Acta Orthop. Belg., 2012, **78**, 175-182

ORIGINAL STUDY

Surgical correction for supination loss following malunited radial fractures

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We evaluated fourteen patients who had restricted supination as a major impairment related with a malunited radius fracture. All patients underwent an opening wedge corrective osteotomy, bone grafting, and volar plate fixation. Clinical results were assessed based on range of motion, visual analogue scale for pain, grip power, and a Modified Mayo Wrist Score. The mean supination increased from 24° preoperatively to 71° postoperatively ($p < 0.01$). Dorsiflexion range, grip power and pain score improved significantly after the operation. The mean value for the Modified Mayo Wrist score improved from 58.6 points to 83.9 points ($p < 0.01$). Radiological measurements showed that the degree of dorsal angulation decreased from a mean of 9.0° to -2.5° after the corrective osteotomy. This study demonstrated that a malunited radius fracture with dorsal angulation, even if the latter appears mild, can induce functional impairment due to limited range of supination. Supination can be restored by an appropriately performed corrective osteotomy.

Keywords : forearm bone fractures ; malunion ; supination ; corrective osteotomy.

INTRODUCTION

Forearm rotation, which is one of the important functions of the upper extremity, takes place in the articulations between the ulna and radius ; their accurate alignment is essential for normal motion. A radius fracture, particularly involving the distal part, is very common, and it is well known that a malunited radius may lead to limitation of forearm rotation (*5,9,20,22,23*). Several authors have investigated the effects of dorsally angulated distal radius fractures on the mechanics of the distal radioulnar joint and forearm rotation (*1,2,8,11,16*) and have suggested that there is an acceptable range of reduction in the treatment of a displaced distal radius fracture. In contrast, a volarly displaced distal radius fracture is relatively rare (24), and there have been no biomechanical studies investigating its effect on distal radioulnar joint function. If the distal radius or radial shaft is volarly flexed with an intact ulna, the ulnar head is subluxed posterior to the radius in the distal radioulnar joint. Based on the normal mechanics of rotation that occur in the distal radioulnar joint, we speculate that posterior subluxation of the ulnar head may restrict normal motion,

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The authors report no conflict of interest.
None of the authors received financial support for this study.

particularly supination (7,9). While a decreased range of pronation can be easily overcome by the abduction of the shoulder joint, it is not well compensated by adjacent joint position when the supination is restricted ; as a result, the patients have greater impairment in activities of daily living (21). To restore a normal range of supination, corrective osteotomy of a malunited radius should be considered as a first line treatment.

This study was conducted to determine the results of surgical correction in patients who had functional impairment mainly from loss of supination associated with a malunited radius.

PATIENTS AND METHODS

Subjects were patients who had restricted supination following a radius fracture and subsequently underwent surgical correction between October 2001 and January 2008. Patients who had painful limited motion due to arthrosis in the radiocarpal joint or distal radioulnar joint, and who had instability of the distal radioulnar joint were excluded. Fourteen patients who could be followed up for more than 18 months were finally included. There were 12 men and two women with a mean age of 40.1 years (range : 20-59 years). The mean follow-up period was 29.2 months (range : 18-53). Nine patients had had a fracture on the dominant side.

The initial fracture was a distal radius fracture in 10 patients, a fracture of both forearm bone shafts in three, and a Galeazzi fracture in one. Initial treatment of the distal radius fractures was cast immobilization for six patients, percutaneous pinning for two, plate fixation for one, and external fixation for one. Three fractures of both forearm bones had been treated with a cast, external fixation, and intramedullary nailing respectively. The Galeazzi fracture had been treated with a plate fixation. The average period from the injury to the index operation was 10.6 months (range : 6-36).

Surgery was indicated when the patients had a persistent loss of supination that caused functional impairment in activities of daily living for at least six months despite nonoperative therapy. The indication for surgery was determined based on the subjective discomfort felt by the patients rather than on the radiological degree of angular deformity. Preoperative supination ranged from -10 to 50°, with a maen of 24.3°. Symptoms other than loss of supination included pain, particularly on the ulnar side, decreased range of flexion-extension arc, weakness, and the appearance of a deformity.

