Correction of Post-Traumatic Wrist Deformity in Adults by Osteotomy, Bone-Grafting, and Internal Fixation

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ABSTRACT: A corrective osteotomy for post-traumatic malalignment of the distal end of the radius was performed in twenty patients who were followed for an average of 3.6 years. The indications for correction were based on age, degree of deformity, limitation of function, pain, and appearance of the wrist. The procedure included an opening-wedge metaphyseal osteotomy combined with insertion of a graft and rigid internal fixation with a plate and screws to permit early motion. Depending on the direction of the angulation, a dorsal or volar approach was employed to guarantee a buttressing effect of the plate. The procedure gave satisfactory results when there were no degenerative changes in the radiocarpal or intercarpal joints and when the preoperative range of motion of the wrist was adequate. The results were graded as excellent in five patients, good in ten, fair in four, and poor in one.

Closed treatment of Colles fractures leads to satisfactory clinical results in the great majority of patients. Adequate function of the wrist and absence of pain can be expected despite radiographic evidence of a malunion and shortening of the radius as well as subluxation of the distal radio-ulnar joint. These results are mainly due to the fact that Colles fractures occur predominantly in elderly patients who no longer engage in strenuous manual activities and therefore the functional requirements of the wrist are much reduced. Conversely, post-traumatic deformity in younger, active patients is less well tolerated, especially in those engaged in heavy manual work or who require a normal range of motion of the wrist (such as musicians, technicians, and surgeons). It is mainly for this group of patients that surgical correction of the malunited radius should be considered.

Serious deformities of the wrist can usually be prevented by proper treatment of the original fracture, especially the unstable types with a strong tendency to redisplace in a plaster cast after adequate initial reduction. Sometimes, however, deformity does develop, and in such patients better function and a more normal-appearing wrist can be restored by a corrective osteotomy through the site of the original fracture.

The deformity usually becomes symptomatic if the angulation of the distal articular surface of the radius is more than 25 to 30 degrees in the sagittal or frontal plane and when there is a significant discrepancy (six millimeters or more) between the lengths of the radius and the ulna, especially in young, manually active patients.

A shortening osteotomy of the ulna or a resection of the distal end of the ulna does not restore the normal anatomy of the wrist joint or correct the pathologically displaced flexion-extension arc of motion in these patients. In the elderly patient, a Darrach resection of the distal end of the ulna is the method of choice for the treatment of derangement, post-traumatic or rheumatoid arthritis, and painful subluxation of the distal radio-ulnar joint due to malunion of a Colles fracture.

In general, radial osteotomy is rarely indicated and should be reserved for a selected group of young patients who need anatomical restoration of the wrist for specific functional requirements.

Linear osteotomy with interposition of a graft has been described in the past by Campbell, Speed and Knight, and Hohmann. Merle d'Aubigné and Joussemet proposed a dome-shaped multiple-facet osteotomy to restore length without using a graft. These techniques require the use of a plaster cast to immobilize the wrist for six to eight weeks after operation.

It is the purpose of this paper to describe an opening-wedge metaphyseal osteotomy that combines the use of a graft and rigid internal fixation, and allows early unrestricted active motion of the wrist. I am reporting on my experience with twenty consecutive patients who had a malunion of the distal end of the radius and an average follow-up of 3.6 years.

Material and Methods

Between 1972 and 1980, twenty adults were treated with corrective osteotomy of the radius at the level of the wrist for an extra-articular post-traumatic deformity. Thirteen patients were men and seven were women. The mean age was thirty-four years (range, twenty to sixty-five years) and the average follow-up was 3.6 years (range, two to eight years).

Corrective osteotomy was considered to be indicated in: (1) manually active patients who had a symptomatic extra-articular malunion of the distal end of the radius causing angulation of more than 25 to 30 degrees in either the frontal or the sagittal plane without significant degenerative changes in the wrist joint (such as narrowing of the joint space, intra-articular incongruency, subchondral sclerosis, and osteophytic reaction), and in whom it was
thought that the result of either a Darrach procedure or a shortening osteotomy of the ulna would be uncertain because the deformity of the radius would not be corrected, and (2) patients who wished to have the deformity corrected even though they had adequate function of the wrist.

