A commentary by Teun Teunis, MD, PhD, is linked to the online version of this article.

Association Between Radiographic and Clinical Outcomes Following Distal Radial Fractures

A Prospective Cohort Study with 1-Year Follow-up in 366 Patients

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Background: Several studies of distal radial fractures have investigated final displacement and its association with clinical outcomes. There is still no consensus on the importance of radiographic outcomes, and published studies have not used the same criteria for acceptable alignment. Previous reports have involved the use of linear or dichotomized analyses.

Methods: The present study included 438 patients who were managed with either reduction and cast immobilization or surgery for the treatment of distal radial fractures. Radiographic outcomes were determined on the basis of radiographs that were made 3 months after the injury. Clinical outcome was determined on the basis of the QuickDASH (an abbreviated version of the Disabilities of the Arm, Shoulder and Hand [DASH] questionnaire) score, range of motion, and grip strength at 1 year after the injury. Nonlinear relations were analyzed with cubic splines.

Results: Three hundred and sixty-six patients (84%) had both radiographic and clinical follow-up. Seventy patients were lost to follow-up. The mean age was 57 years (range, 18 to 75 years), and 79% of the patients were female. Dorsal tilt was the radiographic parameter that was most strongly associated with the QuickDASH score, grip strength, and range of motion. We found nonlinear relations. Clinical outcomes were found to worsen with increasing dorsal tilt, with the cutoff value being approximately 5°.

Conclusions: We found that clinical outcomes following distal radial fractures have a nonlinear relationship with dorsal tilt, with worse outcomes being associated with increasing dorsal tilt. The decline in clinical outcome starts at 5°, but there is unlikely to be a noticeable difference in capability as measured with the QuickDASH until 20° of dorsal tilt (based on the minimum clinically important difference) in a population up to 75 years old.

Level of Evidence: Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Distal radial fracture is the most common fracture in adults[1,2]. According to guidelines from several different countries, treatment is mainly dependent on fracture displacement and functional demands[3-9]. Such guidelines use dorsal tilt, ulnar variance, radial inclination, and intra-articular step-off as the important radiographic parameters. Several studies have investigated the degree of final displacement and its association with clinical outcomes[10-18]. There is still no consensus on the importance of radiographic outcomes, and published studies have not used the same criteria for acceptable alignment. Previous studies have used linear or dichotomized analyses.

For displaced distal radial fractures, the restoration of alignment is important for good clinical outcomes[19]. However, there is no consensus on which radiographic parameter is the best predictor. Dorsal tilt and ulnar variance are often thought to be the most important radiographic parameters[10].

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/H520).

A **data-sharing statement** is provided with the online version of the article (http://links.lww.com/JBJS/H522).

The evidence is inconclusive regarding when surgical treatment is indicated. Despite the lack of evidence, there is a recent trend toward more surgical interventions[20].

The purpose of the present study was to investigate the relationship between radiographic and clinical outcomes following distal radial fractures. Specifically, we investigated (1) whether there is a nonlinear relationship between the degree of final displacement and clinical outcome and (2) whether there is a cutoff value for clinical outcome (i.e., a radiographic measurement threshold beyond which clinical outcome becomes progressively worse).

Materials and Methods

Study Design and Setting

This prospective, multicenter cohort study included patients who were treated for a distal radial fracture between October 2009 and September 2011 at the Departments of Orthopaedics in Sundsvall and Östersund, Sweden. The Sundsvall Hospital and the Östersund Hospital are secondary-level hospitals, with a catchment area for emergency care of approximately 160,000 and 130,000 inhabitants, respectively. The guidelines of the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) statement[21] were followed. The trial was registered at ClinicalTrials.gov (NCT05558306).

Participants and Data Collection

Patients 18 to 75 years of age with closed distal radial physes who presented with an acute distal radial fracture were screened. Data were collected prospectively at follow-up visits (at 10 to 14 days, 3 months, and 1 year) in the orthopaedic departments. Patient data included age, sex, dominant side, initial and definitive treatment (nonoperative/operative), radiographic characteristics, patient-reported outcome (as determined with the QuickDASH [an abbreviated version of the Disabilities of the Arm, Shoulder and Hand (DASH)] questionnaire), and functional outcome (range of motion and grip strength). The exclusion criteria were previous fracture of the ipsilateral wrist, coexisting carpal fracture or SLAC (scapholunate advanced collapse) wrist, rheumatoid arthritis, bilateral fracture, alcohol or drug abuse, open fracture, dementia, neurological impairment, and Galeazzi fracture.

Radiographic Analysis

Posteroanterior and lateral radiographs of the wrist were made after reduction, at 10 to 14 days, and after union at ≥3 months. There were no nonunions. Radial inclination, dorsal tilt, ulnar variance, and intra-articular step-off at the radiocarpal joint were measured on posteroanterior and lateral radiographs in neutral rotation (Fig. 1). Dorsal and volar comminution were assessed on the lateral radiograph[22]. We used a treatment algorithm (Fig. 2) similar to that described by Abramo et al.[23]. Patients were taught finger range-of-motion exercises in the emergency department. Wrist range-of-motion exercises were started at the time of cast removal. During the study period, radiographic data were classified as acceptable or not acceptable according to the predetermined treatment algorithm (with acceptable being defined as dorsal tilt of <10° and >−20°, radial inclination of >10°, positive ulnar variance of <2 mm, and intra-articular step-off of <2 mm). All images were digitally acquired with use of the Picture Archiving and Communication System (PACS) (Impax; Agfa), and all radiographic measurements were made by the first author (V.S.).

Implants and Surgery

Patients with fractures that remained displaced (according to the limits described above) after reduction or that had redisplaced by the time of follow-up were offered surgical treatment with percutaneous pin fixation, external fixation, open reduction and internal fixation with anatomical plates, or a combined method at the discretion of the surgeon.

