Prediction of Instability in Distal Radial Fractures

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Background: Effective methods of treating an unstable distal radial fracture are described in the literature, but there is no reliable method of identifying an unstable fracture in time to initiate appropriate treatment. The purposes of this study were to identify the predictors of fracture instability and to construct a method of prospectively predicting the radiographic outcome.

Methods: Data on approximately 4000 distal radial fractures were prospectively recorded over a 5.5-year period. The database was validated by reexamining a sample of it. Demographic data on the patients and mode of injury, as well as the fracture classification and measurements, were recorded at the time of presentation. Outcome measures consisted of radiographic measurements made at one week and six weeks and assessment of carpal alignment at six weeks. Univariate and multiple logistic regression analyses were performed to identify the significance of the data obtained at presentation in the prediction of early and late instability as well as the risk of malunion and carpal malalignment.

Results: The predictors of early and late instability and malunion differed according to the displacement of the fracture at presentation. Patient age, metaphyseal comminution of the fracture, and ulnar variance were the most consistent predictors of radiographic outcome. Dorsal angulation was not found to be significant in the prediction of radiographic outcome for displaced fractures. The degree to which the patient was independent was predictive of malunion in minimally displaced and displaced fractures. Formulas that are predictive of each of the seven radiographic outcome measurements were constructed.

Conclusions: The study succeeded in identifying the factors that are prognostic of the radiographic outcome for distal radial fractures. Formulas to predict the radiographic outcome were constructed as the independent prognostic significance of these factors was quantified. These formulas can be used to inform the surgeon's decision about the nature of primary treatment of fractures of the distal aspect of the radius. However, they must be validated by further studies before they are used to impact the management of distal radial fractures.

Level of Evidence: Prognostic Level I. See Instructions to Authors for a complete description of levels of evidence.

Fractures of the distal aspect of the radius are common[1], and they constitute a substantial proportion of the workload in orthopaedic trauma practice[2]. Stable fractures can be managed conservatively, with good anatomical and functional results[3,4]. However, the management of the unstable fracture of the distal part of the radius continues to stimulate debate, particularly when such a fracture occurs in an elderly patient. There is currently general agreement that there is a close relationship between anatomy and function[3-9]. This implies that treatment should strive to regain as near an anatomical position as possible, to optimize the functional outcome. A number of treatment methods, including internal and external fixation techniques, have been shown to restore and maintain the radiographic position until union of the fracture[9-14]. Some of these techniques have been shown to be effective in the treatment of this fracture in elderly patients[9,14].

The diagnosis of an unstable fracture of the distal aspect of the radius is usually made by observation of the behavior of the fracture after initial treatment in a cast. Our standard initial management of a displaced fracture is closed manipulation followed by application of a cast. Instability is diagnosed by radiographic examination between one and two weeks later. If appropriate, definitive surgical treatment is instituted at that stage for fractures displaying early instability. However, fractures that exhibit instability after two weeks are not detected by this management protocol.

A reliable method of predicting instability at the time of presentation would enable timely definitive surgical treatment to be undertaken with evidence-based decision-making. The patient would not have to wait for the diagnosis of instability to be made. Unnecessary manipulation of the displaced unstable fracture could be avoided, and fractures with late instability would be less likely to proceed to malunion.

Various studies have defined factors that are predictive of instability[15-17]. Computer algorithms have been used to predict the radiographic outcome for individual fractures, with reasonable results[18]. Unfortunately, this predictive method has not been validated. In an attempt to quantitatively predict anatomical outcome, we prospectively gathered data for approximately 4000 distal radial fractures. The aims of this study were (1) to identify the factors relating to the patient, mode of injury, and the fracture that were of significant prognostic value with respect to radiographic outcomes of the fracture, and (2) to use this data to construct mathematical formulas that are predictive of radiographic outcomes of the fracture.

Materials and Methods

Definitions

The premorbid normal level of function of the patient was categorized as independent, which was defined as the ability to go shopping without assistance, or as dependent, which was defined as the need for assistance in order to go shopping or an inability to go shopping.

