Can carpal malalignment predict early and late instability in nonoperatively managed distal radius fractures?

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Abstract The purpose of this study was to assess the frequency of carpal instability as a concomitant lesion in distal radius fractures and identify other factors including carpal malalignment in an attempt to predict the final radiological outcome more accurately following conservative treatment of distal radius fractures. An observational study from patient records and standardised radiological follow-up examinations as data sources was used. The alignment of each wrist was checked radiographically immediately post-reduction and subsequently at 1- and 6-week follow-up assessments. Serial measurements of radial length, dorsal tilt, radial inclination, scapho-lunate, radio-lunate, radioscapoid, scapho-capitate angles and effective radiolunate flexion angle were made. Regression analysis showed high correlation among the severity of axial shortening, pre-reduction dorsal angulation and radio-carpal malalignment pattern with early loss of reduction at 1 week. We found the age, severity of axial radial shortening, dorsal

angulation, presence of dorsal comminution and radio-carpal malalignment pattern to be significant predictors of adverse radiological outcome at 6 weeks (late instability). Our study highlights the importance of radio-carpal instability pattern on post-reduction radiographs as a predictor of early and late instability.

Résumé Le but de cette étude est de mesurer la fréquence des instabilités du carpe en tant que lésions associées aux fractures du radius distal, de délimiter les facteurs prédictifs de déplacement secondaire précoce et tardif comme les désaxations du carpe, dans le but de prédire le résultat radiologique final de manière plus précise après un traitement orthopédique d'une fracture du radius distal. Il s'agit d'une étude clinique sur dossiers et suivis radiologiques standards. La réduction de chaque poignet a été contrôlée radiographiquement, immédiatement après celle-ci et ensuite à une et six semaines. Des mesures en série de la longueur du radius, de l'inclinaison dorsale, de l'inclinaison radiale, des angles scapholunaires, radiolunaires, radioscapoldiens et scaphocapital ainsi que l'angle de flexion radiolunaire effectif ont été mesurés. Une analyse de type régression statistique a montré une corrélation élevée entre l'importance du raccourcissement axial, de l'angulation dorsale avant réduction et de la désaxation radiocarpienne avec la perte de correction à une semaine. Nous avons trouvé que l'âge, l'importance du raccourcissement axial, l'angulation dorsale, la présence d'une comminution dorsale et la désaxation radiocarpienne étaient significativement prédictifs d'un mauvais résultat radiologique à six semaines (déplacement tardif). Notre étude met en lumière l'importance du morphotype radiocarpien sur les clichés post-réduction pour prédire les déplacements secondaires précoces et tardifs en association avec d'autres facteurs.

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Introduction

Distal radius fracture instability has been the focus of considerable interest for many years. A correlation between the severity of the primary displacement, carpal malalignment and an expected loss of reduction over a given time period has been reported in conservatively managed distal radius fractures [9, 13, 14]. Two distinct patterns of carpal malalignment following distal radius fractures have been observed during immobilisation, which was previously believed to occur only as a sequel to malunion. The first is midcarpal instability in which the proximal carpus tends to face dorsally in line with the dorsally angulated articular surface of the distal radius with a compensatory flexion of the capitate or midcarpus resulting in an unstable, zigzag collapse pattern of the wrist [1]. The second is dorsal subluxation of the carpus, which results in a global radio-carpal dorsal derangement producing the dorsal subluxation of the radio-lunate joint [1, 6].

Recently, an attempt has been made to classify carpal malalignments associated with displaced distal radial fractures in quantitative terms based on the effective radio-lunate flexion angle (ERLF) into two definite groups with possibly different aetiologies and prognoses [11]: midcarpal malalignment with ERLF $<25^\circ$ and radio-carpal malalignment with ERLF $>25^\circ$. To our knowledge no study has exclusively evaluated carpal malalignment based on ERLF as one of the predictors of instability in conservatively managed intra- and extraarticular distal radius fractures.

It is essential to discern which fracture patterns are more susceptible to failure so that surgical intervention can be considered when an acceptable reduction cannot be achieved or has a risk of secondary displacement despite adequate initial reduction [5].

The aim of this study was to assess the frequency of carpal instability as a concomitant lesion to fractures of the distal radius, evaluate further various factors including associated carpal malalignment based on ERLF that are predictive of instability based on a timeline of early and late failure in an attempt to predict the final radiological outcome more accurately. We measured various radial and wrist radiological parameters following distal radial fractures in pre-reduction, post-reduction and the serial follow-up films to measure accurately the displacement of the fracture and the associated carpal malalignments in quantitative terms with particular attention to proximal carpal row.