Operative technique

In patients with a malunited distal radius fracture, a corrective osteotomy followed by plate fixation was performed using a volar approach. A longitudinal skin incision was made and the anterior aspect of the radius was exposed by retracting the flexor tendons and subperiosteally reflecting the pronator quadratus muscle. After the angulated original fracture site was identified under fluoroscopy, an osteotomy was performed parallel to the increased volar tilt angle with a reciprocating saw. To restore the normal volar tilt, the osteotomy site was separated with use of a lamina-spreader. While the osteotomy was fixed temporarily with one or two 1.5 mm smooth Kirschner wires, the forearm rotation was checked to determine whether congruent distal radioulnar joint motion with increased supination was possible. An autogenous corticocancellous graft was harvested from the ipsilateral iliac crest. To restore the radial length and inclination in the frontal plane as well as the normal volar tilt, the graft was trimmed into a trapezoidal shape and fitted into the defect created at the osteotomy site. Rotatory motion was checked again, and the final position of the radius was assessed by fluoroscopy. The osteotomy and the intercalated bone graft were fixed with a 3.5 millimeter angled buttress T plate (Synthes, West Chester, PA, USA) or a volar anatomical locking plate (Acumed, Hillsboro, OR, USA) (Fig. 1).

In patients with a radial shaft malunion, the exact level of angulation was confirmed using fluoroscopy. Before the osteotomy, a vertical marking was made on the surface of the bone to guide the rotation during correction. An osteotomy was created and the distal radioulnar joint subluxation was manually reduced. While maintaining the reduced distal radioulnar joint in a neutral position, the osteotomy site was temporarily fixed with a plate and bone-holding clamps. Then, the congruent motion of the distal radioulnar joint was carefully checked by passively rotating the forearm. Several trials of plate bending and reapplication were occasionally required to confirm the final position of the radius. The osteotomy site was fixed by inserting screws into a 3.5-mm low-contact dynamic compression plate (Synthes, West Chester, PA, USA) (Fig. 2). A bone graft harvested from the iliac crest was inserted into the defect. If the reduction of the distal radioulnar joint was not stable enough, the joint was transfixed with a 1.5 mm Kirschner wire.

Postoperatively, a long arm splint was applied. At two weeks, the Kirschner wire transfixing the distal radioulnar joint was removed, and each patient was instructed

Fig. 1. — A 53-year-old man who had had a distal radius fracture, which was managed with a cast. A and B : Preoperative radiographs show volarly angulated malunion with shortening. C : Clinically, supination of the involved side(right) is significantly restricted. D, E and F : At 24 months after the corrective osteotomy and bone grafting, radiographs demonstrate successful correction of deformity. Supination range increased to 80° without discomfort.

to start active assisted range-of-motion exercise of the wrist while protecting the osteotomy site with a thermoplastic brace in the time between the exercises. Passive forearm rotation was not permitted until bony union was evident on radiographs.

Evaluation

Forearm rotation was measured with the elbow in 90° flexion and kept at the patient's side. An imaginary line connecting the radial and ulnar styloid processes was drawn by palpating these structures. The angle formed between this line and the line perpendicular to the floor was measured. The range of flexion and extension of the wrist were measured with the use of a hand-held goniometer positioned along the ulnar side of the hand and forearm.

Pain was evaluated using a visual analogue scale (10 points for intolerable pain). The grip strength was measured using a Jamar hydraulic dynamometer (JAMAR, Asimow Engr. Co., Santa Monica.Calif., USA). The Modified Mayo Wrist Scoring System, which evaluates pain, return-to-work status, range of motion, and grip strength (a maximum of 25 points for each category), was used to assess comprehensive function (*3*).

