Radial Osteotomy and Bowers Arthroplasty for Malunited Fractures of the Distal End of the Radius*

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ABSTRACT: Radial osteotomy and hemiresection arthroplasty was performed in fifteen patients who had malunion of a fracture of the distal end of the radius with symptoms predominantly in the radio-ulnar joint and limited rotation of the forearm. Postoperatively, all of the patients had improved rotation and stability of the distal radio-ulnar joint, as well as satisfactory relief of pain. Over-all, grip strength increased an average of 30 per cent, and every patient had substantial improvement in function. The result was very good in four patients, good in eight, and fair in three.

In malunions that occur after these types of fractures, the three basic post-traumatic sequelae that can develop are ulnocarpal impingement, dorsal subluxation (instability) of the ulnar head, and incongruity of the surfaces of the radio-ulnar joint.

Until Bowers described his hemiresection interposition technique, I had used a combination of the Darrach operation (as modified by Dingman) and radial osteotomy in patients who had severe shortening of the radius or degenerative changes of the distal radio-ulnar joint. Various authors have stressed the disadvantages of the Darrach procedure — loss of grip strength, loss of ulnar support of the carpus, and painful instability of the distal ulnar stump. Less frequent complications are sensory neuroma of the ulnar nerve, rupture of the extensor tendons, and unsatisfactory cosmetic appearance of the wrist. The main advantages of the Darrach procedure are that it completely relieves the pain and that it can be used as a salvage operation in patients in whom previous reconstructive procedures have failed.

Because the problems that are associated with a Darrach procedure are obviated by an operation that preserves the triangular fibrocartilage and the ulnocarpal ligaments, I started to use the Bowers technique to treat malunited fractures of the distal end of the radius that were associated with symptoms in the radio-ulnar joint. I am presenting the results that were obtained in fifteen consecutive patients who were treated with radial osteotomy and primary hemiresection-interposition arthroplasty (Fig. 1) for malunion of the distal end of the radius. The patients were followed for an average of thirty-six months (range, twenty-four to fifty-four months).

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Malalignment of a four-part articular Colles fracture with ulnocarpal impingement, incongruity of the sigmoid notch, radial shortening, and increased dorsal tilt (A). Restoration of radial length and angular orientation of the surface of the joint with opening-wedge osteotomy of the radius (B). A Bowers arthroplasty with so-called anchovy interposition of the extensor carpi ulnaris is shown.

Materials and Methods

The group of patients included eight women and seven men, and the ages ranged from twenty to sixty-nine years (average, 52.2 years). Malunion had occurred after an intra-articular fracture of the distal part of the radius in eight patients, after a Colles fracture in four, and after a Smith fracture in three. An associated fracture of the head of the ulna was present in two patients (Cases 2 and 15, Table I).

Radiographic measurements were made according to Castaing's modification of the method that was devised by Gartland and Werley. A negative value for ulnar tilt meant that there was no ulnar inclination of the articular surface of the radius. Instead, there was radial inclination, so that the radial articular surface formed a negative angle with relation to a line drawn perpendicular to the radial shaft. Radial shortening was determined by drawing lines perpendicular to the longitudinal axis of the forearm — a line tangential to the proximal surface of the lunate radial facet and a line tangential to the distal articular surface of the ulnar head. The difference, which was measured in millimeters, represented the ulnar variance or the radio-ulnar index. It averaged 5.3 millimeters (Table I).

Eight patients had an increased dorsal tilt (Colles deformity) that averaged 23.5 degrees (range, 5 to 45 degrees), and seven patients had an increased volar tilt (Smith deformity) that averaged 25.3 degrees (range, 15 to 34 degrees). In all of the malunions, the physiological ulnar inclination of the articular surface in the frontal plane had been lost, and the inclination averaged 12.9 degrees. The radial shortening averaged 5.3 millimeters (range, one to nine millimeters).