Patients who had a lengthening osteotomy for shortening of the radius after post-traumatic premature epiphysial fusion, as well as those who had an intra-articular osteotomy, were not included in this series because of the different therapeutic and prognostic problems in those situations. However, these lesions are also indications for a corrective osteotomy at the level of the wrist.

The operation was considered to be contraindicated when there were advanced degenerative changes in the radiocarpal or intercarpal joints, fixed carpal malalignment, or disabling trophic disturbances causing limited over-all function of the hand.

As shown in Table I, there were twelve malunions after a Colles fracture, five after a Smith fracture, and three after a comminuted fracture of the distal end of the radius. Eleven wrists with a Colles fracture had an increased dorsal tilt averaging 34 degrees (range, 25 to 55 degrees), and the twelfth wrist (Figs. 5-A and 5-B) with a Colles fracture initially had been over-reduced and then failed to unite, with a resulting volar tilt of 21 degrees and a radial deviation of 27 degrees at the time of osteotomy. Although there was increased palmar angulation in this wrist, it was included in the Colles group because of the initial fracture type. In these twelve wrists, the radial deviation averaged 12.6 degrees (range, 2 to 27 degrees) and the radial shortening averaged 7.3 millimeters (range, two to twelve millimeters).

In the patients with a Smith fracture, the average volar tilt was 32 degrees (range, 20 to 40 degrees), the average radial deviation was 5.6 degrees (range, zero to 10 degrees), and the average radial shortening was eight millimeters (range, three to fifteen millimeters).

In the patients with a comminuted fracture, the dorsal tilt was zero, 25, and 36 degrees; the radial deviation was 45, 32, and 20 degrees; and the radial shortening was fifteen, eighteen, and ten millimeters.

Before osteotomy, ten of the twenty patients had radiocarpal pain. Of these ten, nine had mild to moderate pain while attempting to position the wrist in forced palmar flexion or dorsiflexion, and one (Case 5, Fig. 7-A) had severe preoperative pain and a mild Sudeck dystrophy that developed during the initial treatment of the fracture. The other ten patients had no radiocarpal pain but complained of functional impairment due to a pathologically displaced...
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* The radiographic measurements were made according to Castaing's modification of the method of Gartland and Werley. Radial deviation of the articular surface of the radius is defined as the difference between the average ulnar tilt (25 degrees) and the radial inclination of the tilted articular surface with respect to the perpendicular to the radial shaft in the frontal plane. A negative value for ulnar tilt means that there is no ulnar inclination of the articular surface of the radius, but instead there is radial inclination so that the inclination of the tilted articular surface with respect to the perpendicular to the radial shaft in the frontal plane. A negative value for radial inclination means a negative angle with relation to the perpendicular of the radial shaft.

† = no deformity (the appearance is symmetrical with that of the opposite wrist); + = mild deformity (the ulnar head is slightly prominent and there is mild radial deviation); ++ = moderate deformity (the ulnar head is prominent and the hand is offset radially); and +++ = severe deformity (the ulnar head is prominent and there is severe radial deviation, shortening, and a so-called dinner-fork deformity).

‡ The original deformity was overcorrected.
flexion-extension arc of motion. Eleven of the twenty patients also had pain at the level of the distal radio-ulnar joint that was associated with more than nine millimeters of radial shortening. Radio-ulnar pain was noted by the patients either during passive movement of the wrist while they were being examined or during forceful rotation of the forearm while they were working.

Preoperative assessment of wrist motion in the pa-

**Fig. 2-A**

Case 15, a malunited Smith fracture.