Outcomes

Clinical assessment was performed with use of the QuickDASH questionnaire to assess subjective functional outcome and quality of life at 1 year after the injury. The QuickDASH is a validated tool for measuring physical function and symptoms in patients with musculoskeletal disorders of the upper limb[24,25].

Grip strength was measured with the elbow in 90° of flexion, the forearm in neutral rotation, and the wrist in 0° to 30° of extension with use of a Jamar dynamometer in setting II[26]. The mean grip strength following 3 tests was recorded. Grip strength was adjusted by 10% for the nondominant hand[27]. The contralateral wrist was used as an internal control. The loss of grip strength was expressed in kilograms of force (kgf) by comparing the fractured wrist with the uninjured wrist.

Ranges of motion of the wrist and forearm were measured on both sides with use of a standard goniometer. The arcs of flexion-extension, pronation-supination, and radioulnar deviation were recorded. Total range of motion was calculated as the sum of these 3 ranges. The loss of range of motion in the fractured wrist was expressed in angular degrees as compared with the contralateral, uninjured wrist.

Independent occupational therapists, blinded to radiographic outcome, measured grip strength and range of motion[28].

Statistical Analysis

We used linear regression modeling for each outcome measure. The same variables (sex, age, dominant hand, whether the fracture had been operatively treated, dorsal tilt, radial inclination, and ulnar variance) were included in all 3 models. For grip strength and QuickDASH outcomes, we also included the grip strength of the uninjured hand in the model. For range-of-motion outcomes, the model also included the total range of motion on the uninjured side. Continuous variables were evaluated for nonlinearity with use of analysis of variance (ANOVA). If nonlinearity was confirmed, the nonlinearity was modeled with restricted cubic splines with 3 to 7 knots, with the number of knots being chosen as the value with the minimum Akaike information criterion (AIC).

In addition, a trichotomized or dichotomized analysis was performed for each variable to allow comparison of our results with those from previous studies and clinical practice.

All analyses were performed with R version 4.1.2 (R Foundation for Statistical Computing), with use of the rms package (v. 6.2.0) for regression modeling and contrasts, knitr (v. 1.36) for reproducible

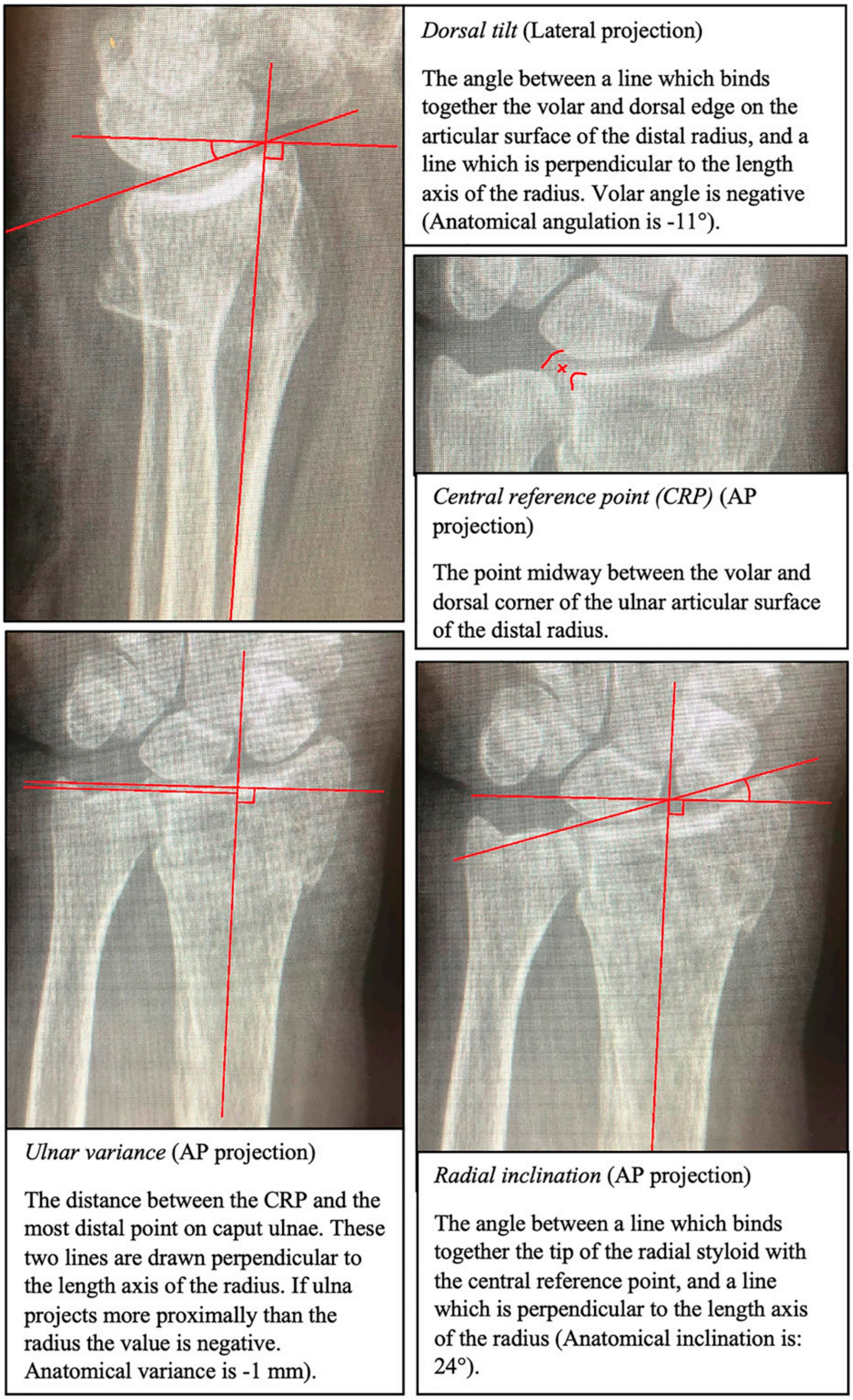

Fig. 1

Radiographic measurements. AP = anteroposterior.

research, ggplot2 (v. 3.3.5) for plots, and Gmisc (v. 2.2.0) with Greg (v. 1.4.0) for table output.