Pain in the wrist was graded as mild, moderate, or severe. Mild pain was present only at the extremes of the active range of motion of the wrist, and the patient was neither physically nor psychologically disturbed by the pain; moderate pain occurred during heavy manual labor and caused the patient to be disturbed physically or psychologically, or both; and severe pain occurred during activities of daily living and even at rest. Preoperatively, all of the patients had moderate or severe pain in the distal radio-ulnar joint, and half of them also had mild or moderate pain in the radiocarpal joint.

The severity of the pain did not correlate well with the amount of radial shortening, the presence of degenerative
Aging the position of the ulnar head with respect to the distal end of the radius. Moderate instability, defined by abnormal prominence of the ulnar head when the forearm is in full pronation, was present in two patients (Cases 4 and 10). Four other patients (Cases 1, 2, 6, and 14) had severe instability of the radio-ulnar joint, prominence of the ulnar head, and a positive so-called piano-key sign, in which the prominent, subluxated ulnar head can be reduced by local pressure but promptly springs back dorsally when finger pressure is released. In these four patients, the distal end of the radius had healed with increased volar tilt and a pronation deformity. This type of malunion increases the dorsal prominence of the ulnar head despite neutral rotation of the forearm (Fig. 2), and it necessitates additional derotation of the radial fragment. Other preoperative findings included carpal tunnel syndrome in two patients (Cases 10 and 13), one of whom also had non-union of the distal part of the radius, and dorsal subluxation of the carpus in another patient (Case 12) (Figs. 3-A through 3-E).

True ulnocarpal impingement, with radiographic evidence of abutment of the ulnar head and the lunate or the triquetrum, was present in six patients (Cases 1, 4, 6, 7, 8, and 10), all of whom had radial shortening of more than six millimeters. Non-union of the styloid process of the ulna was present in two-thirds of the patients. In all fifteen radio-ulnar joints, degenerative changes were radiographically evident. Degenerative changes were evident in only five ra-
## Results at Latest Follow-up

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### Surgical Technique

The type of surgical approach, of radial osteotomy, of the bone graft that was used to fill the defect, and of internal fixation were described in 1977 and 1982.

Six malunions that had increased dorsal tilt were treated with a dorsal opening-wedge osteotomy that was performed through a dorsal approach. Two fractures (Cases 8 and 11) had healed with only 5 degrees of dorsal tilt but with important radial deviation, and for them an opening-wedge osteotomy was used.
Figs. 3-A through 3-E: Case 12. Malunited intra-articular Colles fracture with 45 degrees of dorsal tilt.

Figs. 3-A and 3-B: Note the degenerative changes in both distal radio-ulnar joints and the dorsal subluxation of the carpus on the affected side.

osteotomy that was radially based was done through a volar approach. All seven malunions that had increased volar tilt had a volar opening-wedge osteotomy that was performed through a palmar approach. In eleven patients, the graft was taken from the iliac crest and in four, from the ulnar head.

In all but three patients, the osteotomy was fixed with a plate and screws. One wrist (Case 6) was stabilized with three percutaneous Kirschner wires because the patient did not accept the possibility of a second operation for removal of hardware. In another patient (Case 8), fixation of the radial osteotomy was achieved with two lag screws (Figs. 4-A, 4-B, and 4-C), and in a third patient (Case 12), the osteotomy was fixed with two oblique Kirschner wires and a small external fixator bridging the wrist. The fixator reduced the dorsal subluxation of the carpus, which persisted intraoperatively despite correction of the radial deformity (Fig. 3-C).

On the ulnar side of the wrist, hemiresection interpo-
RADIAL OSTEOTOMY AND BOWERS ARTHROPLASTY FOR MALUNITED FRACTURES

Radiographs made immediately after radial osteotomy and Bowers arthroplasty. A wrist fixator was used to control subluxation of the carpus.