**Fig. 2-B**

Two years after treatment with a palmar opening-wedge osteotomy.
patients with a Colles fracture showed an average loss of 52.9 degrees of palmar flexion and a loss of 9.6 degrees of dorsiflexion when the affected and unaffected sides were compared. In the patients with a Smith fracture, the average losses were 8 degrees of palmar flexion and 60 degrees of dorsiflexion, and in the patients with a comminuted fracture 61.6 degrees of palmar flexion and 33.4 degrees of dorsiflexion were lost.

Pronation and supination before osteotomy were significantly reduced in ten of the twenty forearms. These were the ones with radial shortening of more than ten millimeters (average, 12.6 millimeters) (Table I). In these ten forearms the average loss of pronation was 46.5 degrees and the loss of supination averaged 59 degrees. Radial shortening of as much as six millimeters did not produce serious functional impairment of forearm rotation except in one patient (Case 5) with six millimeters of shortening, in whom a Sudeck dystrophy developed during initial treatment of the fracture. Disabling limitation of ulnar deviation was present in three wrists with severe radial deviation of 20 degrees or more and radial shortening of twelve millimeters or more (Cases 8, 18, and 20) (Table I).

Grip strength was measured with a Schaerer dynamometer and expressed as a per cent of the strength of the uninvolved hand. The average preoperative grip strength in this series was 35.7 per cent (range, 11.6 to 69 per cent) and the average loss of grip strength was 64.3 per cent.

Another common complaint of all patients was the unacceptable appearance of the deformity.

Surgical Technique

Extra-articular malunion after fracture of the distal end of the radius generally produces deformities in more than two planes. After a Colles fracture, the distal fragment is usually tilted dorsally in the sagittal plane and radially in the frontal plane and is supinated in the horizontal plane. The amount of shortening depends mainly on the extent of the comminution and of the impaction of the fragments of the metaphysis. The shortening of the radius relative to the ulna leads to subluxation of the distal radioulnar joint and painful impairment of pronation and supination. Conversely, in a malunited Smith fracture the volar tilt of the radial articular surface is increased and there may be a pronation deformity with associated dorsal subluxation of the distal end of the ulna.

Massive shortening of the radius and radial deviation of the hand without troublesome malalignment in the sagittal plane (less than 25 degrees) are common residual deformities after a comminuted fracture.

Although a moderate loss of motion of the wrist may be expected after an extra-articular fracture, the main problems are the disabling displacement of the flexion-extension arc of motion caused by the residual angulation in the sagittal plane and the symptoms arising from the subluxation of the distal radio-ulnar joint.

Patients usually complain of loss of palmar flexion after malunion of a Colles fracture and loss of dorsiflexion after a malunited Smith fracture. Significant loss of flexion or extension is a frequent sequela to a comminuted intra-
The aims of radial osteotomy are to restore function and improve the appearance of the wrist by correcting the deformity at the level of the old fracture site. For this purpose an opening-wedge osteotomy that is transverse in the frontal plane and oblique (parallel to the joint surface) in the sagittal plane is used\(^9\) (Figs. 1-A and 1-B). This osteotomy allows correction of: (1) the volar tilt in the sagittal plane, (2) the ulnar tilt in the frontal plane, (3) the rotation deformity in the horizontal plane, and (4) shortening of as much as twelve millimeters. By opening the osteotomy on the dorsal and radial aspects of the radius, the bone is lengthened, improving anatomical relationships at the level of the distal radio-ulnar joint, provided that the length discrepancy between the radius and ulna is not greater than twelve millimeters. A cortical cancellous bone graft from the iliac crest is cut to fit the bone defect so that it has a triangular cross section in the sagittal plane and a trapezoidal cross section in the anteroposterior plane, and will restore the physiological volar and ulnar tilts of the joint surface. Internal fixation with a small buttress T-plate is used to maintain correction and to allow early function and rapid rehabilitation of the neighboring joints.