Source of Funding

No external funding was received for this study.

Results

Patients and Descriptive Data

Four hundred and sixty-four fractures in 451 patients were enrolled in the study after informed consent was obtained. Thirteen patients with bilateral fractures were excluded, leaving

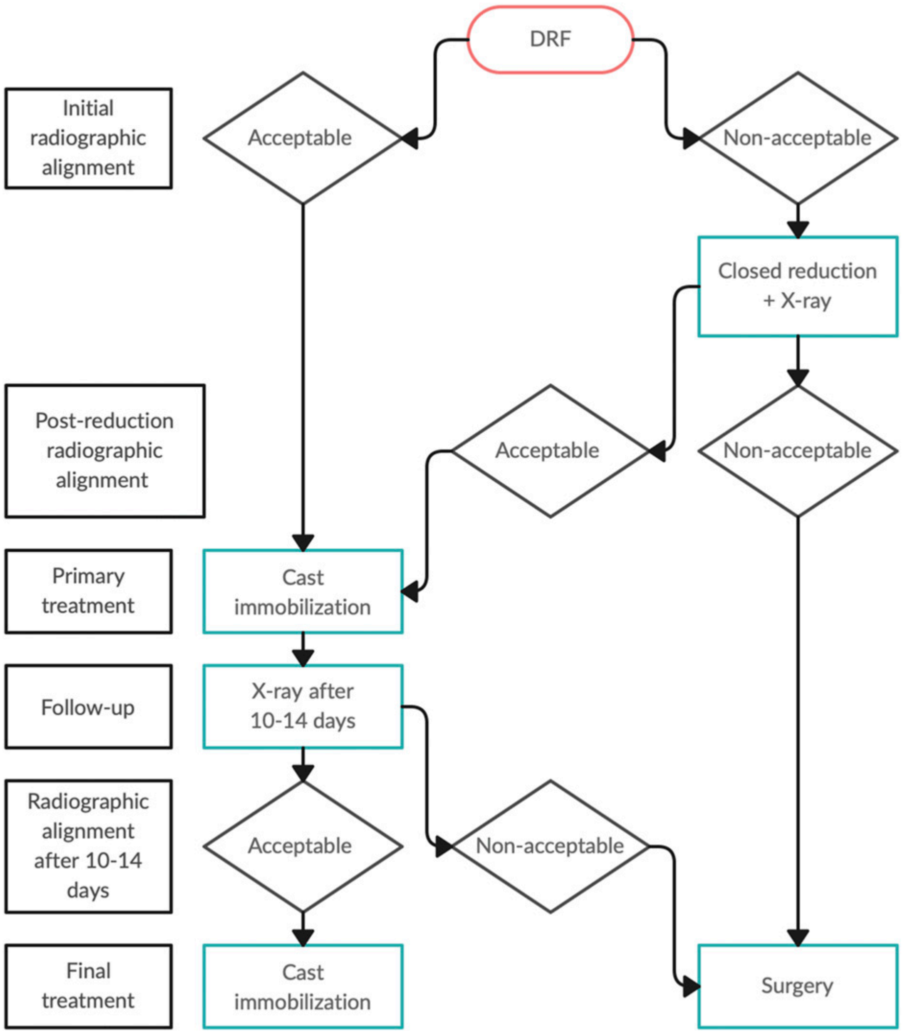

Fig. 2

Treatment algorithm used in the present study. DRF = distal radial fracture.

a final sample of 438 patients. Of these 438 patients, 72 were lost to follow-up (42 because of incomplete clinical follow-up and 30 because of incomplete radiographic follow-up). Thus, 366 patients (84%) had complete follow-up with both radiographic evaluation at 3 months and clinical evaluation at 1 year (Fig. 3).

The study group included 289 women (79%) and 77 men (21%), with a mean age of 57 years (range, 18 to 75 years) (Table I). Ninety-six percent of the patients were right-handed, and 56% sustained the injury on the nondominant side. Most patients (58%) were treated nonoperatively. Fixation with a volar locking plate was the most common surgical method (43%), followed by percutaneous pin fixation (34%), external fixation (15%), dorsal locking plate (4%) and a combination of methods (4%).

Patient-Reported Outcome Measures

The median QuickDASH score was 14 for women and 7 for men. We found a nonlinear relationship between the QuickDASH score at 1 year and dorsal tilt, and the effect of malalignment was significant at ≥6° of dorsal tilt (Fig. 4). The QuickDASH score increased (indicating perception of greater disability) with increasing dorsal tilt. The minimum clinically important difference (MCID), which is 10 points for the QuickDASH, was not attained until malunion involving 20° of dorsal tilt (Fig. 4, Table II). Furthermore, we found a significant association between the QuickDASH score and ulnar variance (Tables III and IV). Dorsal tilt was the radiographic parameter that was most strongly associated with the QuickDASH score with a partial sum of squares that was 4 to 30 times higher than the other analyzed radiographic parameters.

Grip Strength

We found a nonlinear relationship between grip strength at 1 year and dorsal tilt, and the effect of malalignment was significant at ≥10° of dorsal tilt (Fig. 5). Grip strength decreased with increasing dorsal tilt. Median grip strength was 11% less on the injured side as compared with the uninjured side (Table I). The median grip strength was 25 kgf on the injured side, compared with 28 kgf on the uninjured side.