Postoperative Care

For twelve patients, the forearm was immobilized in a soft, bulky dressing and a volar plaster splint for two weeks, and functional range-of-motion exercises were begun after the sutures were removed. Two patients (Cases 6 and 8) wore a sugar-tong splint for four and six weeks to protect internal fixation of the radius that had been performed with Kirschner wires or with screws. The wrist of one patient (Case 12, Figs. 3-A through 3-E) was immobilized in an external fixator for six and a half weeks.

Three months postoperatively, the hardware was removed from the six patients who had a Colles deformity and who had a dorsally applied plate; this was done to avoid tethering of the tendon of the extensor pollicis longus (Figs. 6-A, 6-B, and 6-C). All volar plates were left in place. Percutaneous Kirschner wires were removed eight weeks after operation.

Results

The length of follow-up ranged from two to four and a half years (average, three years) after osteotomy. All of the patients were evaluated for pain, instability of the radioulnar joint, active range of motion of the wrist, and grip strength. Radiographic analysis included measurements of the angular correction of the distal end of the radius and of the radio-ulnar index \(^4\), and assessment of degenerative changes in the radiocarpal joint (Table I).

The average time to healing was 6.8 weeks (range, five to 8.1 weeks). The criteria to establish healing were described previously \(^8\). Radiographic measurements at follow-up showed that an average volar tilt of 5.2 degrees (range, 3 to 7 degrees) was restored in ten patients, while three had correction to a neutral tilt of zero degrees. The other two patients had a residual dorsal tilt of 4 and 3 degrees. The average ulnar...
Radial shortening was corrected with an opening-wedge osteotomy of the radius alone in fourteen patients; one patient (Case 8) also needed a shortening osteotomy of the ulna. At follow-up, measurement of the radio-ulnar index after resection of the head of the ulna showed that the discrepancy in length between the radius and the ulna averaged 0.6 millimeter (range, zero to three millimeters).

Thirteen patients had no pain in the distal radio-ulnar joint, and two patients still had mild pain during the extremes of active pronation and supination. However, these patients had less pain than they had had preoperatively (severe in one and moderate in the other), and the residual pain could not be correlated with radiographic findings at follow-up. In both patients, the radio-ulnar index was zero, and there was no evidence of the ulnocarpal or stylocarpal impingement or of non-union of the ulnar styloid process. The pain was attributed to deep scarring.

Dorsal subluxation of the distal part of the ulna, which had been present in six patients before operation, was not present in any patient at follow-up. The main reasons to restore stability of the distal radio-ulnar joint are to tighten the volar radio-ulnar ligaments through radial lengthening and to correct the pronation malalignment of the distal radial fragment in patients who have a Smith deformity.

Four patients who had pain in the radiocarpal joint, four were free of pain at follow-up, and in four the pain remained mild. In one patient (Case 5) who had had no pain in the wrist preoperatively, mild pain developed after osteotomy. Pain in the radiocarpal joint correlated with radiographic degenerative changes in only two of five patients who had residual pain in the wrist.

Assessment of the function of the wrist showed that the displaced arc of flexion-extension was adequately balanced due to correction of the radial deformity in the sagittal plane, and that rotation of the forearm was substantially improved in all patients after hemiresection arthroplasty. At follow-up, the average loss of motion of the wrist (expressed as a percentage of the values for the uninvolved wrist) in patients who had a Colles deformity were: dorsiflexion, 22 per cent; palmar flexion, 29 per cent; radial deviation, 8 per cent; ulnar deviation, 25 per cent; pronation, 15 per cent; and supination, 12 per cent. In patients who had a Smith deformity, the percentages of loss were: dorsiflexion, 24 per cent; palmar flexion, 31 per cent; radial deviation, 11 per cent; ulnar deviation, 37 per cent; pronation, 9 per cent; and supination, 7 per cent.

An increase in grip strength was noted in all patients at follow-up, although the strength of the involved hand never reached that of the opposite hand. The residual average loss of grip strength for all patients was 25 per cent, which represented an over-all improvement of 32 per cent.
Fig. 3-E
Radiographic appearance at the most recent follow-up, two years and three months postoperatively.