A careful preoperative plan and the use of Kirschner wires to mark the angle of the deformity simplify the procedure, and intraoperative radiographs are seldom necessary (Fig. 3). Radiographs of the uninjured wrist are useful to determine the normal anatomical relationships of the distal radio-ulnar joint in each patient. The presence of an ulnar plus or minus variation on the opposite side should be taken into consideration during preoperative planning, and an effort should be made to obtain anatomical restoration of the radio-ulnar joint.

**Malunited Colles Fractures**

These malunions are approached through a straight dorsoradial incision that is made parallel to the long axis of the radius. It begins at a point two centimeters distal to the Lister tubercle and extends eight centimeters proximally in the forearm. The radius is exposed between the extensor carpi radialis brevis and extensor digitorum communis tendons after mobilizing and carefully retracting the extensor pollicis longus tendon. Exposure of the dorsal aspect of the radius should be subperiosteal, to provide good soft-tissue coverage of the plate and to avoid contact between the internal fixation device and the extensor tendons.

The site of the osteotomy (2.5 centimeters proximal to the wrist joint) is marked with an osteotome. Usually the Lister tubercle is removed with an osteotome to provide a flat surface on which to apply the plate. In accordance with the preoperative plan (Fig. 3), the first Kirschner wire is inserted through the dorsal part of the capsule into the radiocarpal joint and along the articular surface of the radius to guide the direction of the osteotome or oscillating saw as the osteotomy is performed. As this is done, the volar soft tissues are protected with subperiosteal retractors. The osteotomy is then opened dorsally until the two Kirschner wires are parallel to one another. If placement of the wires has been correct (according to the angle calculated from the preoperative drawing), restoration of the normal volar tilt (5 to 10 degrees) of the distal radial articular surface is achieved when the wires are parallel in the sagittal plane.

Correction in the frontal plane is accomplished by opening the osteotomy on the radial side until the gap corresponds to the distance measured on the preoperative drawing (Fig. 3). The reduction is then maintained temporarily with an oblique Kirschner wire that is inserted through the radial styloid process into the proximal fragment of the radius. Next, the bone graft is shaped to conform to the dorsoradial bone defect and is inserted, making sure that there is a snug fit. Any pronation or supination deformity should be corrected, before introducing the graft, by rotating the distal fragment about the long axis of the radius.

The plate should be contoured to fit the surface of the radius perfectly. Fixation with two screws in each fragment offers enough stability for early unrestricted active motion if the screws have a good hold. Otherwise, three screws in each fragment or an additional oblique lag screw driven from the radial styloid process across the osteotomy site into the ulnar cortex of the proximal radial fragment is recommended.

**Malunited Smith Fractures**

For correction of this deformity, a volar approach between the flexor carpi radialis tendon and the radial artery is employed, with detachment of the pronator quadratus muscle from the radius\(^7\). The palmar opening-wedge osteotomy, grafting, and plating are then carried out on the volar side (Figs. 2-A and 2-B). Thus, by applying the plate dorsally for malunited Colles fractures and anteriorly for malunited Smith fractures, a buttressing effect of the plate is achieved in both injuries.

The distal end of the ulna is resected when the radial shortening is more than twelve millimeters, when there are degenerative changes of the distal radio-ulnar joint due to articular fracture of the sigmoid notch, or when troublesome subluxation of the distal end of the ulna is present. However, whenever possible the distal radio-ulnar joint should be preserved, especially in patients who perform heavy manual labor, since a common complaint after the Darrach procedure in young adults is the decrease in grip strength\(^1,8,12\). If the distal end of the ulna is resected, it is used as the graft to fill the osteotomy gap.
Case 19, a malunited Colles fracture with eighteen millimeters of radial shortening, 32 degrees of radial deviation, and 25 degrees of dorsal tilt in a sixty-five-year-old woman who wanted cosmetic correction of the deformity.

Because it was not possible to restore the length of the radius, a Darrach procedure was combined with a radial osteotomy to ensure realignment of the hand in the frontal plane.
Malunited Comminuted Fractures

Simple resection of the distal end of the ulna or a shortening osteotomy of the ulna to correct a deformity of the wrist due to severe shortening of the radius (of more than fifteen millimeters) or radial deviation of the distal fragment of the radius (of more than 30 degrees) does not

Fig. 5-A
Case 2, a non-union of a Colles fracture with 21 degrees of volar tilt, 27 degrees of radial deviation, and nine millimeters of radial shortening.