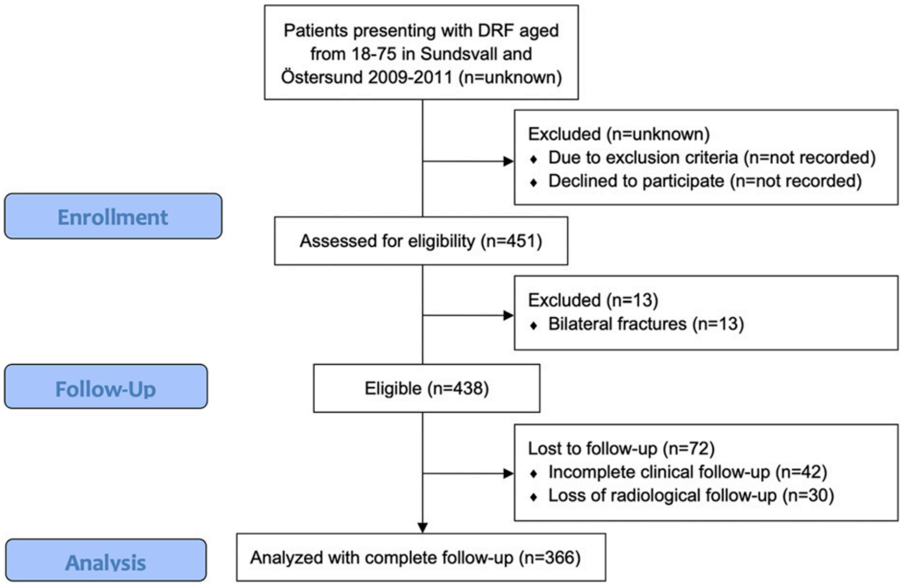

Fig. 3

Flowchart of patients included in the study. DRF = distal radial fracture.

TABLE I Base Data on Participants and Nonparticipants*

	Participants (N = 366)	Non-participants (N = 72)†
Baseline variable		
Female sex *(no. of patients)*	289 (79%)	42 (58%)
Age *(yr)*	59 (52 to 66)	57 (42 to 64)
Right-hand dominant *(no. of patients)*	339 (96%)	47 (90%) of 52
Injured dominant side *(no. of patients)*	157 (44%) of 353	25 (48%) of 52
Treatment *(no. of patients)*		
Cast	214 (58%)	43 (60%)
Percutaneous pin fixation	52 (14%)	14 (19%)
Volar plate	65 (18%)	13 (18%)
Dorsal plate	6 (2%)	0 (0%)
External fixation	23 (6%)	1 (1%)
Combined fixation	6 (2%)	1 (1%)
Radiographic findings		
Dorsal tilt *(deg)*	1 (−5 to 11)	4 (−5 to 11)
Radial inclination‡ *(deg)*	19 (16 to 23)	18 (15 to 22)
Ulnar variance‡ *(mm)*	0 (−1 to 2)	0 (−1 to 2)
Outcomes at 12 months		
QuickDASH	11 (2 to 27)	6 (0 to 13)
Grip strength, uninjured hand *(kgf)*	28 (22 to 34)	28 (22 to 40)
Grip strength, injured hand *(kgf)*	25 (19 to 30)	28 (22 to 38)
Total range of motion, uninjured hand *(deg)*	355 (335 to 370)	370 (342 to 372)
Total range of motion, injured hand *(deg)*	330 (310 to 350)	335 (315 to 350)

*Population statistics for 366 patients. Continuous variables are presented as the median and interquartile range. †Nonparticipants were not different from participants, except that they were younger (p = 0.019) and more likely to be male (p = 0.003). ‡Measured from the central reference point.

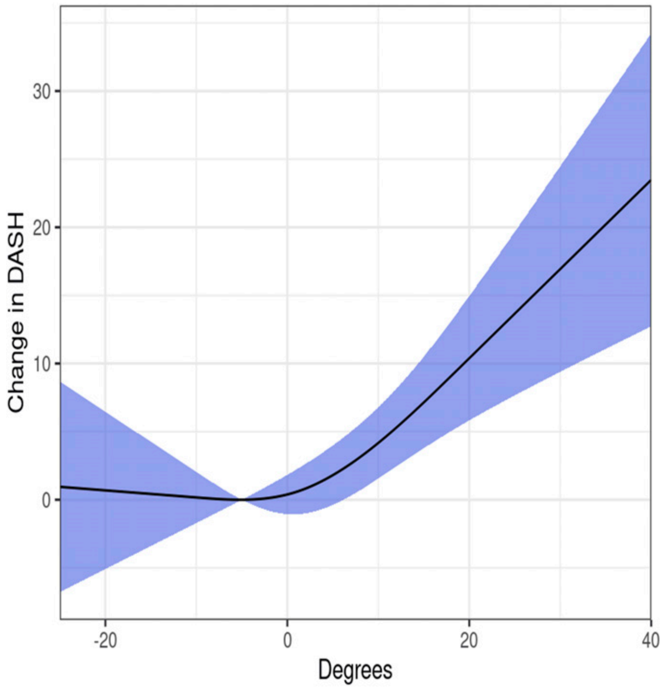

Fig. 4

Change in QuickDASH at 1 year after fracture versus final radiographic tilt (according to the adjusted regression coefficient). A change of 0 represents the baseline value at 1 year, and a negative tilt represent volar tilt. The black curve represents the mean change, and the blue area represents the 95% confidence interval (CI). The lower bound of the 95% CI crosses 0 at a tilt of 6.2° (corresponding to a QuickDASH of 2.3 [95% CI, 0.0 to 4.6]).

Range of Motion

We found a nonlinear relationship between range of motion at 1 year and dorsal tilt, and the effect of malalignment was significant at ≥4° of dorsal tilt (Fig. 6). Increased dorsal tilt was associated with decreased range of motion. Median total range of motion was 7% less on the affected side as compared with the uninjured side (Table I). Volar tilt was also significantly associated with a decrease in total range of motion (Fig. 6).

Categorized Outcome Data

To compare our results with those from previous studies[10] and clinical practice, we performed a dichotomized analysis in which we categorized our data with use of the definition for acceptable alignment in the Swedish National Guidelines[9,29].

Fractures outside national guideline recommendations (Table V) scored significantly worse in the complementary dichotomized analysis (Table IV).