The pain and no pain scales with respect to the preoperative status.

The final assessment of results was rated on a point-score system that was based on the analysis of residual pain in the radiocarpal and radio-ulnar joints, the arc of flexion-extension, over-all rotation of the forearm, and grip strength. Severe pain was assigned zero points; moderate pain, 1 point; mild pain, 2 points; and no pain, 4 points.

Four points was assigned to an arc of flexion-extension of 130 to 140 degrees; 3 points, to an arc of motion of 100 to 130 degrees; 2 points, to an arc of motion of 80 to 100 degrees; and 1 point, to an arc of motion of less than 80 degrees. Rotation of the forearm of 160 to 180 degrees scored 4 points; of 140 to 160 degrees, 3 points; of 120 to 140 degrees, 2 points; and of less than 120 degrees, 1 point.

Grip strength that was 80 per cent or more of that of the uninvolved hand received 4 points; 65 to 70 per cent, 3 points; 40 to 65 per cent, 2 points; and less than 40 per cent, 1 point.

The point scores for each of the five evaluation criteria were added. A rating of very good was assigned to a wrist that had a score of 18 to 20 points; good, 15 to 17 points; fair, 12 to 14 points; and poor, less than 11 points.

Four results were very good, eight were good, and three were fair. The three fair ratings were mainly a result of limited motion of the radiocarpal joint that had been present preoperatively and that did not improve after osteotomy. Furthermore, residual pain in the wrist in each of these three patients definitely played a role in the reduction of active grip strength and resulted in decreased point scores at the final assessment.

Discussion

Excellent recent studies have enriched the anatomical, biomechanical, and the therapeutic understanding of the distal radio-ulnar joint. Bowers and Watson et al. have devised partial resection arthroplasties of the distal end of the ulna that preserve the integrity of the triangular fibrocartilage complex and the ulnocarpal ligaments. The experience of these authors has consisted mostly of the treatment of patients who had rheumatoid arthritis in the wrist. However, the operation is also applicable for post-traumatic incongruity of the articular surfaces of the ulnar head and sigmoid notch with osteoarthritis that has occurred after a fracture of the distal end of the ulna or after a malunion of the distal end of the radius.

The patient's main complaints are painful and limited rotation of the forearm and loss of grip strength. Symptoms that are directly dependent on the angulation of the radial
Figs. 4-A, 4-B, and 4-C: Case 8. Malunion of a Colles fracture with radial shortening, radial deviation, ulnocarpal impingement, and incongruity of the sigmoid notch.

Fig. 4-A: Anteroposterior and lateral radiographs made preoperatively.

Preoperative planning. An ulna-shortening osteotomy was done in addition to Sowers arthroplasty because a radial osteotomy did not restore the full length of the radius.
articular surface, such as dorsal or palmar displacement of the arc of flexion-extension and pain in the radiocarpal joint, are less frequent complaints. Careful examination of the distal radio-ulnar joint is imperative to detect the exact location of pain and to rule out associated instability. When there is ulnocarpal impingement, arthrograms help to determine the importance of the lesion of the triangular fibrocartilage complex. If incongruity of the distal radio-ulnar joint is not apparent on plain radiographs, a computerized tomographic scan will clearly show the irregularities at the sigmoid notch and at the ulnar head (Fig. 5).

Ulnocarpal impingement, with abutment of the head of the ulna against the lunate or triquetrum, is seen when the distal fragment of the radius has healed without substantial dorsal or palmar angulation, but with important shortening. If radial angulation exceeds 35 to 40 degrees in the sagittal plane, the carpus follows the radius and ulnar impingement is rarely present. The head of the ulna lies volarly when there is a Colles deformity and dorsally when there is a Smith deformity. A central ulcer of the triangular fibrocartilage and chondromalacia of the ulnar head and the carpus at the point of overload is always present if true impingement has occurred.