Fig. 5-B
Radiographic appearance of the wrist five years after corrective osteotomy.
re-center the hand in the frontal plane. Both resection of the distal end of the ulna and osteotomy of the radius are necessary to obtain a good cosmetic result under these circumstances (Figs. 4-A and 4-B). Correction of the radial deviation of the distal end of the radius realigns the carpus so that the long axis of the third metacarpal coincides with the long axis of the radius. Simple resection of the distal end of the ulna may improve pronation, supination, and ulnar deviation, but the hand remains radially offset in relation to the long axis of the forearm, so that the wrist still appears deformed.

Postoperative Care

Postoperatively the wrist is immobilized in a volar plaster splint until the soft tissues have healed, usually by two weeks after operation. The patient is then encouraged to perform active exercises of the wrist, initially supervised by a physiotherapist, but is not allowed to lift heavy objects until healing of the osteotomy has been confirmed radiographically. Otherwise, free use of the hand is permitted for everyday activities and returning to heavy manual work is recommended at eight to ten weeks after operation.

Exceptionally, if absolutely stable fixation is not achieved due to local osteoporosis, additional immobilization in a circular plaster cast may be indicated. This situation may arise if the corrective osteotomy is performed too soon after initial treatment of the fracture. I recommend that osteotomy not be performed until five to six months after the fracture, when the maximum possible motion of the wrist has been regained with physiotherapy. At that time the soft tissues are in ideal condition, without trophic disturbances, and there is radiographic evidence of decreased osteoporosis. The plate and screws are removed three months after operation, especially when they are on the dorsal aspect, to avoid tethering of the tendon or tendinitis of the extensor pollicis longus.

Results

For this study, the results were assessed two to eight years (average, 3.6 years) after osteotomy. All of the patients were evaluated for pain, range of active motion, grip strength, and appearance of the wrist. There was a direct correlation between the results in these four categories. For example, a patient with incomplete correction of the deformity and persistent incongruity of the distal radioulnar joint continued to have pain in this joint during forceful pronation or supination, decreased grip strength, and an unsatisfactory cosmetic result. Patients were questioned as to whether they had pain at rest, during normal activities of daily living, or only during heavy manual work. The cosmetic result was assessed by comparing the preoperative and postoperative appearances of the wrist, using photographs of the preoperative deformity.

Detailed information from the postoperative assessment is shown in Table I. All malunions with an increased dorsal tilt were operated on through a dorsal approach, and those with an anterior tilt were operated on through an anterior incision. In one patient (Case 18) who had radial deviation and fifteen millimeters of shortening after a comminuted fracture, a volar approach was used. All osteotomies were fixed with a plate and screws and an interposed graft. In thirteen patients the graft was taken from the iliac crest; in five, from the resected distal portion of the ulna; in one, from the olecranon; and in one, from the local callus mass.

The average time to healing was six weeks (range, 4.5 to seven weeks). The criteria used to establish healing were: the absence of pain, the presence of periosteal bridging callus at the osteotomy site, and radiographic evidence of stability of the internal fixation material. All patients had functional aftertreatment once the wound had healed, except for one with osteoporosis whose wrist was immobilized in a forearm cast for five weeks.

Radiographic measurements that were made after the osteotomy had healed showed significant improvement in the position of the radial articular surface in most patients. Thus, at follow-up of the patients with a Colles fracture, there was a volar tilt of 5, 7, and 7 degrees in three and of zero degrees in five, while in the other four there was a residual tilt that averaged 3.75 degrees (range, 3 to 5 degrees). Furthermore, for all twelve wrists with a Colles fracture, the average residual radial deviation was 5.3 degrees (range, zero to 15 degrees) and the radio-ulnar length discrepancy averaged 0.58 millimeter (range, −2 to four millimeters).