For radiological assessment, dorsal angulation of the radius in the sagittal plane and radial shortening in the frontal plane were measured on preoperative and postoperative radiographs. For the measurement of dorsal angulation in patients with a malunited distal radius, the volar tilt angle of the distal articular surface was measured, and the difference from the contralateral normal side was calculated as the value of dorsal angulation. In patients with a radial shaft malunion, the absolute angle

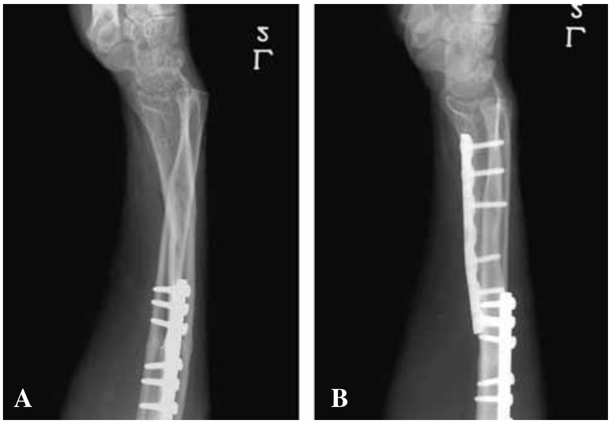

Fig. 2. — A 51-year-old man who had had fractures of both forearm bones, which were managed with plate fixation for the ulna and external fixation for the radius. A : Preoperative lateral radiograph show dorsal angulation at the distal radial shaft with posterior subluxation of the ulna head, causing supination loss. B : Radiograph after corrective osteotomy of the radius with volar plate fixation demonstrates realignment of the radius with the ulna, resulting in successful recovery of rotation.

was measured in the lateral view. Radial shortening was determined by measuring the ulnar variance.

To compare preoperative and latest follow-up evaluation, we used a two-sided paired t-test if the data were normally distributed, and Wilcoxon signed-rank test if they were not. Statistical analysis was performed with SPSS for Windows 10.0 (SPSS Inc., Chicago, IL) and a p-value of < 0.05 was considered to indicate a significant difference.

RESULTS

Mean supination at final follow-up was 69.6° (range : 50 to 80°), which was a significant increase over the preoperative value of 24.3° (range : -10 to 50°) ($p < 0.01$) (Fig. 1). The mean pronation of the forearm also increased from 65.4° (range : 40 to 80°) preoperatively to 70.7° (range : 60-80°) postoperatively, although the improvement was statistically not significant ($p = 0.11$). Mean dorsiflexion of the wrist increased significantly from 55.7° (range : 30-70°) preoperatively to 72.1° (range : 50-80°) postoperatively ($p < 0.01$). Mean volar flexion increased from 44° (range : 20-80°) preoperatively to 57.1° (range : 30-80°) postoperatively ($p = 0.06$). Mean grip strength improved significantly from 22 kg (range : 7-43 kg) preoperatively to 33 kg (range : 14-45 kg) postoperatively ($p < 0.01$), and compared with a mean of 35.0 kg (range : 23-45 kg) on the contralateral side.

The mean visual analogue scale score for pain decreased significantly from 3.1 points (range : 1-5 points) preoperatively to 0.7 points (range : 0-3 points) postoperatively ($p = 0.01$). According to the Modified Mayo Wrist Scoring System, the mean score increased significantly from 58.6 points (range : 35-80 points) preoperatively to 83.9 points (range : 65-100 points) postoperatively ($p < 0.01$). The results were rated as excellent in four patients, good in seven, and fair in three. Radiological evaluation demonstrated that the volar flexion deformity of the radius, which was represented by the degree of angular difference from the normal side on the sagittal view ranged from 5° to 15° with a mean of 9.0° at the initial presentation. Mean angular difference decreased to -2.5° (range : -9°to 0°) after the operation ($p < 0.01$). The negative postoperative value represents dorsally angulated corrections compared with the normal side. The mean ulnar variance after the operation was 0.9 mm (range : -3.0 to 5.0 mm), which had decreased from 4.5 mm (range : 0-9.0 mm) preoperatively. The mean time from the osteotomy to bony union was 7.2 weeks (range : 5-12) (Table I).

There were no complications such as fixation failure, loss of correction, nonunion, and infection.