Fracture displacement (Fig. 1) was characterized as minimally displaced when there was dorsal angulation of ≤10°[5] and an ulnar variance of <3 mm[5,19], as displaced when there was dorsal angulation of >10° and/or ulnar variance of >3 mm, or as re-

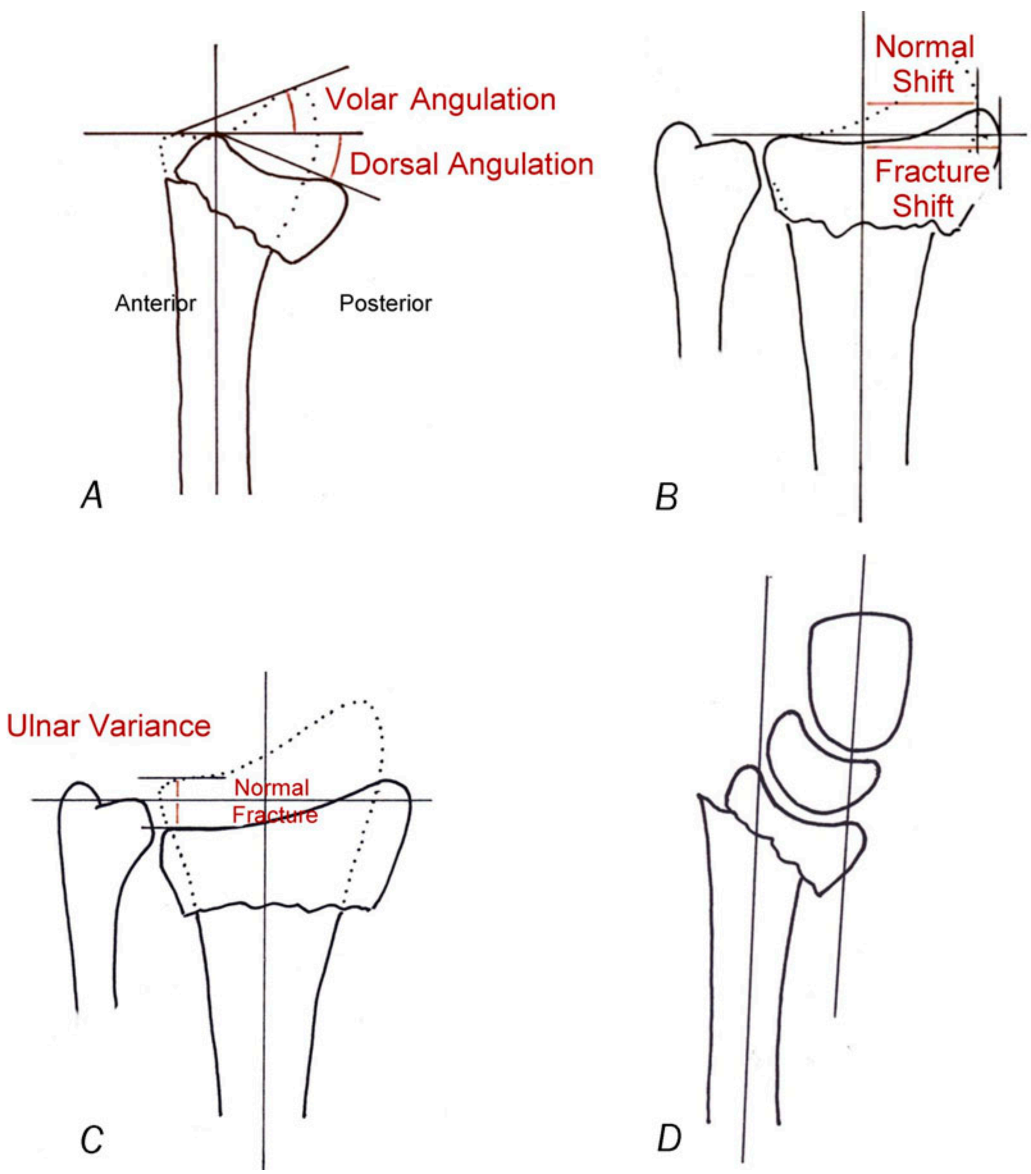

Fig. 1

A: The measurement of dorsal and volar angulation. This is an absolute measurement in degrees and is expressed as a negative value for volar angulation and a positive value for dorsal angulation. *B:* The measurement of radial shift. This is a relative measurement, which is taken as the difference between the measurements of the fractured radius and the normal, uninjured radius. *C:* The measurement of ulnar variance. Again, this is a relative measurement, taken as the difference between the ulnar variance of the fractured radius and that of the normal, uninjured radius. *D:* A fracture-producing carpal malalignment. Malalignment is defined as the long axes of the capitate and radius failing to intersect within the carpus.

TABLE I Characteristics of Groups

	Minimally Displaced Fractures			Displaced Fractures			All Fractures
	Early Instability	Late Instability	Malunion	Early Instability	Late Instability	Malunion	Carpal Malalignment
No. of fractures	1486	1125	1333	1595	829	1236	3559
Mean age *(yr)*	55	54	55	62	59	62	59
Sex *(%)*							
Female	79	80	73	85	72	84	78
Male	21	20	27	15	28	16	22
Patients who were independent *(%)*	91	92	91	85	92	88	88
Injury due to a fall from standing height *(%)*	78	80	79	85	82	85	81

displaced when previous manipulative reduction had been performed. An acceptable reduction was a fracture with dorsal angulation of ≤0° and an ulnar variance of ≤3 mm following closed reduction, and an unacceptable reduction was a fracture with dorsal angulation of >0° and/or an ulnar variance of >3 mm following closed reduction.

Carpal malalignment was deemed to be present when the long axes of the radius and capitate failed to intersect within the carpus on the lateral radiograph of the wrist[5]. To permit an assessment of the natural history of the fracture, this measurement was made with use of the radiographs used for malunion (described below).