Materials and methods

An observational study design based on patient records and follow-up radiological examinations as data sources was

used. Eighty cases of distal radius fractures in skeletally mature patients who met the following inclusion criteria over a course of 2 years were included in this retrospective radiological study. The inclusion criteria were: (1) intra-/extraarticular displaced distal radius fracture, (2) non-operative management, and (3) a full complement of radiological films available (pre- and post-reduction, 1-week and 6-week follow-up). All the films were taken in a standardised fashion with the forearm in neutral rotation. Patients who underwent a secondary manipulation at any stage or those patients who underwent a secondary surgical intervention were excluded. Patients were predominantly female (78%) with a pooled mean age of 53 years. All patients underwent closed reduction under local haematoma block and a below-elbow plaster cast applied up to the metacarpophalangeal joints with the wrist immobilised in neutral rotation, ulnar deviation, and slight flexion.

The fractures were classified according to AO/ASIF classification [7]. The alignment of each wrist was checked radiographically immediately post-reduction and subsequently at 1-week and 6-week follow-up assessments. The procedure was repeated if the alignment was not acceptable. In many of these patients non-surgical intervention had been decided upon either due to medical co-morbidities or patients not willing to undergo surgical intervention.

The primary outcome measure was early and late instability at 1 and 6 weeks, respectively. The measured radiological parameters were: (1) radial length (measured from the medial radial cortex to the ulnar head); (2) dorsal tilt; (3) radial inclination; (4) the presence or absence of an ulnar styloid fracture; (5) presence of dorsal comminution; (6) scapho-lunate angle (SLA): average 46° with a range of 30° – 60° ; (7) radio-lunate angle (RLA): averages 0° with a range of -9° to $+12^\circ$; (8) radioscapoid angle: averages 58° with range of 33° – 73° ; (9) scapho-capitate angle: averages 63° with range of 41° – 83° [3, 17]; (10) effective radio-lunate flexion (ERLF) denotes relative flexion of the lunate and appears to be a sequel to the dorsal rotation of the distal radial articular surface [10, 13]. It is calculated as: dorsal tilt $+11$ (average volar tilt) - RLA (Figs. 1, 2).

These parameters were measured before and immediately after reduction as well at 1- and 6-week follow-up assessments. Based on a review of the literature we selected the following parameters as our primary measure of radiographic reduction and stratified radiographs by the presence of acceptable reduction, and instability was defined as: (1) dorsal tilt $>15^\circ$, (2) volar tilt $>20^\circ$, (3) radial shortening >4 mm, and (4) radial inclination $<10^\circ$. These parameters are among those generally regarded as representing unacceptable anatomical alignment in distal radius fractures [10, 15, 16]. All measurements were carried out by two independent assessors in a blinded fashion. We also measured the scapholunate gap, and those fracture

Fig. 1 Two patterns of carpal malalignment: (a) intact radius with the normal carpal alignment. RLA and volar tilt taken as zero for illustration purposes; (b) midcarpal malalignment: lunate and the axis of the distal radial articular surface; both maintain nearly collinear relationship with ERLF $< 25^\circ$; (c) radio-carpal malalignment: dorsally tilted fracture fragment alone without lunate leading to ERLF $> 25^\circ$, with dorsal subluxation of the radio-lunate joint

patterns that did not show correction in SLA after reduction and were associated with increased SL gap were excluded from the study. This was in accordance with previous reports that the increased SLA found to occur with displaced distal radial fracture in pre-reduction radiographs may be the result of the effective flexed position of the wrist joint due to the dorsal radial tilt and should not always be interpreted as injury to the scapho-lunate complex unless associated with increased scapholunate gap.

Categorical data were described using frequencies and percentages. Continuous variables were described using mean and SD or median and interquartile range, as appropriate. Radiographic alignment parameters (radial shortening, dorsal tilt, comminution, radial inclination) were compared before and after reduction using paired *t*-tests. The outcome variable was the presence or absence of an acceptable result at 1 and 6 weeks. Tests were two-tailed, and $p < 0.05$ was considered statistically significant. Initial alignment parameters were then also analysed in a multiple logistic regression analysis to assess all potential predictor variables of early and late instability.

