, Arlington, Tennessee; Figs. 1-A and 1-B) were enrolled in the study and followed prospectively.
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To be included in the study, a patient had to be skeletally mature and have presented with an unreconstructible radial head fracture and an associated elbow injury. One of three fellowship-trained upper-extremity surgeons deemed the radial head fracture to be unreconstructible on the basis of preoperative imaging (radiographs and computed tomography scans) as well as an intraoperative decision based on the size of the fracture fragments, comminution, and bone quality. The associated elbow injuries included elbow dislocations, ligamentous injuries, and/or fractures. No isolated radial head fractures were included in this cohort.

Exclusion criteria were presentation more than four weeks after the injury (one patient) and performance of the radial head arthroplasty as a second-stage or salvage procedure (one patient). This left twenty-six patients for evaluation. Six of those patients were followed for only one year: one patient died of breast cancer and five were lost to follow-up before their two-year visit.

All implants were inserted by, or under the supervision of, one of three fellowship-trained upper-extremity surgeons at a single tertiary-care referral center. There were seventeen female patients (65%) and nine male patients. Their mean age (and standard deviation) was 54 ± 14.6 years. The dominant arm was involved in eleven (42%) of the twenty-six patients. Of these eleven patients, two had bilateral elbow injuries. One of them had a contralateral undisplaced radial head fracture that was treated nonsurgically. The other had a contralateral Hotchkiss type-III radial head fracture combined with an elbow dislocation and a coronoid fracture that was initially treated with open reduction and internal fixation. The elbow joint remained unstable, and a modular radial head arthroplasty was subsequently performed. Since the arthroplasty was used as a delayed salvage procedure, this elbow was excluded from the study.

The mean time between the injury and the surgery was 7.8 days (range, one to twenty-two days). The average duration of follow-up was 24.5 months (range, one to four years). Nineteen patients were injured in a fall from standing height, four patients fell from a ladder (a height of >6 ft [1.8 m]), two fell from a bicycle, and one fell from a motorcycle at high speed. Nine patients were injured while working, and one patient had made a Workers’ Compensation claim. The mean time lost from work was 13.8 weeks.

Radial head fractures were classified according to the system proposed by Hotchkiss\(^3\), olecranon fractures were classified with use of the Mayo system\(^3\), coronoid fractures were graded with the classification described by Regan and Morrey\(^3\), and distal humeral articular fractures were classified according to the AO system\(^3\).

All patients had associated osseous or soft-tissue injuries about the elbow (see Appendix). Twenty-two of the twenty-six patients had an associated elbow dislocation, and thirteen of the twenty-two had sustained a coronoid fracture, creating the so-called terrible-triad injury (Figs. 2-A and 2-B). In addition to the radial head arthroplasties, thirty-nine simultaneous ipsilateral elbow procedures were performed (repair of the medial and lateral collateral ligaments, excision of the coronoid, open reduction and internal fixation of the coronoid, open reduction and internal fixation of the olecranon, open reduction and internal fixation of the capitellum, open reduction and internal fixation of the trochlea, repair of an avulsed triceps tendon, and open reduction of the radiocapitellar joint).

Operative and Postoperative Protocol
The fractured radial head was replaced with a modular radial head implant system (Evolve) that offers multiple head diame-
juries had the arm splinted in supination for six weeks, and flexion or as dictated by ligamentous stability exercises were performed actively with the elbow in 90° of maximal elbow extension. Forearm pronation and supination were used for elbows that were stable in extension to optimize osteosseous and soft-tissue injuries. A night extension splint was formed within a "safe" arc of motion as dictated by associated injuries that were present. Within one to two days postoperatively, all patients performed active range-of-motion exercises supervised by a hand therapist. With a stable reconstruction were given a collar and cuff to wear between exercises. Patients with associated lateral-sided ligamentous injuries had the forearm splinted in pronation with 90° of elbow flexion for the first six weeks, those with associated medial-sided ligamentous injuries had the arm splinted in supination for six weeks, and those with both medial and lateral-sided ligamentous injuries had the limb splinted in neutral forearm rotation for six weeks. Active flexion-and-extension exercises were performed within a "safe" arc of motion as dictated by associated osseous and soft-tissue injuries. A night extension splint was used for elbows that were stable in extension to optimize terminal elbow extension. Forearm pronation and supination exercises were performed actively with the elbow in 90° of flexion or as dictated by ligamentous stability. After six to eight weeks, active and passive stretching and strengthening exercises were initiated.