Dorsal subluxation with a positive so-called piano-key sign occurs frequently in malunions that occur after a Smith fracture that has healed not only with palmar displacement but also with pronation deformity of the distal fragment with respect to the shaft (Fig. 2). However, instability also may be present in a malunion that occurs after a severely displaced Colles fracture with complete rupture of the dorsal and volar radio-ulnar ligaments. Non-union of the ulnar styloid, which actually is a fibrous union with continuity of the triangular fibrocartilage complex, is not a primary cause of instability of the distal radio-ulnar joint and did not receive special operative treatment in the patients in this series.

Of thirty-eight patients in Bowers' series who were treated with hemiresection arthroplasty, twenty-seven had rheumatoid arthritis, five had a post-traumatic or degenerative abnormality of the distal radio-ulnar joint, and six patients had post-traumatic derangement of the distal radio-ulnar joint after a fracture of the radius. Of the latter six patients, three had a so-called settled Colles fracture with radial shortening, two patients had positive ulnar variance after fusion of a radial epiphysis and a Galeazzi fracture, and one patient had an old radio-ulnar arthrosis secondary to a Colles fracture. After hemiresection arthroplasty, ulnar shortening using the Milch procedure was done to prevent stylocarpal impingement in four patients. Pain as a result of stylocarpal impingement persisted in the two patients in
whom the ulna was not shortened. Bowers suggested that if a positive ulnar variance is greater than two millimeters, hemiresection arthroplasty should be used with ulnar shortening.

Watson et al. reported the results of a similar operation, devised in 1967, that consists of an oblique so-called matched resection of the ulnar head without interposition. In their series of forty-four wrists, with an average follow-up of 6.5 years, most of the patients had rheumatoid arthritis. Of the five malunited Colles fractures in the series, three were treated with matched distal ulnar resection alone and two had additional corrective osteotomy of the distal end of the radius. At follow-up, adequate rotation of the forearm and relief of pain were achieved in all five patients. The preoperative ranges of motion of the wrist were not given. Watson et al. recommended this operation whenever "treatment of a painful distal radioulnar joint is necessary".

In a recent biomechanical study on load distribution of the wrist joint with experimental osteotomies of the distal part of the radius, Short et al. showed that, with increasing values of dorsal tilt, there is overload of the distal end of the ulna of as much as 67 per cent, as well as force concentration on the dorsal aspect of the radiocarpal joint. The results of that experimental study justify the indication for early correction of a malunited Colles fracture, to prevent degenerative changes in the wrist.

Our results showed that partial resection of the ulnar head is a valuable adjuvant procedure in malunion of the distal end of the radius when the predominant symptoms are localized in the distal radio-ulnar joint. Rotation of the forearm and relief of pain increased considerably in all patients. In the fifteen patients, at follow-up the average remaining deficit in pronation was 12 per cent and in supination, 14 per cent, compared with the preoperative deficits of 47 and 77 per cent, respectively. Correction of the associated radial deformity by osteotomy not only restores the normal orientation of the articular surface of the radiocarpal joint, thus re-establishing normal distribution of load, but also corrects the discrepancy in the lengths of the radius and ulna, which is necessary to prevent stylocarpal
impingement after hemiresection arthroplasty. If adequate radial length cannot be restored with radial osteotomy alone, additional ulnar shortening is needed. In these patients, a diaphyseal osteotomy with rigid internal fixation is preferred to the procedure described by Milch, because it permits functional postoperative care with no cast.