Fig. 2 (a) A distal radial fracture with radiocarpal malalignment with ERLF $> 25^\circ$; the SLA is also increased. (b), (c) Post-manipulation AP and lateral radiographs showing satisfactory alignment. The RLA and the SLA have been restored to normal limits. (d) Six-week post-reduction lateral radiographs showing progressive loss of the fracture reduction. Dorsally subluxed radiolunate joint is apparent

Table 1 Incidence of the two carpal malalignments on the basis of effective radio-lunate flexion (ERLF) in each type of fracture

Type of carpal malalignment	No. of fractures	Type of fracture				
		A2	A3	C1	C2	C3
Midcarpal (<25°)		51	7	19	8	13
Post reduction	70					
One week	68					
Six weeks	63					
Radio-carpal (>25°)		5	2	3	4	6
Post reduction	10					
One week	12					
Six weeks	17					

Results

Severity of initial displacement and secondary displacement parameters

There was a significant improvement in all the parameters measured ($p < 0.05$) in pre- and post-reduction measurements with mean correction falling within acceptable limits. The mean improvement in various fracture characteristics described as (pre-reduction; post-reduction mean $\pm$ standard deviation, p value) was as follows: radial inclination (16.9 ± 5.7 ; 20.2 ± 4.3 , $p = 0.028$); radial shortening (4.8 ± 2.4 ; 0.9 ± 2.3 , $p = 0.016$); volar tilt (-15.5 ± 12.8 ; -0.6 ± 10.2 , $p = 0.021$).

Secondary shortening ≥ 4 mm was seen in 18% of fractures with no initial shortening, in 41% with moderate, i.e., 1 to 4 mm shortening and in 52% with severe initial shortening > 4 mm ($p = 0.03$). Regression analysis showed high correlation between severity of initial pre-reduction radial shortening and that at 6 weeks. There was a progressive collapse up to 6 weeks in 53.5% of fractures with radial shortening and 60.1% of fractures with dorsal

angulation. However, on regression analysis, while initial dorsal angulation was predictive of late failure, it did not predict early failure. The severity of radial shortening reliably predicted both.

Fractures were classified according to the Association for the Study of Internal Fixation (AO/ASIF)⁸. The distribution of patients according to the type of the fracture and the pattern of malalignment is shown in Table 1 (Tables 2 and 3).

Mean values of various radiographic parameters according to the type of carpal malalignments (Table 2)

All the radiological parameters were independently analysed on the basis of midcarpal and radiocarpal patterns of malalignments based on ERLF. The radio-scaphoid and the scapho-capitate angles did not show significant change among the pre-, post-reduction or the follow-up films in both the patterns of fracture. The fractures when redisplaced followed the same pattern of carpal malalignment as seen at the time of injury.

Early failure (Table 3)

Regression analysis showed high correlation between the severity of axial shortening, initial dorsal angulation before reduction and age of the patient (> 65 years) with early loss of reduction at 1 week. We did not find gender, presence of dorsal comminution, flattening of the radial angle and ulnar styloid fracture to be significant predictors of failure at 1-week post-reduction. The incidence of failure was significantly correlated to radiocarpal malalignment pattern in post-reduction radiographs (ERLF > 25) at 1 week when analysed independently or in combination ($p < 0.01$).

Table 2 Mean values of various radiographic parameters according to the type of carpal malalignments (n=80)

	Midcarpal malalignment				Radio-carpal malalignment			
	Pre - reduction	Immediate post reduction	At 1 week	At 6 weeks	Pre reduction	Immediate post reduction	At 1 week	At 6 weeks
Radial angulation (degrees)	13.40 (5.75)	18.86 (4.19)	17.28 (5.22)	16.20 (4.60)	14.38 (5.74)	17.88(4.77)	16.29 (4.78)	16.22 (5.20)
Radial length(mm)	4.02 (2.60)	9.09 (3.80)	5.84 (4.30)	5.14 (4.24)	3.64 (2.24)	7.20 (3.56)	5.34 (3.46)	4.86 (3.20)
Volar tilt in degrees	-15.5 $\pm$ 12.8	-1.6 (10.14)	-10.23 (11.08)	-12.5 (12.8)	-16.2 (11.8)	-3.2 (11.10)	-13.5 (12.8)	-15.4 (13.4)
Scapho-lunate angle (degrees)	58.78 (13.78)	48.34 (13.34)	59.10 (13.16)	61.16 (15.10)	51.90 (7.27)	50.20 (9.20)	48.82 (7.73)	51.2 (9.68)
Radio-lunate angle (degrees)	22.12 (10.42)	7.80 (5.24)	16.40 (6.82)	17.46 (5.54)	3.22 (2.20)	3.04 (1.42)	3.10 (1.76)	3.12 (1.86)
ERLF(degree)	10.22 (3.14)	12.64 (3.10)	14.22 (2.84)	15.24 (2.34)	34.54 (9.03)	18.74 (7.06)	27.79 (8.98)	26.74 (9.54)

