Evaluation of Risk Factors for Loss of Acceptable Alignment for Distal Radius Fractures That Are Nondisplaced or Minimally Displaced on Initial Presentation

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Purpose Numerous studies have evaluated risk factors for loss of acceptable radiographic alignment, as described by the American Academy of Orthopaedic Surgeons Clinical Practice Guidelines (CPG), following closed reduction of distal radius fractures (DRFs). Less is known about DRFs that are well aligned on initial presentation and do not require closed reduction. We evaluated the rate of and risk factors for displacement of DRFs that are nondisplaced or minimally displaced on initial presentation.

Methods This retrospective cohort study identified patients with nondisplaced or minimally displaced DRFs seen at a single academic tertiary center between 2015 and 2019. DRFs that required a reduction or initial surgical treatment based on the American Academy of Orthopaedic Surgeons CPG and those with a volar shear pattern were excluded. We recorded standard radiographic measurements on presentation and wrist radiographs after 6 weeks. Univariate and binary multivariable logistic regression analyses evaluated associations between sex, age, the presence of dorsal comminution, intra-articular involvement, associated ulnar fractures, and minimal displacement (vs nondisplacement on initial radiographs) with loss of acceptable alignment.

Results Of the 110 included patients, 72% were female and the mean age was 52 years (SD, 17 years). Overall, 33 (30%) had displacement beyond the AAOS CPG criteria at 6 weeks. A multivariable analysis demonstrated that the presence of dorsal comminution (odds ratio, 37.8) and age >60 years (odds ratio, 3.6) were significantly associated with loss of acceptable alignment, whereas sex, intra-articular involvement, associated ulnar styloid/neck fractures, and minimal displacement were not associated.

Conclusions For DRFs that were initially nondisplaced or minimally displaced, the overall rate of unacceptable radiographic displacement at 6 weeks was 30%. Dorsal comminution and age >60 years were both independently associated with displacement, suggesting that patients with these risk factors may warrant closer follow-up than those without risk factors. *(J Hand Surg Am. 2022;47(1):54−61. Copyright © 2022 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Diagnostic IV.

Key words Distal radius fracture, late displacement, loss of reduction, radiographic alignment, wrist fracture.

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Distal radius fractures (DRFs) are common injuries, with over 640,000 in 2001 in the United States alone, and account for 2.5% of all emergency department visits.[1] This number has continued to increase over the last 40 years.[1] Treatment options for these fractures are influenced by radiographic displacement and patient-specific factors, and include orthosis/cast immobilization without reduction, closed reduction followed by immobilization, and operative fixation. The American Academy of Orthopaedic Surgery (AAOS) Clinical Practice Guidelines (CPG) for DRFs have defined criteria for unacceptable alignment, for which they recommend operative fixation as opposed to nonsurgical treatment with immobilization.[2] Specifically, these criteria include radial shortening >3 mm, dorsal tilt >10°, and intra-articular displacement or step-off >2 mm.[2]

For displaced fractures that undergo initial treatment with closed reduction and immobilization, prior studies have established risk factors that predispose patients to a loss of acceptable alignment, which may in turn lead to the need for surgical intervention or to worse clinical outcomes if neglected. LaFontaine et al[3] initially described 5 risk factors for instability in DRFs treated with closed reduction, which included initial dorsal angulation >20°, dorsal comminution, intra-articular involvement, associated ulnar fracture, and age >60 years. Numerous studies since then have sought to further clarify risk factors for displaced DRFs requiring closed reduction. Nesbitt et al[4] prospectively studied fractures defined as unstable per the LaFontaine criteria and found that only age was a significant predictor of losing reduction. A recent meta-analysis by Walenkamp et al[5] identified female sex, age 60 to 65 years, and dorsal comminution as factors that consistently have been associated with fracture displacement and a need for operative fixation following closed reduction. In addition to these traditionally described factors, Ghodasra et al[6] recently explored the role of osteoporosis, finding an increased risk of displacement of nonoperatively treated DRFs in patients with low bone mineral density.