In the five forearms with a Smith fracture, examination at follow-up showed that the volar tilt was corrected to an average of 5.2 degrees (range, zero to 9 degrees), and that there were no overcorrections into dorsal tilt. The radius was restored to normal length and the anatomical relationship of the distal radio-ulnar joint was re-established in three forearms, while in the other two a primary Darrach procedure had been performed.

At follow-up of the three forearms with a comminuted fracture, the dorsal tilt was zero degrees in one while in the other two it was reduced to 5 and 6 degrees. The residual radial deviation was 15, 15, and 10 degrees, an average reduction of 19 degrees compared with the preoperative status. The length discrepancy before osteotomy had been fifteen, eighteen, and twelve millimeters. A primary Darrach resection was performed in all three wrists because the shortening exceeded twelve millimeters in two and there were degenerative changes in the sigmoid notch in the third.

The appearance of the wrist in fourteen of the twenty patients was restored to normal compared with the unaffected side. In four other wrists that were treated by osteotomy combined with a Darrach resection, there was no residual deformity but the normal prominence of the distal end of the ulna was missing (Figs. 4-A and 4-B). In the two remaining wrists, a mild deformity that was characterized by slight radial deviation (15 degrees) persisted due to insufficient correction in the frontal plane.
Of the ten patients who had had pain in the radiocarpal joint preoperatively, three (Cases 18, 19, and 20) who had had a comminuted fracture and primary intra-articular involvement still had moderate radiocarpal pain during heavy manual work. Another patient (Case 5, Figs. 7-A, 7-B, and 7-C) had increasing pain and loss of function after osteotomy due to progressive degenerative changes and a fixed dorsiflexion carpal-collapse deformity. Two years after the osteotomy, this patient had a total arthroplasty of the wrist and the outcome was satisfactory.

Two patients had persistent pain in the distal radioulnar joint. One (Case 5) had gained very little forearm rotation (5 degrees) after operation despite restoration of radial length. The lack of improvement in this patient was due to a mild Sudeck dystrophy that had developed during initial treatment, with resultant retraction and fibrosis of the capsular and ligamentous structures of both the radiocarpal and the radio-ulnar joint. Rotation of the forearm was subsequently restored to normal by resection of the distal end of the ulna during total wrist arthroplasty.

Figs. 6-A and 6-B: Case 7. Radiographs made before and two years after correction of a malunited Colles fracture. The result was rated as excellent.
CORRECTION OF POST-TRAUMATIC WRIST DEFORMITY IN ADULTS

The other patient (Case 8) had a secondary Darrach procedure because of residual dorsal subluxation at the distal end of the ulna and limited supination. This patient had a fair result.

Over-all there was a marked improvement of the range of flexion and extension in fifteen patients, while five (Cases 5, 8, 18, 19, and 20) (Table I) showed little or no improvement.

The displaced flexion-extension arc of motion of the twenty wrists was restored to normal in nineteen, while in the other wrist (Case 5) the postoperative gain was only 10 degrees of palmar flexion.

At follow-up, the average range of dorsiflexion was 63 degrees in the patients with a Colles fracture, 53 degrees in those with a Smith fracture, and 40 degrees in those with a comminuted fracture, while the average range of palmar flexion was 50 degrees in those with a Colles fracture, 50 degrees in those with a Smith fracture, and 33.3 degrees in those with a comminuted fracture.

The average grip strengths of the affected hands in the three groups were expressed as percentages of the average grip strengths of the normal opposite hands before operation and at follow-up. The preoperative and follow-up averages were: 40 per cent and 82.7 per cent in the patients with a Colles fracture, 30.3 and 82.3 per cent in those with a Smith fracture, and 27.2 and 55.5 per cent in those with a comminuted fracture. Restoration of the ability to position the wrist actively in slight dorsiflexion and ulnar deviation for maximum mechanical efficiency of the flexor tendons and the elimination of pain were the main reasons for the improvement in grip strength.