Fracture instability was divided into three types: early instability, late instability, and malunion. Early instability was defined as a fracture that was displaced (or redisplaced following closed reduction) radiographically within two weeks after the injury. Late instability was defined as a fracture that was displaced radiographically at the time of union (i.e., six weeks) but had not previously demonstrated early instability. Malunion was defined as the theoretical risk of a fracture being displaced at the time of union if the fracture was untreated other than by closed reduction at presentation. This allowed an assessment of the natural history of the fracture. For the purposes of identifying factors predictive of malunion, any fracture that was displaced (or redisplaced) at or prior to union was recorded as a malunion (as a malunion would have occurred if no intervention other than closed manipulative reduction had been undertaken).

Demographic Data

During the period from June 1988 to December 1993, 28,376 new fractures were seen at the Orthopaedic Outpatient Department of the Royal Infirmary of Edinburgh. The distal aspect of the radius was involved in 4024 (14.2%) of the fractures, and they formed the study group. Seventy-nine percent (3173) of the fractures were in female patients, and 21% (851) were in male patients. The age range was fourteen to 100 years (mean, sixty-four years) for female patients and fifteen to ninety-four years (mean, forty-two years) for male patients. The mean age for all patients was fifty-nine years. Fifty-one patients had a bilateral fracture.

Seven groups were considered for analysis, and the demographics of each group are shown in Table I. The number of fractures in each group varied for two reasons. With respect to early instability and malunion, the difference in numbers was due to missing data. With respect to late instability, the numbers are also reduced because of the definition of late instability: only fractures that had not demonstrated early instability could be used in this analysis.

Displaced fractures occurred in older patients and were more frequent in females. These patients were less likely to be independent. The displaced fracture was also more frequently due to a low-energy injury (i.e., a fall from standing height).