The details of the surgical technique for implanting this prosthesis have been described elsewhere. In brief, a midline posterior elbow incision was used to avoid injury to cutaneous nerves and to allow access to both the medial and the lateral deep muscular intervals as required to treat more complex instability. A full-thickness lateral flap was elevated on the deep fascia. In many cases, the common extensor muscles and the lateral collateral ligament had been avulsed from the lateral epicondyle, allowing easy access to the radial head. When the common extensor origin was intact, the Kocher interval between the extensor carpi ulnaris and the anconeus was opened and the radial collateral and annular ligaments were divided at the midportion of the radial head. The radial collateral ligament was elevated off of the lateral epicondyle as needed for further exposure. The more important lateral ulnar collateral ligament, a major contributor to varus and posterolateral rotatory stability, was left intact when possible. Associated injuries of the coronoid, olecranon, and lateral and/or medial collateral ligament were managed as necessary to ensure a congruous stable elbow joint and to allow an immediate postoperative range of motion.

The postoperative rehabilitation protocol was individualized according to the associated injuries that were present. Within one to two days postoperatively, all patients performed active range-of-motion exercises supervised by a hand therapist. Patients with a stable reconstruction were given a collar and cuff to wear between exercises. Patients with associated lateral-sided ligamentous injuries had the forearm splinted in pronation with 90° of elbow flexion for the first six weeks, those with associated medial-sided ligamentous injuries had the arm splinted in supination for six weeks, and those with both medial and lateral-sided ligamentous injuries had the limb splinted in neutral forearm rotation for six weeks. Active flexion-and-extension exercises were performed within a "safe" arc of motion as dictated by associated osseous and soft-tissue injuries. A night extension splint was used for elbows that were stable in extension to optimize terminal elbow extension. Forearm pronation and supination exercises were performed actively with the elbow in 90° of flexion or as dictated by ligamentous stability. After six to eight weeks, active and passive stretching and strengthening exercises were initiated. The patients were given indomethacin (25 mg orally three times a day) for prophylaxis against heterotopic ossification (unless otherwise contraindicated) for three weeks postoperatively.

Outcome Measures

Patients were prospectively evaluated with use of a series of questionnaires, objective physical examinations, and an assessment of radiographs. An independent observer collected all data.

Self-report scales were used to evaluate different health perspectives, including general health (Short Form-36 [SF-36] Health Survey), upper-extremity disability (Disabilities of the Arm, Shoulder and Hand Questionnaire [DASH]), and pain and disability specific to the elbow (Patient Rated Elbow Evaluation [PREE] and American Shoulder and Elbow Surgeons [ASES] self-report form). The Mayo Elbow Performance Index (MEPI) (an elbow impairment and functional index) was calculated with use of the self-reported responses to five specific questions on the PREE that are mapped to MEPI items and with use of measured strength and motion impairments. Grip strength and range-of-motion testing was performed with use of the NK Hand Evaluation System (NK Biomechanical Engineering, Minneapolis, Minnesota). Instruments were calibrated prior to each test session, and standardized protocols were used for evaluations of grip strength and motion. The Lido Workset (Loredan Biomedical, West Sacramento, California) was used for isometric testing of elbow flexion, elbow extension, pronation, and supination strength, with the elbow in 90° of flexion and the forearm in neutral rotation.

Anteroposterior and lateral radiographs of the elbow with the arm in pronation and supination were reviewed for congruity of the radial head with the capitellum, evidence of capitellar osteopenia, prostatic prosthesis, heterotopic lucency, periprosthetic osteopenia, heterotopic ossification, joint incongruity, and osteoarthritis. Capitellar osteopenia was graded as none, mild, moderate, or severe. Prosthetic sizing and overstuffing were judged by comparing the medial ulnohumeral joint space of the operatively treated and untreated elbows on follow-up anteroposterior radiographs. If the medial ulnohumeral joint surfaces were parallel and the joint space was equal to that of the contralateral elbow, it was deemed that there was no overstuffing of the joint. Periprosthetic lucency around the stem was graded as none, mild, moderate, or severe on the basis of the number of zones (adopted from the Gruen classification for the hip) involved (Figs. 3-A and 3-B) and the amount of lucency (in millimeters) observed. Lucency was rated as mild when one or two zones were involved by lucent lines of <2 mm in thickness, moderate when three to six zones were involved or the lucency was ≥2 mm in thickness, and severe when all seven zones were involved. Heterotopic ossification was graded as I, II, III, or IV according to the scoring system of Brooker et al. The degree of degenerative change was classified, with the system described by Broberg and Morrey, as grade 0 (a normal joint), grade 1 (slight joint space narrowing and minimum osteophyte formation), grade 2 (moderate joint space narrowing and moderate osteophyte formation), or grade 3 (severe degenerative changes with gross destruction of the joint).
Statistical Methods