Table 3 Data concerning early and late failure (1 week; mean +SD)

Failures			
Early failure			
Parameter	Failed	Did not fail	<i>p</i> value
Total (<i>n</i> =80)	<i>n</i> =16	<i>n</i> =64	
Age (years)	72.4±22.3	68.9±19.7	<0.01
Female	97%	84.2%	>0.05
Radial inclination	21.0±6.8	19.2±5.2	>0.05
Radial shortening	3.2±2.4	0.52±1.3	<0.01
Volar tilt	-11.8±12.6	-3.0±8.2	<0.05
Dorsal comminution	85.7%	59.6%	>0.05
Ulnar styloid fracture	28.6%	14.0%	>0.05
ERLF>25	45.6%	18.0%	<0.01
Late failure (6 weeks; mean +SD)			
Parameter	Failed	Did not fail	<i>p</i> value
Total (<i>n</i> =80)	<i>n</i> =25	<i>n</i> =55	
Age (years)	78.3±22.3	62.9±18.7	>0.05
Female	83.6%	84.2%	>0.05
Radial inclination	18.0±5.6	19.1±4.9	>0.05
Radial shortening	2.8±3.0	0.46±1.2	<0.05
Volar tilt	-12.0±13.8	-2.4±7.4	<0.05
Dorsal comminution	89.8%	57.6%	<0.05
Ulnar styloid fracture	31.6%	15.0%	>0.05
ERLF >25	55.8%	19.0%	<0.01

Late failure (Table 3)

In those with late failure at 6 weeks, we found age (>65 years), severity of axial radial shortening, dorsal angulation, presence of dorsal comminution and ERLF >25 to be significant predictors of adverse radiological outcome. Flattening of the radial angle, ulnar styloid fracture and midcarpal pattern of carpal malalignment were not predictive of secondary displacement when analysed independently or in combination. Gender was analysed and men were more likely to maintain an acceptable reduction than women at 6 weeks. This was not found to be a ($p=0.42$) predictor, however, of fracture alignment outcome. Statistical significance was not achieved owing to low power because of the smaller number of males in the study population.

Discussion

The previous studies have identified a linear relationship between the final radiological outcome approaching primary displacement and the number of individual risk factors present in the original injury films in conservatively managed distal radius fractures. The redisplacements are commonly perceived to occur during the 1st week of reduction. Jenkins [8] suggested that most fractures show a slow and progressive loss of reduction during immobilisation. The incidence and natural course of carpal malalign-

ments occurring in association with displaced distal radius fractures have recently been described in greater detail. Bickerstaff and Bell measured and correlated the radio-lunate angle in cases of Colles' fractures with the functional results, but did not define any measurement that would indicate some ligamentous injury leading to poor functional results [9]. Saraffian et al. in their radiographic study investigating components of wrist motion showed that in palmar flexion of the normal wrist, approximately 60% of motion occurs at the mid-carpal joint, and the remaining flexion occurs at the radio-carpal joint, i.e., approximately 25° [14]. In a subsequent study, Batra et al. has attempted to quantify these, deriving from the above results by Saraffian et al. that up to 25° flexion at the radio-carpal joint is within normal physiological limits [11]. Effective radio-lunate flexion (ERLF) describes relative flexion of the lunate that occurs secondary to the dorsal rotation of the distal radial articular surface. It is calculated as: dorsal tilt +11 (average volar tilt) - RLA [10]. To our knowledge no study so far has evaluated carpal malalignment based on ERLF as one of the predictors of instability exclusively in conservatively managed intra- and extraarticular distal radius fractures. The results of our study will aid the clinician in identification and treatment recommendations for unstable distal radius fractures on a defined timeline for early and late failure.