Radiographic Analysis

The reliability of radiographic measurements varies[30]. The ICC (intraclass correlation coefficient), calculated to determine intrarater reliability with use of the radiographs for 25 patients, was 0.97 (excellent) for dorsal tilt, 0.94 (excellent) for radial inclination, 0.89 (good) for ulnar variance, and 0.76 (good) for intra-articular step-off, with 1 year between measurements.

Discussion

The present study demonstrated a nonlinear relationship between dorsal tilt and clinical outcome. Although clinical outcome after a distal radial fracture was significantly associated with increased dorsal tilt starting at 5°, the association was not clinically important at values of <20°. From anatomic alignment to approximately 5° of dorsal tilt, the malalignment did not seem to be associated with any measured outcome parameter.

We cannot draw any conclusions regarding whether patients with greater malalignment would benefit from surgical treatment, as any benefit of intervention must substantially outweigh the harm that it potentially causes. Surgical treatment could have varying implications depending on the functional demands and hand dominance of the individual patient.

We found that dorsal malunion was associated with patient-rated disability (as measured with the QuickDASH) 1 year after a distal radial fracture. There is no clear consensus in the literature, with several authors finding that dorsal tilt had a significant effect on patient-reported outcome measures (PROMs)[12-16] and others finding that it did not[11,17,18]. Likewise,

TABLE II Change in QuickDASH, Grip Strength, and Range of Motion According to Dorsal Tilt*

	QuickDASH		Grip Strength *(kgf)*		Range of Motion *(deg)*	
Dorsal Tilt *(deg)*	Regression Coefficient	95% CI	Regression Coefficient	95% CI	Regression Coefficient	95% CI
−20.0	0.3	−6.9 to 7.5	−1.1	−3.5 to 1.2	−12.1	−23.0 to −1.3
−10.0	−0.2	−3.5 to 3.1	−0.4	−1.5 to 0.7	−2.3	−6.3 to 1.7
0.0	Ref.	—	Ref.	—	Ref.	—
10.0	3.8	2.1 to 5.5	−1.0	−1.6 to −0.4	−10.4	−15.2 to −5.5
20.0	10.0	5.5 to 14.5	−3.1	−4.7 to −1.5	−21.4	−27.6 to −15.3
30.0	16.5	8.8 to 24.3	−5.3	−8.0 to −2.5	−32.4	−43.7 to −21.0

*Estimates at different dorsal tilt degrees according to a linear regression estimate.

TABLE III Variation in QuickDASH, Grip Strength, and Range of Motion by Linear Regression with No Nonlinear Terms*

	Crude		Adjusted	
Outcome and Predictors	Regression Coefficient	95% CI	Regression Coefficient	95% CI
QuickDASH (R^2 = 0.18)				
General				
Male	**−5.0**	**−9.4 to −0.6**	2.7	−5.0 to 10.3
Age, per yr	**2.3**	**0.9 to 3.7**	0.4	−1.2 to 2.0
Measurements				
Radial inclination, per 10°	−3.3	−6.7 to 0.1	−1.6	−5.1 to 1.9
Ulnar variance from CRP, per mm	**2.1**	**1.2 to 3.0**	**1.1**	**0.2 to 2.0**
Other				
Injured dominant side	1.0	−2.6 to 4.7	1.1	−2.3 to 4.6
Surgery	2.5	−1.2 to 6.2	3.2	−0.5 to 6.9
Grip strength, in kgf (R^2 = 0.76)				
General				
Male	**19.5**	**17.3 to 21.7**	**2.8**	**0.4 to 5.2**
Age, per yr	**−3.4**	**−4.3 to −2.5**	−0.5	−1.0 to 0.1
Measurements				
Radial inclination, per 10°	**2.3**	**0.0 to 4.6**	0.6	−0.7 to 1.8
Ulnar variance from CRP, per mm	−0.9	−1.5 to −0.3	−0.2	−0.5 to 0.1
Other				
Grip strength on uninjured side	**0.8**	**0.8 to 0.9**	**0.7**	**0.6 to 0.8**
Injured dominant side	2.0	−0.4 to 4.5	**2.7**	**1.4 to 3.9**
Surgery	**−3.6**	**−6.1 to −1.2**	**−2.7**	**−4.0 to −1.4**
Range of motion, in deg (R^2 = 0.61)				
General				
Male	**−14.0**	**−22.5 to −5.5**	**−9.1**	**−15.0 to −3.1**
Age, per yr	**−9.0**	**−11.6 to −6.3**	−1.4	−3.5 to 0.7
Measurements				
Radial inclination, per 10°	**8.5**	**1.8 to 15.2**	3.4	−1.3 to 8.2
Ulnar variance from CRP, per mm	**−3.3**	**−5.1 to −1.5**	−0.8	−2.1 to 0.5
Other				
Injured dominant side	**−13.6**	**−20.6 to −6.5**	**−6.9**	**−11.6 to −2.1**
Surgery	**0.8**	**0.7 to 0.9**	**−16.4**	**−21.4 to −11.3**

*Linear analysis of the effect of each variable on QuickDASH, grip strength, and range of motion 1 year after injury, without any nonlinear elements. Negative values for ulnar variance represent the ulna projecting more proximally than the radius. CI = confidence interval, and CRP = central reference point. Values in bold denote significant differences.

conflicting conclusions have been drawn regarding the relationship between ulnar variance and PROMs[12-18].

What all previous reports have in common is that they involved a linear or a dichotomized analysis (Table VI). The present study analyzed nonlinear associations. Mulders et al., in a systematic review and meta-analysis regarding radiographic and patient-reported outcomes, found that dorsal tilt (470 patients) and ulnar variance (471 patients), dichotomized into acceptable or not acceptable, were the 2 factors with a significant association with PROMs10. Those findings are consistent with our findings.

Brogren et al. reported similar findings, with dorsal tilt being significantly associated with a poorer DASH score (mean difference, 9 points)[31].