Descriptive statistics were used to identify outliers and missing values. Patients were evaluated on repeated occasions; if a single patient was missing some (<10%) of the values from his or her data, the missing score was imputed from the patient’s prior and subsequent score with use of regression equations (to allow complete repeated-measures analysis). Repeated-measures analysis of variance across occasions was used to identify differences in outcome measures over time. Paired t tests were used to assess the difference between affected and unaffected sides at the two-year follow-up evaluation ($\alpha = 0.05$).

Results

The details of the injuries, treatment, complications, and outcomes in each of the twenty-six patients are outlined in the Appendix. Computed with the values observed immediately postoperatively, significant improvements ($p < 0.05$) in all self-reported measures were seen at six months, with minimal additional improvement occurring between six months and two years. The mean SF-36 physical function score was 33.0 points in the initial postoperative period (six weeks), and it improved to 41.8 points at two years (United States population norm = 50 points) (Table I). At two years, on the average, the ASES pain score was 13.4 points (best possible score = 0 points, worst possible score = 50 points), the ASES function score was 27.5 points (best possible score = 36 points, worst possible score = 0 points), the ASES satisfaction score was 9.0 points (best possible score = 10 points, worst possible score = 0 points), the total PREE score was 22.9 points (best possible score = 0 points, worst possible score = 100 points), and the DASH score was 24.4 points (best possible score = 0 points, worst possible score = 100 points). The average MEPI score was 82 points at one year and 83.4 points at two years. Of the twenty-four patients for whom a MEPI score was calculated (missing information prevented the score from being calculated for two patients), 50% (twelve) had an excellent result; 17% (four), a good result; 25% (six), a fair result; and 8% (two), a poor result.

Physical impairment of strength and motion decreased over time, with the majority of the improvement occurring within the first year. At two years, there were still significant differences between the capabilities on the affected and unaffected sides (Table II, $p < 0.05$). Minor side-to-side differences were noted in mean elbow flexion (138.1° on the affected side compared with 140.6° on the unaffected side), forearm pronation (71.0° and 78.7°, respectively), and grip strength (24.5 and 28.6 kg, respectively). Moderate side-to-side differences were noted in mean elbow extension (24.9° on the affected side compared with 6.2° on the unaffected side), forearm supination (56.2° and 71.1°, respectively), and isometric strength testing in extension (31.2 and 38.7 Nm, respectively), flexion (35.5 and 44.6 Nm, respectively), supination (46.6 and 65.2 Ncm, respectively), and pronation (44.3 and 56.9 Ncm, respectively).

The average time lost from work was 13.8 weeks. Of the thirteen patients employed outside of the home prior to their accident, nine returned to full-time work with regular duties,
TABLE I Self-Reported Outcome Measures at Two Years