Although extensive research has gone into predicting which patients lose alignment after closed reduction, many fractures initially present with nondisplaced or minimally displaced alignment and do not require closed reduction. In this subset of patients, it remains unclear how frequently acceptable alignment is lost. Further, risk factors for displacement beyond acceptable alignment are yet to be elucidated for this subset of DRFs. Identifying the overall incidence of loss of acceptable radiographic alignment and knowledge of predictive factors to identify which DRFs are at highest risk for failure of nonsurgical treatment will help guide clinical and radiographic follow-up. These findings may have implications for patient counseling, clinical decision-making, functional outcomes, and the overall cost of DRF treatment.

Therefore, the primary purpose of this study was to evaluate the overall incidence of displacement beyond acceptable radiographic alignment parameters for patients presenting with DRFs that are initially well aligned without need for a closed reduction, based on the AAOS CPG. The secondary purpose was to evaluate possible risk factors for displacement beyond acceptable radiographic alignment in this patient population.

MATERIALS AND METHODS

This retrospective cohort study was completed at an academic Level 1 Trauma Center over a 4-year period from January 2015 to December 2019, following institutional review board approval by the University of Utah. Patients were initially identified via an electronic search for distal radius fracture using ICD-9 (813 and all subcategories) and ICD-10 codes (S52.5 and all subcategories). Adult patients (age $\geq$ 18 years) with isolated nondisplaced or minimally displaced DRFs (Arbeitsgemeinschaft für Osteosynthesefragen classifications 23-A2, 23-A3, B-1, and C1-3) were considered for inclusion through manual review of presenting radiographs. Having nondisplacement or minimal displacement was defined as presenting radiographic alignment within the AAOS CPG guidelines for nonsurgical treatment, without closed reduction prior to orthosis fabrication (dorsal tilt $\leq$ 10°, step-off $\leq$ 2 mm, or radial shortening $\leq$ 3 mm).[2] A minimum of 5 weeks of radiographic follow-up after initial injury was required. As the care pathway at our institution is set up such that all DRFs are managed by orthopedics, a follow-up visit with an orthopedic provider (hand, trauma, and nonsurgical sports) was also required for inclusion.

Patients with volar or dorsal shear fracture patterns (Arbeitsgemeinschaft für Osteosynthesefragen 23-B2 and 23-B3), isolated radial styloid fractures, or open injuries were excluded. Also excluded were those who underwent a closed reduction in the emergency department or a primary surgical intervention (defined as an operative intervention within 2 weeks of presentation). Additional exclusion criteria included inadequate presenting and 6-week radiographs of the wrist (absence of both anteroposterior and lateral views), initial presentation >2 weeks from injury, initial unacceptable alignment according to the AAOS CPG, and previous DRF. Basic demographic information, including age, sex, and working status, was extracted from the history and physical, consultation notes, or the electronic medical record demographics section, where available. Age and sex data for patients excluded due to inadequate radiographs were compared to those of the included patient cohort using a *t* test and chi-square test, respectively.

Radiographic measurements were taken using Sectra PACS software with a calibrated virtual ruler rounded to the nearest 0.1 mm or 0.1° (IntelliSpace PACS Enterprise, Phillips). Measurements were made by 2 independent reviewers (K.E.S., P.J.K.). Standard radiographic measurements were used.[7] Radial height (RH), radial inclination (RI), and ulnar variance (UV) were measured on the anteroposterior radiograph. Volar tilt (VT) and dorsal comminution, defined as a free-floating piece of dorsal cortex of any size, were assessed on the lateral radiograph. For intra-articular fractures, the maximal amount of articular step-off (SO) was measured on both radiographic views, and the greater of the 2 was recorded. Ratios were not made to normalize the data given that wrist radiographs are taken per standardized protocol at a single institution using calibrated measurements. Ten randomly chosen patients were measured by both reviewers (K.E.S., P.J.K.), who were blinded to the other's measurements, to determine inter- and intra-observer reliability. Inter- and intra-observer reliability were determined using the intraclass correlation coefficient, where 0 to 0.5 represents poor agreement, 0.51 to 0.75 represents fair agreement, 0.76 to 0.9 represents good agreement, and 0.9 to 1 represents excellent agreement.