Plant et al., in a linear analysis involving 50 patients, found that PROMs and physical measures of function correlated poorly with radiographic parameters[32]. There was no relationship between radiographic parameters and grip strength, range of motion, or DASH scores at 1 year after a distal radial fracture. Wilcke et al., in a study of 78 patients, found no linear relationships but did find significant relationships with DASH scores when the degrees of malunion were dichotomized into acceptable or not acceptable[15]. Finsen et al. found a linear relationship when they excluded all patients with a volar tilt of ≥5°[33].

Alignment deteriorates in 2 directions (volar and dorsal). As such, it is not surprising that previous studies have

TABLE IV Data Categorized by Limits of Acceptable Radiographic Parameters as Defined by Swedish National Guidelines*

Outcome and Predictors	Dorsal Malunion (≥10°) (N = 98)	Acceptable (<10° and >–15°) (N = 257)	Volar Malunion (≤–15°) (N = 11)	Crude		Adjusted	
				Regression Coefficient	95% CI	Regression Coefficient	95% CI
Dorsal tilt							
QuickDASH *(points)*	22 (18)	16 (10)	14 (5)				
Dorsal malunion†				**6.6**	**2.6 to 10.7**	**6.2**	**2.1 to 10.3**
Volar malunion†				–2.0	–13.0 to 9.0	–4.5	–15.6 to 6.6
Grip strength *(%)*	83 (86)	90 (91)	92 (92)				
Dorsal malunion†				**–0.07**	**–0.13 to –0.01**	**–0.07**	**–0.13 to –0.01**
Volar malunion†				0.01	–0.14 to 0.16	0.01	–0.14 to 0.17
Range of motion *(%)*	93 (94)	95 (96)	90 (89)				
Dorsal malunion†				**–0.02**	**–0.04 to –0.00**	**–0.02**	**–0.04 to –0.00**
Volar malunion†				**–0.05**	**–0.09 to –0.01**	**–0.05**	**–0.09 to –0.00**

Parameter	Extra-Articular (N = 214)	<2 mm (N = 146)	≥2 mm (N = 6)	Crude		Adjusted	
				Regression Coefficient	95% CI	Regression Coefficient	95% CI
Intra-articular step-off							
QuickDASH *(points)*	16 (11)	18 (11)	27 (30)				
<2 mm‡				2.1	–1.6 to 5.8	2.7	–1.0 to 6.4
>2 mm‡				10.4	–3.9 to 24.7	8.4	–5.5 to 22.4
Grip strength *(%)*	90 (91)	87 (90)	69 (71)				
<2 mm‡				–0.04	–0.09 to 0.01	–0.04	–0.09 to 0.01
>2 mm‡				**–0.21**	**–0.41 to –0.01**	**–0.20**	**–0.40 to –0.00**
Range of motion *(%)*	95 (96)	93 (94)	90 (86)				
<2 mm‡				**–0.02**	**–0.03 to –0.00**	**–0.02**	**–0.03 to –0.00**
>2 mm‡				–0.05	–0.11 to 0.01	–0.05	–0.11 to 0.01

Parameter	<2 mm (N = 305)	≥2 mm (N = 61)	Crude		Adjusted	
			Regression Coefficient	95% CI	Regression Coefficient	95% CI
Ulnar variance						
QuickDASH *(points)*	16 (11)	24 (18)	**8.3**	**3.4 to 13.1**	**7.4**	**2.4 to 12.5**
Grip strength *(%)*	89 (91)	87 (87)	–0.02	–0.08 to 0.05	0.00	–0.07 to 0.07
Range of motion *(%)*	95 (96)	92 (93)	**–0.02**	**–0.04 to –0.00**	–0.01	–0.03 to 0.01

Parameter	≥15° (N = 305)	<15° (N = 61)	Crude		Adjusted	
			Regression Coefficient	95% CI	Regression Coefficient	95% CI
Radial inclination						
QuickDASH *(points)*	17 (11)	18 (16)	–0.7	–5.6 to 4.2	2.8	–2.1 to 7.8
Grip strength *(%)*	89 (91)	86 (87)	0.03	–0.03 to 0.10	0.00	–0.07 to 0.08
Range of motion *(%)*	94 (95)	94 (94)	0.00	–0.01 to 0.02	–0.01	–0.03 to 0.01

	Minimally Displaced (N = 202)	Displaced (N = 164)	Crude		Adjusted	
			Regression Coefficient	95% CI	Regression Coefficient	95% CI
Fracture displacement, any						
QuickDASH *(points)*	14 (9)	21 (16)	**6.8**	**3.2 to 10.4**	**6.0**	**2.4 to 9.6**
Grip strength *(%)*	91 (92)	86 (87)	–0.05	–0.10 to 0.00	–0.05	–0.10 to 0.01
Range of motion *(%)*	95 (96)	93 (94)	**–0.03**	**–0.04 to–0.01**	**–0.03**	**–0.04 to–0.01**

*The values in the second, third, and fourth columns are given as the mean, with the median in parentheses. Values in bold in the subsequent columns denote significant differences. CI = confidence interval. †Reference = acceptable. ‡Reference = extra-articular.