Ten of the twenty patients whose average radial shortening was 12.6 millimeters had average losses of 46.5 degrees of pronation (range, 35 to 70 degrees) and 59 degrees of supination (range, 5 to 70 degrees) before osteotomy. At follow-up, nine of these ten patients had a normal range of pronation-supination and one (Case 8) had persistent limited rotation of the forearm (pronation, 75 degrees and supination, 60 degrees) due to residual dorsal subluxation of the distal end of the ulna. Of the other ten patients with shortening of less than six millimeters, only one had significant preoperative limitation of rotation of the forearm (Case 5). Thus, at follow-up rotation was restored to normal in nine of these ten wrists while there was a 50-degree loss of rotation compared with the unaffected wrist in one (Case 5).

Based on evaluations of pain, range of active motion, grip strength, and appearance, four result ratings were established (Table I). An A or excellent rating was given to a wrist with no pain, normal or almost normal motion, grip strength of not less than 80 per cent of normal, and no visible deformity (Figs. 6-A, 6-B, and 6-C). A B or good rating was given to a wrist with no pain, moderate limitation of motion (not less than 65 to 70 per cent of normal), grip strength of not less than 70 per cent of normal, and no deformity. A C or fair rating was given to a wrist with moderate pain during work activities, limitation of motion of 40 to 65 per cent of normal, grip strength of 50 to 70 per cent of normal, and mild deformity. A D or poor rating was given to a wrist that was considered to be a failure of treatment because of persistence of pain during work or daily activities, severe loss of motion (less than 40 per cent of normal), and reduction of grip strength to less than 40 per cent of normal or associated stiffness of the finger joints with impairment of function of the hand. The overall results in the twenty patients were five excellent, ten good, four fair, and one poor rating.

The causes of the unsatisfactory results were primary
intra-articular involvement after a severely comminuted fracture in three patients (Cases 18, 19, and 20), painful subluxation of the distal end of the ulna in one (Case 8), and pre-existing stiffness and degenerative changes in the radiocarpal and intercarpal joints in one (Case 5).

In the three patients who had a comminuted fracture with intra-articular involvement, there was minimum improvement of flexion and extension after radial osteotomy combined with a Darrach procedure, but the external appearance and rotation of the forearm were improved. In the patient with subluxation of the ulna there was insufficient lengthening of the radius and probably overcorrection of the distal radial fragment which produced a pronation deformity, while in the patient with degenerative changes (Figs. 7-A, 7-B, and 7-C) the osteotomy procedure was definitely not indicated since the extent of the radiocarpal and intercarpal degenerative changes and the severity of the joint stiffness were underestimated prior to operation.

Figs. 7-A and 7-B: Case 5. This patient had a poor result after osteotomy because of preoperative narrowing of the radiocarpal joint and a fixed malalignment of the carpus in dorsiflexion. The wrist remained painful after operation and the arthritis progressed.
Complications

Persistent postoperative edema and delayed restoration of motion of the fingers were common when the osteotomy of the radius was combined with resection of the distal end of the ulna. There was one postoperative hematoma (Case 18) which was associated with massive swelling of the distal part of the forearm and was drained surgically forty-eight hours after osteotomy.

Tendinitis of the extensor pollicis longus was observed in two wrists in which there was direct contact of the tendon with the dorsal plate. The symptoms were relieved after the plate was removed, and no late tendon ruptures occurred.

There were no superficial or deep infections in this series. Partial loss of correction was observed radiographically in two patients who had osteoporotic bone. In one, the initial correction of the volar tilt to 10 degrees was gradually lost during the first two weeks. The resulting dorsal tilt of 5 degrees did not affect the late result. In the other patient, the initial correction of 25 degrees of ulnar inclination in the frontal plane was reduced to 15 degrees due to collapse of the graft on the lateral side of the radius.