Basic descriptive statistics were calculated for demographic and radiographic measurement variables. Paired equivalence testing was performed to determine whether changes in alignment parameters between initial and follow-up radiographs exceeded published margins of measurement error.[8] Specifically, measurement errors of ±6° to 8° for VT, ±1° to 2° for RI, ±2 to 4 mm for UV, 4 to 6 mm for RH, and ±1 mm for SO have been reported in a recent systematic review.[8] Note that the null hypothesis for equivalence testing is that a difference exceeding the chosen threshold exists, and therefore significant *P* values ($P < .05$) signify equivalence within that threshold. We then evaluated whether patients had displacement beyond acceptable alignment on follow-up radiographs, which was defined as meeting

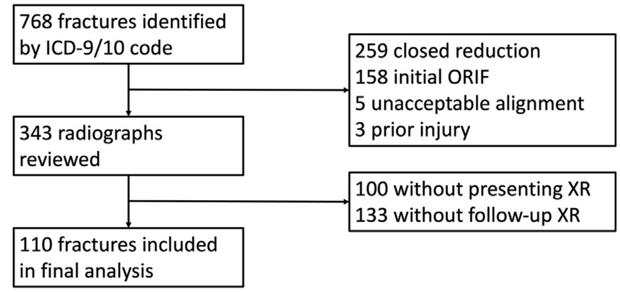

FIGURE 1: Flowchart of patient inclusion and exclusion. ORIF, open reduction internal fixation; XR, x-ray.

any 1 or more of the following parameters based on the AAOS CPG: dorsal tilt > 10°, SO > 2 mm, or RH < 8.5 mm (which is consistent with radial shortening >3 mm in light of normative values of 11.5 mm).[7,9,10]

We used univariate and multivariable binary logistic regression with a logit link function to evaluate for associations between loss of reduction and possible risk factors, including age >60 years, sex, the presence of dorsal comminution, non- versus minimal displacement, the presence versus absence of a concomitant ulnar styloid or neck fracture, and extra- versus intra-articular fracture patterns. Only variables that were statistically significant on univariate analysis (*P* value < .05) were included in a multivariable model that used backward term elimination with a cutoff α of 0.10. Performance characteristics of the multivariable model were assessed using the area under the curve (AUC) for the receiver operator characteristic curve using previously described methods and cutoff thresholds (AUC $\leq$ 0.5 indicates no discrimination; 0.7 $\leq$ AUC < 0.8 indicates acceptable discrimination, 0.8 $\leq$ AUC < 0.9 indicates excellent discrimination, and AUC $\geq$ 0.9 indicates outstanding discrimination).[11]

An *a priori* sample size estimate showed that 110 patients would be required to detect a change in VT of ±4.0° (which is less than the margin of measurement error of 6° to 8°) on the paired equivalence test, with an α of 0.05 and 80% power.[8] Statistical comparisons with *P* values < .05 were considered significant.

RESULTS

Using ICD-9/ICD-10 codes, 768 patients were identified. Of those, 259 had an initial closed reduction, 158 were initially treated with open reduction and internal fixation, 5 had unacceptable alignment but were being treated nonoperatively due to medical conditions, and 3 had a previous distal radius injury

TABLE 1. Demographic Information of Included Patients

Demographic Characteristic	n (%)
Age (y)	
≤60	70 (64%)
>60	40 (36%)
Sex	
Female	79 (72%)
Male	31 (28%)
Smoking	
Yes	14 (13%)
No	96 (87%)
Work status	
Working, nonlabor	42 (38%)
Working, labor	10 (9%)
Not working	42 (38%)
Unknown	16 (15%)