<table>
<thead>
<tr>
<th>Measure</th>
<th>Score (points)</th>
<th>Mean and Stand. Dev. (Range)</th>
<th>Normal Score</th>
<th>Worst Possible Score</th>
<th>Best Possible Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF-36</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Physical</td>
<td>41.8 ± 11.4</td>
<td>11.7-60.6</td>
<td>50 ± 10</td>
<td></td>
<td></td>
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<tr>
<td>Mental</td>
<td>51.5 ± 10.4</td>
<td>26.0-64.8</td>
<td>50 ± 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DASH</td>
<td>24.4 ± 21.4</td>
<td>0-59.2</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MEPI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>80.5 ± 16.7</td>
<td>9-100</td>
<td>0</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>31.4 ± 10.4</td>
<td>9-45</td>
<td>0</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Motion</td>
<td>114.7 ± 20.1</td>
<td>69°-146°</td>
<td>0</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td>10 ± 0</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Function</td>
<td>22.0 ± 4.7</td>
<td>14-25</td>
<td>0</td>
<td>25</td>
<td></td>
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<tr>
<td>ASES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>13.4 ± 11.5</td>
<td>0-38.0</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Function</td>
<td>27.5 ± 9.4</td>
<td>8.0-38.0</td>
<td>0</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Satisfaction</td>
<td>9.0 ± 1.9</td>
<td>2.0-10.0</td>
<td>0</td>
<td>10</td>
<td></td>
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<tr>
<td>PREE</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td>14.6 ± 11.5</td>
<td>0-40.0</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Function</td>
<td>17.4 ± 20.7</td>
<td>0-64.0</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>22.9 ± 22.4</td>
<td>0-77.0</td>
<td>100</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Radiographic evaluation demonstrated that all radial head implants articulated congruently with the capitellum. Seventeen (65%) of the twenty-six patients did not have any evidence of osteopenia, five (19%) had mild capitellar osteopenia, and four (15%) had moderate capitellar osteopenia. There was no evidence of implant overstuffing, as there was parallelism of the unnohumeral joint. Thirteen patients (50%) did not have any evidence of lucency around the stem of the prosthesis, nine (35%) had minor lucencies (≥2 mm in thickness or involvement of three to six zones) around the stem, and four (15%) had moderate lucencies (≥2 mm in thickness or involvement of three to six zones). Grade-1 osteoarthritis developed in five patients (19%), but the remaining patients (81%) did not have any arthritic changes. The implants showed excellent survivorship. At the two-year interval, no implant had fractured, loosened, or required removal or revision.

There was a total of eleven complications. Six patients had heterotopic ossification, which was stage I in four of them, stage II in one, and stage IV in another. Eleven patients had not received indomethacin because of other medical co-morbidities, and the two patients in whom stage II or IV heterotopic ossification developed were among that group.

Transient neurologic symptoms developed in three patients, two of whom had a transient sensory ulnar neuropathy.
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( McGowan grade I or II $^{51}$ ) and one of whom had a moderate posterior interosseous nerve palsy (McGowan grade II). All three patients had complete resolution of the symptoms at the time of final follow-up. A severe reflex sympathetic dystrophy developed in one patient, who required two stellate ganglion blocks. One patient underwent surgical release of a $65^\circ$ flexion contracture, and another was offered a surgical release of a $62^\circ$ flexion contracture but declined to have the procedure.

Discussion

To our knowledge, this is the first publication reporting the outcomes of an arthroplasty with a modular metallic radial head implant for the acute treatment of an unreconstructible radial head fracture with an associated elbow injury.

As expected, large improvements in strength and the range of motion were observed within the first year, and modest additional improvements were noted for up to two years. Self-reported measures indicated that the injury had a profound effect on both upper-extremity function and overall health. Self-reported outcome measures (the DASH, PREE, and ASES) also showed large improvements in the initial postoperative period (up to six months), but the scores then plateaued, with little additional improvement observed between six months and two years (Fig. 4).

One of the main limitations of this study is that a single cohort was evaluated with no control or comparison group. This introduces uncertainty about what outcomes might have been achieved with other interventions such as radial head excision or open reduction and internal fixation. We used other comparisons to assess the value of this intervention. When normal values or comparative values for similar patients had been reported for the disability scales, we were able to make inferences about disability. We know that, immediately postoperatively, our patients had high DASH scores (mean, 58.3 points), which improved greatly (to a mean of 24.4 points) but did not reach population norms (mean, 12 points) by an average of two years. This observation is supported by our findings regarding physical impairment: although the strength and range of motion of the affected arm showed considerable improvement over time, they still differed significantly from those of the unaffected arm at two years. We used the uninjured side for comparison because, in the absence of injury, strength values on contralateral sides are highly correlated ($r = -0.98$).$^{52}$

Two patients had a poor result and six patients had a fair result based on the MEPI score$^{53}$. The two poor results can be accounted for by a combination of factors, including the severity of the initial injury, other associated fractures, and postoperative complications. Both patients had a terrible-triad injury in association with another fracture. The patient with the MEPI score of 43 points had an associated distal humeral fracture (AO type C3) and the patient with the MEPI score of 53 points had an associated olecranon fracture. A proximal radioulnar synostosis also developed in the latter patient postoperatively. The six patients who had a fair result (a MEPI score of between 60 and 74 points) also had associated injuries. Four patients had a terrible-triad injury, and another had a chondral injury to the capitellum and a contralateral elbow fracture-dislocation. The sixth patient had ulna-sided wrist pain with negative ulnar variance and required débridement of the triangular fibrocartilaginous complex two years after the injury. This patient was also involved in litigation associated with the initial injury.