Database Construction

Fracture management followed a standard protocol. The emergency-room staff undertook the initial assessment and treatment. Fractures deemed to be in an acceptable position were managed with a dorsal plaster-of-Paris slab. If the fracture position was thought to be unacceptable, the emergency-room staff, prior to application of a dorsal plaster-of-Paris slab, performed closed reduction using intravenous regional anesthesia.

The exclusion criteria were (1) skeletal immaturity, (2) primary operative treatment, (3) prior fracture malunion, and (4) missing data.

Primary operative treatment was selected for intra-articular fractures or volarly displaced fractures (ninety-four patients), open fractures (thirty-nine patients), fractures with severe nerve compression syndromes (ten patients), and fractures complicated by compartment syndrome (three patients). Patients with missing radiographic data from the evaluation at the time of presentation were excluded from all statistical analysis, as fractures were analyzed according to whether they were displaced or minimally displaced at presentation. Patients with missing radiographic data from the one-week evaluation were excluded from the analyses of early instability and late instability. Patients with missing radiographic data from the six-week evaluation (union) were excluded from analyses of late instability and malunion.

The patients were evaluated clinically and radiographically at approximately one and six weeks after the injury as per the protocol of the orthopaedic trauma unit, which included radiographs of the normal, uninjured wrist made at one week.

At approximately one week following the injury, the data on the patients were reviewed by the senior author (M.M. McQ.) in a special research clinic. The clinical, demographic, and radiographic data were recorded and entered into a database either by the senior author or a research nurse. In addition to standard demographic details, the patient's normal level of function (as described earlier) and mode of injury were recorded. Radiographs of the uninjured, normal wrist were made, and radiographs of the injured wrist were repeated. The patients with a fracture that had maintained a good position (i.e., no early instability was demonstrated) had the dorsal slab completed to a below-the-elbow forearm cast with the wrist in slight flexion and ulnar deviation. Patients with a fracture that had displaced (or redisplaced) were admitted to the orthopaedic trauma unit for further intervention, unless the patient had low functional demands and operative intervention was deemed inappropriate.

The patients were subsequently evaluated at approximately six weeks. Radiographs were repeated for the assessment of displacement and carpal alignment. If surgical intervention had been undertaken prior to six weeks for displaced fractures, then all radiographic measurements subsequent to surgery were excluded from statistical analysis and the fracture was recorded as having gone on to malunion.

Radiographic Measurement Techniques

All radiographs (those made at presentation, at the time of reduction, and at the one-week and six-week evaluations) were measured manually with use of a protractor and a ruler to provide values for the dorsal angle, radial shift[19], and ulnar variance[20]. These measurements are illustrated in Figure 1. The ulnar variance and radial shift are expressed as the difference between the injured side and the normal, uninjured side. In the cases of the patients for whom normal values were unavailable, the mean values for the normal side were used[17]. The fractures were classified with use of both the Frykman and AO/OTA classifications[21,22]. The type of metaphyseal comminution was recorded, according to the location, as absent or as involving the dorsal metaphysis, volar metaphysis, or both the dorsal and volar metaphysis. Thus, comminution was a purely qualitative measurement. Carpal alignment (as defined earlier) was assessed on the radiographs made at the time of the final review. The senior author alone was responsible for fracture classification and the assessment of comminution and carpal alignment.

Database Validation

No widely accepted method of database validation is available. Validation was performed by reexamining selected data for a sample of patients. Nineteen data fields were reexamined for 116 patients (every thirtieth patient in the database). Data fields included demographic information, mode of injury, and all radiographic measurements. Any difference in categorical data was considered an error. For quantitative data, a difference of >5° in angular measurement and 2 mm in length was considered an error. Data for 331 fields were missing, leaving 1808 pairs of data for comparison.

The error rate was expressed simply as a percentage calculated according to the following formula:

$$\frac{(\text{pairs of data in disagreement} \times 100)}{\text{total number of pairs of complete data}}$$

Errors in categorical fields were rare. No difference in the error rates was recorded for angular measurements compared with length measurements. The overall rate of error was 3.5%.