TABLE 2. Fracture and Treatment Characteristics of Included Patients

Characteristic	n (%)
Arbeitsgemeinschaft für Osteosynthesefragen fracture classification	
23-A2	48 (44%)
23-A3	43 (39%)
23-B1	11 (10%)
23-C1	7 (6%)
23-C2	1 (1%)
Fracture affecting dominant hand	
Yes	41 (37%)
No	37 (34%)
Unknown	32 (29%)
Fracture characteristics	
With dorsal comminution	45 (41%)
Without dorsal comminution	65 (59%)
Intra-articular extension	40 (36%)
Extra-articular	70 (64%)
Minimally displaced	61 (55%)
Nondisplaced	49 (45%)
Associated ulnar fracture	27 (25%)
No associated ulnar fracture	83 (75%)
Initial immobilization	
Orthosis	103 (94%)
Cast	5 (5%)
Brace	1 (1%)
Sling	1 (1%)
Treating physician specialty	
Hand	72 (65%)
Hand trauma	15 (14%)
Nonsurgical sports medicine	23 (21%)

(Fig. 1). Of the 343 eligible remaining patients, 133 were lost to follow-up and 100 did not have initial radiographs within 2 weeks of injury. Therefore, 110 patients were included in the analysis. The mean age was 52 years (SD, 17 years; range, 19−85 years; interquartile range, 40−66 years) and 72% were female (Table 1). On average, initial and follow-up radiographs were obtained 1.5 ± 2.8 days and 53 ± 38 days after the injury, respectively. For initial treatment, 94% received orthosis immobilization (noncircumferential plaster of Paris or fiberglass), 5% cast immobilization (circumferential fiberglass), <1% a removable wrist brace (fabric with metal insert), and <1% a sling without other immobilization (Table 2). No patients were converted to operative treatment prior to the 6-week follow-up. Patients were seen by either hand specialists (65%), hand trauma specialists (14%), or nonsurgical sports medicine physicians (21%). Additional fracture and treatment characteristics are reported in Table 2.

A comparison of the included patient cohort with the 233 patients who were excluded from the study due to a lack of initial radiographs within 2 weeks of injury or a lack of follow-up radiographs showed that the 2 groups had similar compositions in terms of age and sex. The average age of the excluded patient cohort was 49.0 years (SD, 20.5 years; $P = .16$) and 64.8% were female ($P = .20$).

Table 3 provides initial and follow-up radiographic measurements. Notably, at the level of the whole study sample, the VT, RH, UV, and RI were not displaced beyond the limits of reliable clinical detection. There was a mean loss of VT of 4.0° (range, −7° to 53°; average 6-week VT 1.7°), a loss of RH of 0.7 mm (range, −3 to 10.1 mm; average 6-week RH 10.7 mm), an increase in UV of 0.4 mm (range, −2.8 to 3.3 mm; average 6-week UV 1.2 mm), and loss of RI of 0.7° (range, −7° to 7°; average 6-week RI 23.2°). For intra-articular fractures, which comprised 36% of the cohort, initial and follow-up SO values were 0.89 ± 0.92 mm and 0.88 ± 0.83 mm, respectively, which were equivalent within a threshold of 0.5 mm ($P < .05$).

Of the whole cohort, 33 patients (30%) changed from having acceptable to unacceptable alignment per the AAOS CPG at follow-up, while 77 (70%) had

TABLE 3. Change in Radiographic Measurements From Presentation to 6-Week Follow-Up

Measurement	Presentation, Mean ± SD	6-Week Follow-Up, Mean ± SD	Paired Equivalence Test P Value*
VT	5.7° ± 7.7°	1.6° ± 12.4°	<.05
UV	0.8 ± 1.7 mm	1.2 ± 1.8 mm	<.05
RI	23.9° ± 4.5°	23.2° ± 4.9°	<.05
RH	11.4 ± 2.2 mm	10.7 ± 2.6 mm	<.05
SO†	0.89 ± 0.92 mm	0.88 ± 0.83 mm	<.05

*The following thresholds were used for paired equivalence testing: ±6° for VT, ±1° for RI, ±1 mm for UV, ±1 mm for RI, and ±0.5 mm for SO. A significant P value (<.05) is consistent with equivalence.