DISCUSSION

We performed a corrective osteotomy in patients who had restricted supination as the main functional problem associated with a malunited radius. Patients tend to feel greater discomfort when supination is restricted compared to restriction of pronation because the loss of supination cannot be compensated for by shoulder movement. In our study, the patients who had a maximum supination of 50° required corrective osteotomy because of functional impairments in activities of daily living. Although the functional range of forearm rotation is generally thought to be from 50° of supination to 50° of pronation (8,17), we suggest that at least

Table I. — Surgical outcomes of malunited volarly angulated fractures of the radius

Case #	Age	Sex	Fracture type	Initial Treatment	Radiographic Measurement Angulation (°) ; Ulnar variance (mm)				Preop. Wrist ROM (affected/Normal) *(Degrees)*				Postop. Range of Mortion of Wrist (affected/Normal) *(Degrees)*				Grip strength (affected/Normal) *(Kg)*		Pain Score		Modified Mayo Wrist Score	
					Preop.* *(Degrees)*	Postop.* *(Degrees)*	Variance Pre.	Variance Post	Ext.	Flex.	Pron.	Sup.	Ext.	Flex.	Pron.	Sup.	Pre.	Post.	Pre.	Post.op	Preop.	Postop.
1	52	M	Both bones.	IM nailing	5.0	0	9.0	5.0	40	30	80	-10	80	80	70	60	9	34	5	3	65	75
2	51	M	Both bones	Ext fix	9.0	0	3.0	3.0	70	40	70	-10	70	50	70	50	27	45	1	0	65	95
3	21	F	Distal Radius	Percut pin	5.0	-1	1.0	2.0	40	30	60	30	70	50	80	60	23	32	3	1	65	85
4	33	M	Galeazzi	Plate fixation	6.0	0	0.0	1.0	70	60	40	20	80	60	60	60	16	18	4	1	65	80
5	59	F	Distal Radius	Cast	10.0	-8	7.0	3.5	40	50	70	50	70	40	80	80	7	14	5	2	45	65
6	24	M	Distal Radius	Cast	7.0	-5	4.0	-3.0	70	60	75	30	70	60	75	75	43	43	2	1	70	100
7	32	M	Both bones	Cast	7.0	0	1.0	1.0	50	20	60	35	80	70	60	65	23	27	3	0	60	80
8	53	M	Distal Radius	Cast	10.0	-1	6.0	-1.0	60	20	70	10	60	30	70	75	20	25	3	0	40	70
9	51	M	Distal Radius	Plate fixation	14.0	-2	6.5	2.0	30	20	40	45	70	50	80	80	23	32	2	1	40	85
10	37	M	Distal Radius	Percut pin	10.0	-2	6.0	-1.5	40	30	70	0	70	50	60	75	16	41	3	1	35	85
11	54	M	Distal Radius	Cast	9.0	-5	8.0	-1.0	70	80	70	50	80	70	70	80	29	38	2	0	75	85
12	38	M	Distal Radius.	Cast	15.0	-9	6.0	2.0	70	80	60	40	80	60	75	70	20	32	2	0	70	90
13	20	M	Distal Radius	Cast	8.0	0	1.0	1.0	70	70	80	40	80	70	70	70	32	45	1	0	80	95
14	37	M	Distal Radius	Ext f ix	11.0	-2	4.0	-1.0	60	20	70	10	50	60	70	75	16	41	5	0	45	85
mean					9.0	-2.5	4.5	0.9	55.7	44	65.4	24.3	72.1	57.1	70.7	69.6	22	33	3.1	0.7	58.6	83.9

70°of supination is needed for normal function in daily activities. The mechanism of limited supination associated with a volarly flexed radial malunion can be explained by the normal kinematics of the distal radioulnar joint. The normal rotational motion of the distal radioulnar joint is accompanied by translation as a result of the different radii of curvature of the two articular surfaces. During supination, anterior translation of the ulnar head relative to the radius normally occurs (*12,14*). If the radius is volarly angulated while the ulna is intact, the malalignment in the distal radioulnar joint with posterior subluxation of the ulna head should block the anterior translation of the ulnar head, resulting in restricted supination. The increased tension on the triangular fibrocartilage complex secondary to radial deformity also limits rotation (*1,11,22*). This is reflected by our observation that supination was mechanically blocked at a certain angle in all patients. If the distal radioulnar joint was completely dislocated or the distal radioulnar ligaments were severely injured, rotatory movement without a block might be possible, although it would be accompanied by marked instability. Such patients were excluded from this study.