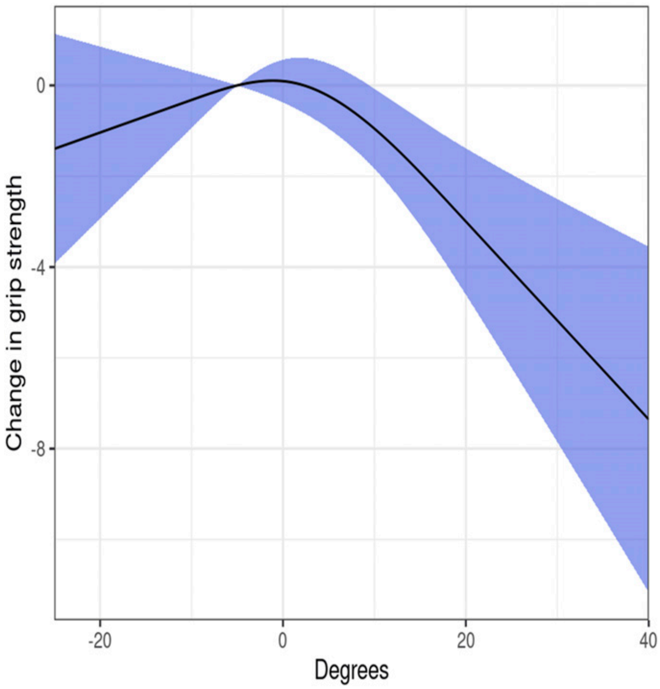

Fig. 5

Change in grip strength (in kgf) at 1 year after fracture versus final radiographic tilt (according to the adjusted regression coefficient). A change of 0 represents the baseline value at 1 year, and a negative tilt represent volar tilt. The black curve represents the mean change, and the blue area represents the 95% confidence interval (CI). The upper bound of the 95% CI crosses 0 at a tilt of 9.5° (corresponding to a QuickDASH of −0.9 [95% CI, −1.7 to 0.0]).

demonstrated significance for dichotomized data but have found no linear relationships, given that the expected relationship is nonlinear. Our data confirm that alignment deteriorates in 2 directions as we found nonlinear relations. These relationships were demonstrated in our U-shaped curves, with better outcomes being associated with anatomical alignment (Figs. 4, 5, and Fig. 6). The relationship is visually comprehensive when viewing the curve for dorsal tilt and range of motion (Fig. 6), with both increasing volar and increasing dorsal tilt being associated with a significantly decreased range of motion. Thus, our findings support those of Plant et al., Wilcke et al., and Finsen et al.[15,32,33].

Grip strength is a simple, noninvasive marker of function and is well suited for clinical use. Bobos et al. reported a clinically meaningful improvement in grip strength for up to 1 year[34]. However, Brogren et al. and Landgren et al. found continued improvement at up to 2 to 4 years[35,36]. Cowie et al. found that dorsal tilt was associated with a decrease in grip strength[18].

We found that grip strength correlated with dorsal tilt and that the decline became significant at 10°. Dias et al. found that an abnormal capitate shift occurred with >9° of dorsal tilt, affecting the mechanical axis of the carpal bones[37]. McQueen reported that carpal malalignment had a significant association with diminished recovery in grip strength after 1 year[38]. Our results seem to be in line with those findings. We found that grip strength was 11% (3 kgf) less on the affected side, but we do not know whether this difference is clinically important.

Total range of motion after a distal radial fracture recovers over time, with marginal improvement after 1 year[35]. We found that dorsal tilt of ≥4° was associated with a decrease in range of motion compared with the uninjured side and that increased tilt was associated with decreased range of motion (Fig. 6, Table II). The median total range of motion decreased by 7% on the injured side as compared with the uninjured side; we do not know whether this difference is clinically important. From this observation, we conclude that, in order to minimize the risk of a stiffening wrist, a dorsal tilt of <4° should be the goal. Volar tilt from an anatomical position resulted in a decrease in range of motion (Fig. 6). The low number of patients healing with volar malunion (n = 11) may explain why no significant associations were found when analyzing volar malunion with regard to the QuickDASH score and grip strength.

The cutoff to distinguish satisfaction from dissatisfaction occurs when younger patients recover 65% of grip strength and 95% of range of motion and when older patients recover 59% of grip strength and 79% of range of motion[39,40].

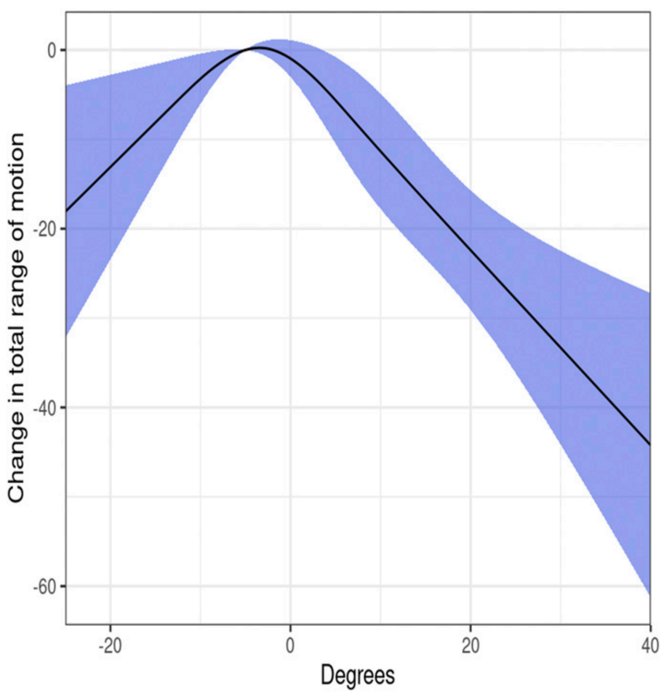

Fig. 6

Change in total range of motion (in degrees) at 1 year after fracture versus final radiographic tilt (according to the adjusted regression coefficient). A change of 0 represents the baseline value at 1 year, and a negative tilt represent volar tilt. The black curve represents the mean change, and the blue area represents the 95% confidence interval (CI). The upper bound of the 95% CI crosses 0 at tilts of −7.5° (corresponding to a QuickDASH of −1.2 [95% CI, −2.5 to 0.0]) and 3.6° (corresponding to a QuickDASH of −4.1 [95% CI, −8.2 to 0.0]).