†Step-off values were derived only from intra-articular fractures.

alignment that remained within acceptable limits. Of those with loss of acceptable alignment at follow-up, 29 had unacceptable VT (mean change of 13.9°; range, 6°−53°), 4 had unacceptable SO (mean change of 0.5 mm; range, 0.3−0.8 mm), and 1 had unacceptable RH (change of 10.1 mm; this patient also had unacceptable VT). Of those with dorsal comminution, 30 of 45 (67%) had unacceptable displacement, compared to only 3 of 65 (4.6%) of those without dorsal comminution. Of those older than 60 years, 20 of 40 (50%) had displacement compared to only 13 of 70 (18.6%) who were 60 or younger. Of those with minimally displaced fractures, 25 of 61 (41%) had displacement compared to only 8 of 49 (16.3%) of those that were nondisplaced.

The univariate binary logistic regression analysis revealed significantly greater odds of losing acceptable alignment for fractures with dorsal comminution (odds ratio [OR], 41.3; 95% confidence interval [CI], 11.1−153.8; $P < .05$), patients >60 years of age (OR, 4.4; 95% CI, 1.9−10.4; $P < .05$), and minimally versus nondisplaced fractures (OR, 3.56; 95% CI, 1.43−8.87; $P < .05$; Table 4). There was no association between a loss of acceptable alignment and sex ($P = .12$), associated ulnar fracture ($P = .06$), or intra-articular pattern ($P = .09$). The multivariable binary logistic regression model demonstrated that dorsal comminution (OR, 37.8; 95% CI, 9.9−144.9; $P < .05$) and an age >60 years (OR, 3.6; 95% CI, 1.1−11.2; $P < .05$) remained significant risk factors for unacceptable displacement, while minimal displacement became insignificant ($P = .71$). The AUC for the multivariable model was 0.91, consistent with outstanding discrimination for the prediction of unacceptable displacement based upon these 3 predictor variables (Fig. 2). Of patients with neither dorsal comminution nor an age >60 years, 1 of 48 (2.1%) had displacement beyond acceptable alignment. Displacement occurred in 14 of 39 (35.9%) patients with 1 risk factor and 18 of 23 (78.3%) of patients with both risk factors.

Inter-observer and intra-observer reliability were determined to be good to excellent for all radiographic measures. Inter-observer reliability was deemed excellent for VT (intraclass correlation coefficient [ICC] = 0.93) and SO (ICC = 0.97) and was deemed good for RH (ICC = 0.85), UV (ICC = 0.75), and RI (ICC = 0.79). Intra-observer reliability was deemed excellent for VT (ICC = 0.98), SO (ICC = 0.98), RH (ICC = 0.96), and UV (ICC = 0.95), while it was deemed good for RI (ICC = 0.87).

DISCUSSION

Substantial prior work has identified risk factors for unacceptable displacement following closed reduction of DRFs; however, less is known about the propensity for further displacement to unacceptable alignment for patients presenting with fractures that are initially well aligned.[3,4,12] This study demonstrated a relatively high rate of unacceptable displacement (29%), as defined by exceeding recommended radiographic alignment parameters outlined in the AAOS CPG, among patients initially presenting with acceptably aligned DRFs. Previous studies have reported rates of loss of alignment as low as 0% for initially nondisplaced fractures and up to 33% for heterogeneous groups of nondisplaced and minimally displaced fractures.[13−15] Our finding of 29% is similar to these prior estimates, although even within our nondisplaced group, 16% went on to have unacceptable alignment.