Range-of-motion and strength testing showed little impairment when compared with the results on the contralateral side. The average losses were $4^\circ$ of flexion, $7^\circ$ of pronation, $16^\circ$ of extension, and $16^\circ$ of supination ($p < 0.05$). Grip strength was comparable with that on the contralateral side.

All outcome scores showed significant improvement from baseline (immediately postoperatively) to six months. The ASES function score showed a trend toward continued improvement after one year ($p = 0.08$), whereas the other outcome scores plateaued and did not show any significant change between six months and two years.

![Fig. 4](image_url)

Fig. 4

All outcome scores showed significant improvement from baseline (immediately postoperatively) to six months. The ASES function score showed a trend toward continued improvement after one year ($p = 0.08$), whereas the other outcome scores plateaued and did not show any significant change between six months and two years.
(24.5 compared with 28.6 kg). Radiographic outcomes were also favorable, with only mild evidence of capitellar osteopenia, mild periprosthetic lucency, and mild osteoarthritis developing in only a few patients by two years. The complications were mild, and they resolved in all except three patients, two of whom had heterotopic ossification and one of whom had a severe reflex sympathetic dystrophy.

The results in our study compare favorably with those in other reports on metallic radial head arthroplasties for the treatment of comminuted unreconstructible radial head fractures (see Appendix). In 2004, Ashwood et al. reported the outcomes of treatment of comminuted unreconstructible radial head fractures with a monoblock titanium prosthesis, soft-tissue reconstruction, and an early range of motion in sixteen patients followed for an average of 2.8 years\(^a\). In 2001, Moro et al. reported the outcomes of treatment of comminuted unreconstructible radial head fractures with a metallic monoblock radial head prosthesis in twenty-five patients followed for an average of thirty-nine months\(^b\). Both studies showed favorable outcomes, with average MEPI scores of 87\(^a\) and 80\(^b\) points, respectively. Ashwood et al. reported that their patients lost an average of 10\(^o\) of flexion, 15\(^o\) of extension, 12\(^o\) of pronation, 12\(^o\) of supination, and 12\(^%\) of grip strength when compared with the values on the contralateral side. Moro et al. demonstrated similar results, with significant losses of elbow flexion, extension, and supination of the affected extremity when compared with the unaffected extremity (p < 0.05). Grip strength was decreased by 18\%; isometric forearm pronation, by 17\%; and isometric supination, by 18\%\(^b\).

The overall clinical outcomes observed in our cohort of comminuted unreconstructible radial head fractures were favorable given the severity of the injuries and the difficulty of this clinical problem. In addition, the prosthesis offers many theoretical advantages over the traditional monoblock design because of the modularity of its components.

Aside from ease of insertion, the surgeon can alter the components of the prosthesis independently, achieving optimal stability without overstuffing the joint\(^c,d\), which can be a problem with the monoblock design. In this series, we accurately measured both the diameter and the thickness of the excised radial head intraoperatively (with the sizer provided) and were able to consistently avoid overstuffing the joint. A thorough radiographic review confirmed that there were no cases of ulnohumeral joint incongruity in this series, supporting our hypothesis that a modular prosthesis allows the problem of overstuffing to be avoided.

In this two-year follow-up study, the prosthesis had a 100\% survival rate, and all joints remained reduced and stable. Most of the improvement was seen during the first six months following the surgery, although it would be accurate to instruct patients that small improvements of uncertain benefit will continue throughout the following eighteen months. Although long-term follow-up is ongoing, the early results of this modular metallic arthroplasty are promising, so that it can be safely recommended as an effective option for the treatment of unreconstructible radial head fractures with associated elbow injuries.

### Appendix

Tables showing the cases in detail and presenting a summary of findings in historical controls are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on “Supplementary Material”) and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM).

The authors did not receive grants or outside funding in support of their research for or preparation of this manuscript. They did not receive payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. A commercial entity (Wright Medical Technology) paid benefits to a research foundation (St. Joseph’s Health Centre Foundation) with which the authors are affiliated or associated.

doi:10.2106/JBJS.E.00962

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