Statistical Methods

The following variables were analyzed: (1) age, (2) gender, (3) mechanism of injury, (4) independence, (5) type of comminution, (6) AO/OTA type, (7) AO/OTA group, (8) AO/OTA subgroup, (9) Frykman classification, (10) dorsal angle at presentation, (11) radial shift at presentation, (12) ulnar variance at presentation, (13) dorsal angle at one week, (14) radial shift at one week, and (15) ulnar variance at one week.

Univariate association between outcomes and potential predictors was tested by chi-square tests for nominal data and Mann-Whitney tests for ordinal or quantitative data. All variables achieving a p value of ≤0.05 in univariate analysis were included in the regression analysis. Stepwise logistic regression was then used to determine independently significant variables, thus accounting for relationships or confounding between variables. The parameter estimates produced by the regression analysis were then used to produce a predictive formula for radiographic outcome. The instability score calculated from the formula could then be converted to a percentage with the use of an exponential equation. The goodness of fit of each logistic regression analysis was assessed with the Cox and Snell R^2 statistic.

Results

The results of statistical analysis for minimally displaced and displaced fractures and carpal malalignment are summarized in tables in the Appendix. It is noteworthy that marked differences are seen between univariate and regression analyses in all cases. For example, patient gender, mode of injury, and original radial shift are almost invariably significant following univariate analysis, and they are almost invariably of no prognostic value following multiple logistic regression. The latter statistical method allows demonstration of dependence between variables; thus, gender loses significance as most females are older and males are younger.

Fractures That Were Minimally Displaced at Presentation

Prediction of Early Instability

Early instability occurred in 149 (10%) of 1486 patients with minimally displaced fractures at presentation. Only four factors remained significant following regression analysis. The most important factor was age ($p < 0.001$). Early instability occurred ten times more frequently in patients who were more than eighty years old compared with patients who were less than thirty years old. Comminution was also highly significant ($p < 0.001$). Early instability occurred six times more frequently in fractures with any form of comminution (dorsal, volar, or both dorsal and volar) compared with fractures with no comminution. The original dorsal angle and ulnar variance were also of significance ($p < 0.01$). Early instability occurred five times more frequently in fractures with a dorsal angle between 5° and 10° compared with fractures that maintained a degree of volar angulation. The frequency of early instability in fractures with an ulnar variance of >0° was twice that in fractures with an ulnar variance of ≤0°.

Prediction of Late Instability

Late instability occurred in 244 (22%) of 1125 patients. This was a lower rate of late instability than that reported by other investigators[16]. Only the age of the patient ($p < 0.001$), the presence of comminution ($p < 0.01$), and the dorsal angle ($p < 0.001$) and ulnar variance ($p < 0.001$) measured at one week retained significance following regression analysis. Again, age was the most important factor, with late instability occurring four times more frequently in patients more than eighty years old compared with patients less than thirty years old. The presence of fracture comminution of any type increased the frequency of late instability by a factor of three.

Prediction of Malunion

If all 1333 minimally displaced fractures had been treated only with closed reduction at presentation, then 27% (354) would have gone on to malunion. Factors that were predictive of malunion following regression analysis were age, dorsal angle, and ulnar variance at presentation ($p < 0.001$); comminution, AO/OTA group, and radial shift at presentation ($p < 0.01$); and independence, AO/OTA subgroup, and Frykman classification ($p < 0.05$). An age of more than eighty years increased the frequency of malunion by sixfold compared with an age of less than thirty years. The frequency of malunion is three times as great in fractures with a dorsal angle of between 4° and 10° compared with fractures maintaining some degree of volar angulation. Malunion is three times more common in fractures with any type of comminution. In fractures with no involvement of the distal radioulnar joint (a Frykman score of 1 to 4), malunion occurred more frequently in fractures involving the ulnar styloid (a Frykman score of 2 and 4). Dependent patients more frequently had a malunion.