While an initial review of the entire cohort found that none of the studied radiographic parameters significantly changed beyond described thresholds of measurement error at follow-up, further investigation identified specific patient subsets that were at high risk of unacceptable displacement. Specifically, the

TABLE 4. Univariate and Multivariate Analysis of Risk Factors for Displacement Beyond AAOS Acceptable Criteria*

Risk Factor	Number (%) Displaced		Univariate Analysis			Multivariable Analysis		
	Without Risk Factor	With Risk Factor	OR	95% CI	*P* Value	OR	95% CI	*P* Value
Dorsal comminution	3 (4.6%)	30 (66.7%)	41.33	11.11−153.80	<.05	37.79	9.86−144.90	<.05†
Age >60 y	13 (18.6%)	20 (50.0%)	4.38	1.85−10.41	<.05	3.56	1.12−11.22	<.05†
Minimally displaced (vs nondisplaced)	8 (16.3%)	25 (41.0%)	3.56	1.43−8.87	<.05	N/A	N/A	N/A‡
Associated ulnar fracture	21 (25.3%)	12 (44.4%)	2.36	0.95−5.85	.063	N/A		
Female (vs male)	6 (19.4%)	27 (34.2%)	2.16	0.79−5.91	.132	N/A		
Intra-articular (vs extra-articular)	25 (35.7%)	8 (20.0%)	0.45	0.18−1.12	.088	N/A		

N/A, not applicable.
*Only factors that were significant on univariate analysis were included in a multivariate analysis that used backward term elimination with a cutoff α of 0.10.
†Both of these factors are independent predictors for loss of acceptable alignment at 6-week follow-up.
‡This predictor was included in the multivariable model but was eliminated through backward term elimination given that it did not reach appropriate significance at the threshold α of 0.10.

presence of dorsal comminution appears to be the greatest risk factor for subsequent loss of acceptable alignment because 64% of fractures with dorsal comminution went on to have displacement, whereas only 5% of those without dorsal comminution were displaced. An age >60 years appears to also be a significant risk factor for displacement, perhaps due to an increased prevalence of osteopenia and osteoporosis in this age group.[16] This theory is supported by a recent study by Ghodasra et al,[6] which found a significant correlation between bone mineral density and the risk for displacement in nonsurgical DRFs. A multivariable model with these 2 factors had outstanding discrimination, illustrated by the fact that patients with neither dorsal comminution nor an age >60 years had a low risk of displacement (2%) while those with 1 or both risk factors had a greater than a 50% risk of displacement. The risk factors for displacement identified in this study (the presence of comminution and older age) corroborated results from previous studies of both initially nondisplaced and displaced fractures.[4,12,14,15] While minimally displaced fractures seemed to be at higher risk than nondisplaced fractures on initial analysis, this became insignificant with a multivariable analysis. These results are likely due to overlap in patients who have both minimal displacement and the presence of dorsal comminution, with the presence of dorsal comminution essentially trumping minimal displacement in a multivariable analysis.

Limitations of the current study include the study design of a retrospective review at a single academic institution, which may introduce enrollment bias. Similarly, our institution has a large catchment area of approximately 10% of the US land mass, which may lead to a lower rate of follow-up. Although there was no difference in the age and sex composition of patients lost to follow-up, it is possible that patients who followed-up systematically differed from those who were lost to follow-up in other ways that may affect radiographic or functional outcomes. It is also important to note the statistical limitations. The 95% CIs for the point estimates of the ORs for dorsal comminution and age were wide, likely due to the relatively small sample size. Therefore, while these factors appear to influence the outcome, the magnitude of the effect is not known with precision. In addition, although we did not find statistically significant associations between loss of acceptable alignment and sex, associated ulnar fracture, or articular pattern (as defined by the semi-arbitrary but ubiquitous *P* value threshold of <.05 used in the field of medicine), the study was not specifically powered