TABLE V Acceptable Dorsal Tilt According to National Guidelines

National Guidelines (Year)	Dorsal Tilt	Comment
U.K. (2018)	10°	20° for age >75 yr
U.S. (2021)	10°	Guidelines do not recommend surgery for age >65 yr
Netherlands (2021)	10°	Guidelines do not recommend surgery for patients with low functional demands or short life expectancy
Norway (2015)	10°	Recommends restraint in patients with a low functional level
Denmark (2016)	10°	Recommends cautiousness regarding surgery in patients with a low level of function
Finland (2016)	15°	Guidelines do not recommend surgery for age >65 yr
Sweden (2021)	10°	20° for intermediate functional demands, and the guidelines do not recommend surgery for low functional demands

Positive ulnar variance was associated with worse QuickDASH scores but was not associated with grip strength or range of motion (Tables III and IV). Although positive ulnar variance may result in a painful ulnar impaction syndrome[41], it may have less effect on the mechanical axis of the wrist and thus on grip strength and range of motion. A possible explanation for why ulnar variance was found to have important effects on grip strength and range of motion in earlier studies is that their use of the dorsalmost radiolucent corner of the bone, rather than the central reference point[42] as in the present study, resulted in ulnar variance measurements that indirectly measured dorsal tilt as well[43].

In the present study, radial inclination was not significantly associated with either objective or subjective outcome measures (Tables III and IV). This finding is consistent with the conclusions reported in the meta-analysis by Mulders et al.[10].

Two previous studies showed no significant relationship between intra-articular step-off on final radiographs and functional outcome[44,45]. However, an increased risk of radiocarpal osteoarthritis has been reported after healing with an intra-articular step-off[44-46]. Nevertheless, no significant relationship between the posttraumatic radiocarpal osteoarthritis and worse outcome has been demonstrated after a distal radial fracture[44,46]. This may be because patients with a large step-off are uncommon, resulting in low statistical power. For example, of the 366 patients in our study, only 6 had a step-off of >2 mm at 3 months (Table IV). A larger cohort and longer follow-up are needed to increase our understanding of the impact of intra-articular step-off.

The outcome after distal radial fracture is multifactorial and depends on more than radiographic findings alone. Finsen et al., in a retrospective cohort study of 214 patients, reported that only 7% of the variability of QuickDASH scores was due to radiographic factors[33]. In the present study, dorsal tilt accounted for 5% of the variability of QuickDASH scores at 1 year. Jayakumar et al., in a prospective study of 364 patients, found that 80% of the variability in QuickDASH scores could

TABLE VI Compilation of Studies Assessing the Relationship Between Dorsal Tilt and Clinical Outcome with PROMs

Author	Year	Type of Study	Analysis	Population	Relationship Found	Conclusion
Mulders et al.[10]	2018	Systematic review, meta-analysis	Dichotomized	470 to 471	Dichotomized relationship	Worse PROM* with unacceptable dorsal tilt (mean difference of 5).
Plant et al.[32]	2017	Prospective	Linear	50	No linear relationship	Radiographic parameters correlated poorly with functional outcomes. Volar tilt correlated to the greatest extent.
Wilcke et al.[15]	2007	Retrospective	Dichotomized and linear	78	Dichotomized relationship, no linear relationship	Weak or insignificant linear correlations. However, dorsal tilt >15° significantly associated with poorer DASH score (mean difference, 10).
Brogren et al.[35]	2011	Prospective	Dichotomized	143	Dichotomized relationship	Dorsal tilt >10° significantly associated with poorer DASH score (mean difference, 9).
Finsen et al.[33]	2013	Retrospective	Linear	260	Linear relationship (excluded those with a volar tilt of ≥5°)	Significant correlation of PRWE and QuickDASH scores with unacceptable dorsal tilt.

*Measured with DASH/QuickDASH/PRWE (Patient-Rated Wrist Evaluation).

be explained by psychological and social factors assessed early after the injury[47]. Some other relevant factors are income level14, injury compensation[48], length of education[49], and physiotherapy[50].

The main strengths of the present study are the prospective multicenter design, the large sample size, and the use of well-validated objective outcome measures. The study was strengthened by the analysis of fracture tilt as a continuous variable, enabling the use of cubic splines to assess nonlinear effects of tilt on the outcomes.

The present study also had some limitations. We analyzed outcomes at 1 year; however, improvement in PROMs continues for up to 2 to 4 years[35]. Nevertheless, only a limited number of participants (16%) were lost to follow-up. The QuickDASH score may reflect disability related to upper-extremity disorders involving locations other than the wrist. Still, the DASH and QuickDASH tools have been shown to be reliable and valid for the evaluation of outcomes following distal radial fracture[24,25]. The absence of more sensitive PROMs for evaluating distal radial fractures is also a limitation. Both operatively and nonoperatively treated patients were included in our cohort. However, our statistical model compensated for this potential weakness. The curves in the figures are easy to misinterpret; for example, Figure 4 does not show the actual QuickDASH value for a given dorsal tilt, but rather how much the QuickDASH values for particular patients, given their individual predisposing factors, would be expected to worsen with that value of dorsal tilt. Furthermore, this work provides guidance and should not be considered prescriptive. It is known that the reliability of radiographic measurements varies[30]; however, in this study, the reliability was found to be good to excellent. Injury to the dominant hand may also affect the results; thus, this was included in our models.

The shape of the distal radioulnar joint was not assessed in this study, inhibiting our ability to draw definitive conclusions regarding the association between ulnar variance and outcomes. The shape of the distal radioulnar joint could be important in terms of the association of tilt and length with outcome data-sharing statement, but this was not the focus of the present study.

In conclusion, the present study showed that clinical outcomes following distal radial fractures have a nonlinear relationship with dorsal tilt, with worse outcomes being associated with increasing dorsal tilt. The decline in clinical outcome starts at 5°, but based on the MCID, there is unlikely to be a noticeable difference in capability as measured with the QuickDASH until 20° of dorsal tilt in a population of patients up to 75 years old. In addition, dorsal angulation only accounted for a limited amount of variation in capability at 1 year. However, malalignment could have varying implications depending on the functional demands of the patient, and no conclusions regarding surgical benefit can be drawn from the present study. The results of the present study could be used to help clinicians inform patients of expected outcomes but they cannot be used to determine thresholds for acceptable alignment. ■

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