Patients in this study had varying degrees of angular deformity, which ranged from 5 to 15°. Theoretically, angulation developed in the distal radius has less influence on the alignment of the distal radioulnar joint, compared with the same degree of angulation in the shaft. Nevertheless, we observed that an increased volar tilt of as little as 5° led to limited supination, to the point that corrective osteotomy was required. This finding contrasts with a distal radius malunion with a dorsal tilt deformity, in which the rotation is not affected even with a change of 20° of dorsal angulation (*4,8,11*). It is well known that a volarly displaced Smith fracture tends to be more unstable than a dorsally displaced Colle's fracture (*23*). An increased volar tilt, even if it appears unremarkable, invariably accompanies volar translation of the distal radius, aggravating the dorsal subluxation of the ulnar head (*23*). It should be noted that all but one patient with a distal radius fracture had a cast, external fixation or percutaneous pinning instead of plate fixation as the initial fracture treatment. An increase in volar tilt of 5° is not acceptable ; for this reason, open reduction and internal fixation with an anterior buttress plate is strongly recommended in patients with an unstable Smith fracture.

A radial shaft fracture with an angular deformity accompanying a disruption of the distal radioulnar joint is known as a Galeazzi fracture. Our study included patients with a radial shaft deformity accompanied by an intact or normally healed ulna following Galeazzi fractures or fractures of both forearm bones. Initial treatment included a cast, external fixation and intramedullary nailing in three of four patients, instead of open reduction and plate fixation. Our study revealed that anatomical reduction and stable fixation is mandatory for Galeazzi fractures and both forearm bone fractures to prevent incongruent motion of the distal radioulnar joint.

We only measured the degree of angulation in the sagittal plane based on lateral radiographs ; it was used as a guideline for corrective osteotomy. It is clear that a malunited radius always has a three-dimensional deformity including a rotational component rather than a one-plane angular deformity. However, it is difficult to measure the degree of rotational deformity radiographically. Recently, a method of measurement using computed tomographic scans was introduced (*19*), but we did not attempt to use it. The distal radius tends to rotate around the ulnar head as a hinge when it is displaced to the volar or dorsal side because the ulnar side is linked to the ulnar head through the distal radioulnar joint, while the radial side is rather free to move. Therefore, we can presume that volar flexion of the distal radius should induce some degree of pronation, whereas dorsiflexion of the distal radius accompanies a supination deformity (*6,10*). The more volarly flexed the distal radius is, the greater the pronation deformity that should develop, and consequently, the range of supination is further decreased. On the other hand, several authors investigated rotational deformities in the malunited distal radius using computed tomography, and reported that the rotational deformity appears to have little influence on the restricted forearm rotation (*9,19*). From a clinical view, we can expect a positive effect of osteotomy on the restoration of supination as correction of the volarly angulated deformity simultaneously derotates the pronated distal fragment (*7*).

Most previous studies on the surgical treatment of a malunited radius focused on dorsally displaced distal radius fractures, and all authors reported that favorable results could be obtained by an opening wedge osteotomy (*5,15,18,25*). Several studies on the treatment of a volarly angulated malunited distal radius also demonstrated that osteotomy improves pain, grip strength and wrist motion including the range of forearm supination (*13,21,22,23*). For the correction of a volarly flexed radius, an opening wedge osteotomy on the anterior aspect is necessary to prevent radius shortening. The reduction and fixation of the malunited distal radius using a volar approach is technically easier with several advantages compared to that using a dorsal approach. The friction can be minimized because the volar side is more spacious and the plate can be covered with the pronator quadratus muscle. Furthermore, it is easy to apply the plate because the anterior surface is relatively flat (*20,23*). Inserting an adequately sized structural bone graft is essential in restoring the normal length, radial inclination, and volar tilt of the radius. In addition to the preoperative measurement of the appropriate size of the bone graft based on the radiographs, it is also necessary to ensure that congruent rotational motion is actually possible, since the goal of the operation is to obtain sufficient range of forearm rotation. Intraoperative assessment of rotation is essential, particularly in cases with a radial shaft malunion, since no radiographic criteria are reliable in assuring appropriate correction.

Our study suggests that, in the initial treatment of a radius fracture or both forearm bone fractures, great attention should be paid to achieving and maintaining an anatomical reduction of the volarly flexed displacement of the radius even if the displacement appears mild in the initial treatment. Loss of supination associated with a malunited radius can be successfully corrected by an appropriately performed osteotomy.

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