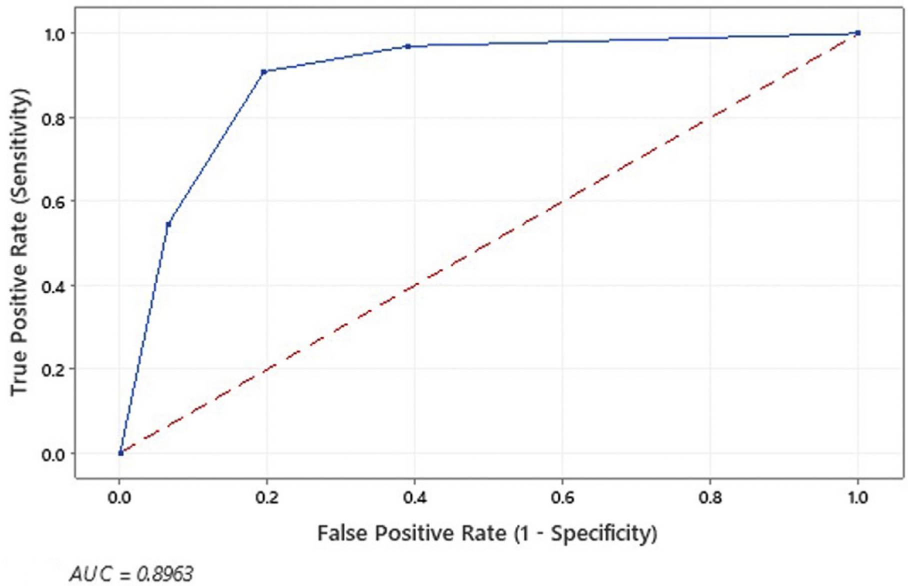

FIGURE 2: Receiver operator characteristic curve for multivariable analysis with AUC of 0.90, indicating outstanding discrimination for the prediction of loss of acceptable displacement based on age >60 years and dorsal comminution (backward term elimination with $\alpha = 0.10$).

for each of these variables, which could lead to a type 2 error.

Additionally, this study is not an exhaustive evaluation of all possible risk factors, as we focused only on risk factors that have consistently been shown to predispose patients to secondary displacement in DRFs that underwent closed reduction. Osteoporosis or osteopenia may contribute to displacement in this patient population, but due to a potential lack of applicability to younger patients and to a lack of consistent screening in the United States for older or at-risk patients, we believed that the presence versus absence of a chart diagnosis was not accurate enough for study purposes.[16,17] We did not attempt to identify the timing at which unacceptable displacement occurred with more granularity than a 6-week time frame. Nevertheless, this information would be helpful to further optimize the timing of clinical follow-up.

In recent years there has been an increased focus on value-based care of orthopedic problems, including DRFs. However, there is little evidence to help guide the clinician in terms of follow-up for nondisplaced DRFs in adults.[18–20] The current AAOS CPG recommend radiographic follow-up for 3 weeks and at the end of immobilization for all DRFs, based on consensus opinion, but without strong clinical evidence to guide this recommendation.[2] As such, many patients tend to undergo serial radiographs with little effect on treatments or outcomes.[21] In addition, these unnecessary follow-up visits are costly, at an average of $128 per visit for Medicare patients, $236 for privately insured patients, and $350 for uninsured patients.[22] The findings of the current study may help guide recommendations for clinical and radiographic follow-ups for these fractures. For example, young patients presenting with acceptably aligned DRFs without dorsal comminution are at a low risk of unacceptable displacement, and likely do not require as close follow-up as those patients with dorsal comminution or those >60 years of age. This knowledge can allow a tailoring of the clinical workflow, reduce overall costs to the health-care system, and decrease the burden for patients by minimizing low-value clinic visits and radiographs for those at low risk of loss of reduction.

In conclusion, nearly a third of DRFs with acceptable alignment on presentation end up with unacceptable displacement. Although the average radiographic parameters for the entire cohort did not significantly change between initial and 6-week radiographs, we were able to identify a subset of patients with the presence of dorsal comminution and/or an age >60 years who are at high risk for unacceptable displacement. Since these 2 clinical factors show outstanding ability to discriminate between those who do and do not lose acceptable initial alignment, our results may help guide hand surgeons when determining the frequency of follow-up and may be helpful for counseling patients on the risk for late displacement. As late displacement is relatively common, some of those patients may benefit from surgical intervention, and patients should be apprised of this possibility at their initial visit.

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