Fractures Displaced at Presentation

Prediction of Early Instability

Early instability occurred in 682 (43%) of 1595 displaced fractures. Following regression analysis, the factors retaining significance were age and ulnar variance at presentation ($p < 0.001$) and the type of comminution ($p < 0.01$). Early instability occurred in 62% of the fractures in patients who were more than eighty years old, nearly three times more frequently than in patients who were less than thirty years old. This is also two and one-half times more frequent in patients more than eighty years old with a minimally displaced fracture. Dependent patients again had greater rates of early instability. Interestingly, in displaced fractures, the dorsal angle had no effect on the frequency of early instability.

Prediction of Late Instability

Late instability occurred in 391 (47%) of 829 patients. After regression analysis, the following factors were significant: age ($p < 0.001$) and the dorsal angle ($p < 0.001$) and ulnar variance ($p < 0.001$) measured at one week. As in minimally displaced fractures, the radiographic measurements at presentation are of no significance in predicting late instability.

Prediction of Malunion

Malunion in displaced fractures was very common. If all 1236 displaced fractures had been treated by closed reduction alone at presentation, then 60% (744) would have gone on to malunion.

Age, ulnar variance and patient independence at presentation ($p < 0.001$), and the type of comminution ($p < 0.01$) retained significance following regression analysis. Age had a striking effect: 82% of the patients more than eighty years old had a malunion compared with 30% of those who were less than thirty years old. Again, malunion occurred more frequently in dependent patients. An ulnar variance of >2 mm increased the frequency of malunion by 10%. As was seen for fractures with early instability, dorsal angulation had no bearing on the frequency of malunion in displaced fractures.

Prediction of Carpal Alignment in All Fractures

Carpal malalignment was present in 1121 (31.5%) of 3559 patients. Age, independence, type of comminution, AO/OTA subgroup, and original dorsal angulation ($p < 0.001$ for each) all retained significance following regression analysis. In contrast to the prediction of instability, for which the presence or absence of comminution was important, it was specifically dorsal comminution that was associated with an increase in the frequency of carpal malalignment. Carpal malalignment occurred more often in fractures of AO/OTA subgroup 2, and less often in AO/OTA type-B fractures.

The Probability of Fracture Instability and Carpal Malalignment

The formulas for instability scores (X) were calculated from the weighting of the significance of factors following the regression analysis. These formulas are listed below along with the Cox and Snell R^2 statistic.

Minimally Displaced Fractures

For the prediction of early instability ($R^2 = 0.12$): $X = (0.03 \times \text{age}) + 1.39$ (if any type of comminution present) $+ (0.05 \times \text{dorsal angle at presentation}) + (0.21 \times \text{ulnar variance at presentation}) - 4.82$.

For the prediction of late instability ($R^2 = 0.18$): $X =$

(0.03 × age) + 0.93 (if any type of comminution present) + 1.45 (if dorsal angle is >4° at one week) + 0.33 (if ulnar variance >–1 mm at one week) – 3.92.

For the prediction of malunion ($R^2 = 0.2$): X = (0.03 × age) + 1.04 (if any type of comminution present) + (0.06 × dorsal angle at presentation) + (0.2 × ulnar variance at presentation) – 3.41.

Displaced Fractures

For the prediction of early instability ($R^2 = 0.09$): X = (0.03 × age) + 0.38 (if there is any type of comminution) + (0.21 × ulnar variance at presentation) – 3.12.

For the prediction of late instability ($R^2 = 0.11$): X = (0.02 × age) + (0.07 × dorsal angle at one week) + (0.22 × ulnar variance at one week) – 1.53.

For the prediction of malunion ($R^2 = 0.13$): X = (0.04 × age) – 0.8 (if independent) + 0.53 (if comminution type = dorsal) + (0.09 × ulnar variance at presentation) – 1.65.

All Fractures

For the prediction of carpal malalignment ($R^2 = 0.12$): X = (0.03 × age) – 0.56 (if independent) – 0.97 (if comminution type = none) – 0.46 (if comminution type = dorsal and volar) + 0.34 (if AO/OTA subgroup = 2) + (0.0017 × dorsal angle at presentation) – 2.14.