Subsequent Operations

The internal fixation device was removed from seventeen of the twenty wrists. Three volar plates were left in place. There were four second operations: one to drain a hematoma, one total wrist arthroplasty, one secondary Darrach procedure, and one for multiple z-plasties to correct a dorsal scar contracture.

Discussion

Several authors have advocated corrective osteotomy for malunited fractures of the distal end of the radius in order to improve function, deformity, and disability of the wrist\textsuperscript{7,8,10-12,14}. Campbell described excellent cosmetic and functional results in eleven of nineteen patients in whom a transverse osteotomy with interposition of a graft was used. The graft was taken from the prominent medial border of the ulna and the distal radio-ulnar joint was preserved. Although detailed data on postoperative assessment of wrist function were not presented, it appeared that this procedure gave better functional and cosmetic results than those after simple osteotomy that only corrected the backward angulation of the articular surface of the radius.

Speed and Knight recommended the use of an intramedullary bone peg or dual onlay grafts to avoid loss of correction in wrists with severe deformity or osteoporosis. This method of fixation, however, did not allow unrestricted motion of the wrist postoperatively, and external immobilization was maintained until union was confirmed clinically and radiographically. Internal fixation was advocated by these authors in “all but the simplest malunions”.

Merle d’Aubigné and Tubiana\textsuperscript{12} described satisfactory results in twenty-seven wrists that were treated with so-called facet osteotomy, which was designed to restore radial length without the need of a graft. However, the distal end of the ulna was resected in seventeen of these twenty-seven wrists. By virtue of its shape this osteotomy produces a slight palmar displacement of the distal fragment with respect to the shaft of the radius, and permits no correction in the frontal plane. One oblique Kirschner wire was used for fixation and postoperatively the wrist was immobilized in a forearm cast for two months. The results
in that series were presented as mean values and percentages of improvement of motion of the wrist and grip strength, and were compared with results after twenty-seven Darrach procedures. There were no radiographic measurements or assessments of residual pain. The authors concluded that osteotomy of the radius combined with resection of the distal end of the ulna offered better cosmetic and functional results than did a Darrach resection alone, but that the disadvantage was the prolonged period of postoperative immobilization. They also concluded that even though the Darrach procedure gave satisfactory functional results after a short period of immobilization, the cosmetic correction was insufficient when so-called important dorsal angulation was present.

The over-all results in my series showed that osteotomy is a valuable procedure for the treatment of extra-articular malunions of the distal end of the radius provided that there is an adequate preoperative range of motion (that is, not less than 70 per cent of normal) and there are no degenerative changes in the radiocarpal joint. The improvement in flexion and extension after osteotomy is a valuable procedure for the treatment of extra-articular malunions of the distal end of the radius and functional results after a short period of immobilization, the cosmetic correction was insufficient when so-called important dorsal angulation was present.

The main advantages of this technique are the maintenance of correction by a tight-fitting bone graft and the rigid internal fixation, which allows early unrestricted active motion of all joints in the extremity. Predictable anatomical results can be expected if the procedure is executed in accordance with a careful preoperative plan based on an analysis and measurements of the preoperative radiographs. I believe that this preoperative plan is of extreme importance because it allows calculation of the exact amount of correction in the frontal and sagittal planes, the amount of shortening, and the size of the graft needed in each patient. Although the need for removal of the plate and screws in a second operation is a disadvantage, this is balanced by the rigid fixation which offers stability, allows early motion, and reduces the need for both the physiotherapy and the rehabilitation that often are necessary after six to eight weeks of immobilization of the wrist.

The operation is recommended for young, manually active patients with significant deformity and functional impairment of the wrist and is considered to be a reconstructive procedure that is designed to restore to normal the anatomy of the distal end of the radius and its relationship to the ulna. Radial osteotomy is not recommended in the presence of advanced degenerative changes, fixed carpal malalignment, osteoporosis, or trophic disturbances of the hand. Radial osteotomy does not replace the Darrach procedure, which still has a role in the treatment of malunions after Colles fractures in elderly patients.

References