The measurement of ERLF helps to classify carpal malalignments into two definite groups with possibly different aetiologies and prognoses [9, 13]. Fractures with less than 25° of ERLF were considered to belong to the most common group of "adaptive" midcarpal malalignments. Here neither the radiocarpal capsule nor the carpal ligaments are disrupted; the malalignment merely reflects the adaptation to the malunion at the midcarpal level with the lunate moving with the fracture fragment like a composite radio-lunate complex. Fractures showing more than 25° of ERLF are described as having the radio-carpal malalignment pattern, which denotes an excursion definitely beyond the physiological range. Here the fracture also results in a global radio-carpal dorsal derangement producing the dorsal radiocarpal subluxation as the lunate contact area translates dorsally (Fig. 1) [1, 2]. It involves the fracture fragment rotating dorsally independent of the lunate. Gong et al. in an experimental study suggested an associated injury to the radio-carpal ligaments to explain the occurrence of such an injury pattern [4]. We agree with previous reports that fractures when redisplaced seem to develop a radiocarpal malalignment pattern both during and after immobilisation [1, 9, 11]. Batra et al. in their study included conservatively treated distal radius fractures and those managed with internal/external fixation and concluded that the functional results were poor in cases with a radiocarpal malalignment pattern [2]. We found a signifi-

cant number of patients who had a palmar-flexed lunate with no dissociation from the scaphoid. We believe that they represent nondissociative carpal instability indicating extrinsic ligamentous derangement occurring at the time of the radial fracture or shortly afterwards, perhaps due to incongruity of the articular facets of the radius. These carpal malalignments therefore are seen to occur as an integral component of the fracture redisplacement rather than solely as an adaptive sequel to the malunion.

Carpal angles measure the alignment of the carpal bones in relation to the longitudinal axis of the radius, but are able to serve the desired purpose due to the fixed and constant relationship between the longitudinal axis of the radius and its articular surface in an unbroken radius. That is why ERLF appears to be a more appropriate measurement in patients with fractured distal radius, as it takes into account the influence of dorsal tilt and RLA.

Specific characteristics of the initial displacement were correlated with radiological failure at early (1 week) and late (6 week) follow-up. Our results indicate that despite having achieved a satisfactory reduction, the patients in the higher age group with radial shortening and radiocarpal malalignment pattern in post-reduction radiographs (ERLF $>25^\circ$) are more likely to displace early (within 1 week).

The tendency for late redisplacement at 6 weeks was predicted by increasing age, severity of axial radial shortening, dorsal angulation, presence of dorsal comminution and radiocarpal pattern of carpal malalignment.

The increased SLA found to occur with displaced distal radial fracture in pre-reduction radiographs has been proposed to be the result of the effective flexed position of the wrist joint due to the dorsal radial tilt and should not always be interpreted as injury to the scapho-lunate complex unless associated with a pathological gap of greater than 3 mm [12]. The wrist flexion involves the scaphoid moving more than the lunate by an average of 17° . This makes the proximal carpal row move in a columnar manner with the least excursion at the radio-lunate joint. The increased SLA and the midcarpal instability with an extended lunate could almost always be corrected with reduction of the fracture. The increased SLA was present in the pre-reduction radiograph of 31 (39%) of our patients with SLA exceeding 60° .

Our study reaffirms the need to pay attention to initial fracture characteristics in displaced distal radial fractures and highlights the importance of radiocarpal instability pattern on post-reduction radiographs as a predictor of both early and late instability. Measurement of ERLF can serve as a valuable and sensitive adjunct to determine the prevalence and severity of intracarpal soft-tissue lesions that are usually overlooked on standard radiographs with fractured distal radius. An awareness of these factors will not only aid anticipation of the radiological outcome, but

would allow the surgeon to inform the patient of chances of success with closed treatment and alternative treatment options.

The limitations of our study were the small number of patients and wide range of their age. Another limitation was the fact that criteria for an acceptable result are based on radiographic measurements and not clinical results. There may be a group of patients who displaced to an unacceptable level based on radiographs, but clinically have an acceptable outcome. More research is needed in this area to elucidate the influence of carpal malalignment in association with distal radius fractures on the long term functional outcome.

Conclusion

Two patterns of carpal malalignment, midcarpal and radio-carpal, were associated with displaced distal radial fractures. The same instability pattern reappeared with the redisplacement of the fractures and occurred during the immobilisation itself rather than as a later compensatory mechanism of the malunion. Fractures with the radio-carpal instability pattern were difficult to reduce satisfactorily and had an increased incidence of early and late redisplacement. The abnormal carpal angles seen in the patients with the displaced radial fractures such as SLA can be because of altered biomechanics. Our study highlights the importance of the radio carpal instability pattern on post reduction radiographs as a predictor of early and late instability in conservatively managed distal radius fractures.

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