The probability of instability or carpal malalignment can be expressed as a percentage with use of the following conversion equation:

$$\text{Probability (\%)} = ([e^x] \times 100)/(1 + e^x)$$

where X is the value calculated from the predictive formulas above.

In practice, the prediction of malunion is of the most clinical relevance, especially in displaced fractures.

Discussion

Most work examining the factors that are predictive of radiographic outcome has not made the distinction between early and late collapse of the fracture. In addition, fracture instability has not been examined with stratification of the position of the fracture at presentation. The heterogeneity of study populations may explain the disagreement among authors as to the most important factors determining fracture stability. Hove et al.[15] analyzed data for 645 conservatively managed distal radial fractures. Using multiple regression analysis, the authors found that the initial dorsal angulation, radial length, and patient age were predictors of malunion. It was not possible to determine whether these factors may have been different for early and late fracture collapse, as all fractures that required treatment for redisplacement at one week were excluded from the analysis. Jenkins[16] found that the position of the fracture at presentation was a good indicator of the fracture position at union. He also found that the absence of dorsal comminution was protective against malunion in dorsal angulation. However, he did not calculate the independent significance of these factors. He also analyzed only radiographic data. All of the patients in his study had a displaced fracture at presentation, but displacement was not defined other than by the need for reduction. Lafontaine et al.[23] reported predictors of fracture instability: age (>60 years), dorsal angulation (>20°), dorsal comminution, intra-articular fracture (radiocarpal joint surface), and associated ulnar fracture. Again, all fractures in the study were initially displaced. A scoring system for fracture instability was produced on the basis of the aforementioned factors. This scoring system has been further evaluated, finding the age of the patient most useful in the assessment of instability[24]. Abbaszadegan et al.[17] calculated the independent significance of a range of factors; ulnar variance, Lidstrom class[24], and patient age proved to be the most important. The authors also quantified the risk of instability but only with respect to ulnar variance. Adolphson et al.[18] used computerized analysis to quantify the risk of fracture instability. However, this method of prediction has not been prospectively validated.

A list of significant predictors of fracture instability is available[25]. The presence or absence of these predictors will facilitate management decision-making. However, assessment with use of these predictors is qualitative. Fracture instability cannot be quantified with use of this information; thus, the assessment of instability is ultimately based on clinical judgment. The present study demonstrated that certain factors identifiable at presentation have a highly significant relationship with radiographic outcomes of distal radial fracture. From the results of the statistical analysis, it was possible to construct weighted mathematical formulas that predict these outcomes. These formulas are based on data available in the emergency room and are thus applicable at presentation. If validated, these formulas will be an invaluable adjunct in the decision-making process for the management of distal radial fractures.

The most important predictive factors were the age of the patient, the type of comminution of the fracture, and the position of the fracture at presentation. We showed that early and late instability and carpal malalignment increase relentlessly with age. In the prediction of malunion, the presence or absence of comminution was important, whereas in the prediction of carpal malalignment, the location of comminution (dorsal) was important. This is unsurprising as carpal malalignment following distal radial fracture is due almost exclusively to dorsal instability of the carpus[26].

The dorsal angle at presentation was not important in predicting malunion in displaced fractures. This result is explained by the importance of comminution. Dorsal angle and comminution are intimately related in displaced fractures. For a greater dorsal angle to be present, the metaphysis must be deficient, except in fractures in which the distal fragment is dorsally translocated. Thus, of the two factors, only comminution retained significance following regression analysis. The position of the fracture at presentation was predictive of the position at union. Malunion occurred more frequently in displaced fractures. Initial ulnar variance was consistently significant. Dorsal angle was of variable significance. It was important in the fractures that were minimally displaced at presentation and in the prediction of carpal malalignment. Patients with low functional requirements were unlikely to have anything other than nonoperative management of the fractures. Although the independence of the patient was likely to influence the decision as to whether the fracture required manipulation, it was still an independently significant predictor of radiographic outcome.