On the basis of this experience, I believe that partial resection of the ulnar head for malunion of the distal end of the radius should be performed as a primary operation in combination with radial osteotomy when the patient’s main symptom is limited rotation of the forearm because of pain and when degenerative changes in the distal radio-ulnar joint are present. However, most patients do not wish to undergo such an extensive procedure. I have, therefore, occasionally used a limited resection for the treatment of symptomatic malunion with patients who do not want to undergo a more extensive procedure. In these patients, a limited resection of the ulnar head is performed through a lateral incision just proximal to the level of the pronator teres muscle. The articular cartilage of the ulnar head is then removed with a burr, and the fragment is trimmed to fit into the flexor carpi ulnaris groove. The fragment is then allowed to heal in place. The patient is allowed to move the wrist at the end of the first week and to begin wrist exercises after two weeks. The cast is removed after six weeks, and the patient is allowed to begin gentle use of the forearm.
Radiographic appearance of the wrist three years after osteotomy, showing anatomical restoration of the volar tilt.

The distal radio-ulnar joint are radiographically evident. Dorsal instability of the distal end of the ulna and ulnocarpal impingement as a result of shortening, angulation, or malrotation of the distal end of the radius, with no degenerative arthritic changes, can be corrected by restoration of the radial deformity by osteotomy alone in an effort to preserve the distal part of the ulna.

If the patient still has pain in the distal radio-ulnar joint after radial osteotomy, hemiresection arthroplasty (with or without ulnar shortening, depending on the residual radio-ulnar index) can be performed as a secondary procedure.

The Darrach procedure still has a place in the treatment of distal radio-ulnar derangement or osteoarthritis after Colles fracture in the elderly patient, or as a salvage procedure (the so-called Girdlestone procedure of the wrist) for previously failed reconstructive procedures of the distal radio-ulnar joint.

References
Release of Gentamicin from Acrylic Bone Cement

ELUTION AND DIFFUSION STUDIES

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ABSTRACT: It has been generally assumed that release of antibiotic from methylmethacrylate occurs either from the surface, through pores in the matrix of the cement, or by diffusion through the matrix. In vitro and in vivo studies of the release of antibiotic from cement have produced variable and inconsistent results. In our laboratory, preliminary observations suggested that antibiotic is released from methylmethacrylate by flow through an interconnecting series of voids and cracks in the cement, rather than through diffusion after having been homogeneously distributed throughout the cement. Therefore, experiments were performed to answer the fundamental question of whether the matrix of methylmethacrylate bone cement is permeable to gentamicin.

In vitro elution studies were performed on injection-molded rods of methylmethacrylate that had been loaded with two different amounts of gentamicin. The first group of rods contained 0.5 gram of gentamicin for each packet and the second, 1.5 grams for each packet. The rods were embedded subcutaneously in the subcostal region of sheep for three months. Bioassay of sections of the rods, using the tube-diffusion technique of Mitchell and Spicer, showed that the more highly loaded cement had released a significantly greater proportion of gentamicin. This occurred because the more highly loaded cement contained a greater number of defects that contained gentamicin (filled voids and interconnecting cracks).

In vitro diffusion studies were also performed, using 0.8-millimeter-thick disks of methylmethacrylate that did not contain antibiotic. Test solutions of either gentamicin or methylene blue were placed in the inner compartments of diffusion chambers. The outer compartments contained tissue-culture medium 199, which was sampled monthly and assayed for gentamicin or methylene blue. During the nine-month experiment, no gentamicin or methylene blue diffused through the cement disks. At the end of the experiment, the cement disks from the chambers that contained methylene blue were removed and were broken. The broken surface was not found to be stained, and there was no blue tinge mark along the surface to suggest the presence of a diffusion front.

After the in vivo elution studies had been performed, immunofluorescence and phase-contrast studies of the cement rods demonstrated the distribution of residual gentamicin. Scanning electron-microscopy studies confirmed the presence of cracks and defects in the cement matrix.

The in vivo and in vitro studies showed that methylmethacrylate bone cement that has no defects is imperious to gentamicin. Release of gentamicin probably reflects the presence of defects in the cement, which consist of voids containing antibiotic and radiopaque marker, of bubbles, and of interconnecting cracks.

CLINICAL RELEVANCE: Release of antibiotic from bone cement occurs from the surface of the cement and through a network of bubble-like voids and cracks in its