In minimally displaced fractures, those classified as AO/OTA group 3 had a significantly higher frequency of early instability ($p < 0.05$). These were almost exclusively A3.2 and C3.2 fractures, both of which have metaphyseal comminution. Similar findings were noted in the prediction of malunion in minimally displaced fractures. In the prediction of carpal malalignment, the AO/OTA type and subgroup were significant ($p < 0.01$ and $p < 0.001$, respectively). Carpal malalignment was more frequent in fractures with no continuity between the diaphysis and the articular surface (types A and C), and in subgroup 2 (again, mainly A3.2 and C3.2) because of the metaphyseal component of the fracture.

The Frykman classification was also significant in the prediction of carpal malalignment ($p < 0.05$) and malunion ($p < 0.05$) in minimally displaced fractures. The frequency of malunion in fractures involving the ulna and those involving the radiocarpal joint increased by 15% and 20%, respectively. The frequency of carpal malalignment was reduced by approximately half if fractures were in group 1 or 3. Other investigators have reported the importance of ulnar styloid involvement[27]. In contrast, the Frykman classification was of no prognostic value in displaced fractures. In addition, it must be noted that the prognostic value of these classification systems is affected by their marked interobserver variability[28,29].

In view of the size of the database, reexamination of all data was thought to be impractical. The measurement and recording of data were consistent in the samples of patient data that were reexamined. It is recognized that the missing data restrict the data validation and the statistical analysis of the study.

In an independent fifty-five-year-old patient with a displaced distal radial fracture with no comminution and no shortening (ulnar variance = 0°), the value of X is calculated as follows:

$$X = (0.04 \times 55) - 0.8 + (0.09 \times 0) - 1.65 = -0.25$$

With the conversion formula used to produce a percentage probability of malunion:

$$\text{Probability} = (e^{-0.25} \times 100)/(1 + e^{-0.25}) = 44\%$$

In an independent eighty-five-year-old patient with a dorsally comminuted displaced fracture with an ulnar variance of 2 mm, the value of X is calculated as follows:

$$X = (0.04 \times 85) - 0.8 + 0.53 + (0.09 \times 2) - 1.65 = 1.66$$

In addition, the probability of malunion is calculated as follows:

$$\text{Probability} = (e^{1.66} \times 100)/(1 + e^{1.66}) = 82\%$$

Thus, the risk of malunion is higher in the older patient with comminution. However, the significance of the difference in probabilities is yet to be ascertained. To help in decision-making, these probabilities need to be converted into a binary outcome: will this fracture go on to malunion or not? Thus, prospective studies are required to validate the predictive formulas. The formula must be specific (i.e., able to detect stable fractures), otherwise the number of stable fractures treated surgically will be unacceptably high. It must also be sensitive (i.e., able to detect unstable fractures), otherwise there will be little reduction in the number of unstable fractures that go on to malunion.

In conclusion, this study identified at presentation the patients in whom instability and carpal malalignment were more frequent. The position of the fracture at presentation influences the radiographic outcome. The age of the patient, the type of comminution, and the ulnar variance at presentation are important predictive factors. We produced a predictive formula for carpal malalignment. This phenomenon is related to the degree of malunion of the fracture, but it may occur in fractures with relatively little displacement. This may go some way to explaining the results of studies that have demonstrated that functional outcome is not necessarily related to radiographic outcome and that functional outcome may deteriorate with time[30-33].

As far as we are aware, this is the only study identifying independently significant predictors of the radiographic outcome of distal radial fractures. It is also, as far as we know, only the second study to produce a method of prospectively quantifying the risk of fracture instability. It is hoped that a user-friendly method of prediction can be produced from the mathematical formulas derived in the study. If validated, these predictive formulas have the potential to remove the delay in definitive fracture treatment and to reduce the number of late corrective procedures that need to be performed.

Appendix:

eA Tables presenting the results of the statistical analysis for minimally displaced and displaced fractures are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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