Clinical and Radiographic Factors Associated With Distal Radioulnar Joint Instability in Distal Radius Fractures

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Abstract

Background Distal radioulnar joint (DRUJ) instability is an important cause of ulnar-sided wrist pain in distal radius fractures. However, instability is frequently undiagnosed and the clinical and radiographic factors associated with instability are not well understood.

Questions/purposes We therefore identified clinical and radiographic factors associated with DRUJ instability in distal radius fractures.

Patients and Methods We retrospectively reviewed all 221 patients who underwent surgical treatment for unstable distal radius fractures from 2007 to 2010. Ten patients (five men and five women) had DRUJ instability by intraoperative manual testing (Group I); these patients had a median age of 52 years. The other 211 patients (81 men and 130 women) (Group II) had a median age of 55 years.

Clinical and radiographic data were compared between the groups.

Results The incidence of open wounds at the wrist and the relative ulnar length measured on the prereduction radiograph were greater in Group I. An open wound at the wrist and positive ulnar variance of 6 mm or greater on the prereduction radiograph increased the risk of DRUJ instability (relative risks = 45 and 17, respectively) in distal radius fractures.

Conclusions An open wound at the wrist or positive ulnar variance of 6 mm or greater observed on the prereduction radiograph in patients with distal radius fractures should alert the physician to the possibility of DRUJ instability.

Level of Evidence Level II, prognostic study. See the Guidelines for Authors for a complete description of levels of evidence.

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This study was performed at Hallym University Sacred Heart Hospital.

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Introduction

Distal radioulnar joint (DRUJ) instability is an important cause of ulnar-sided wrist pain after bony healing of distal radius fractures [9, 40]. Two to 37% of patients with distal radius fractures reportedly have DRUJ instability after bony union, and approximately $\frac{2}{3}$ of these patients were symptomatic [9, 24]. A substantial proportion of DRUJ instability cases seem to be caused by injuries to soft tissue stabilizers of the DRUJ such as the triangular fibrocartilage complex [24].

Identifying factors related to DRUJ instability would be helpful in diagnosing DRUJ instability by raising the index of suspicion among surgeons, but they are not well understood. The ulnar styloid fractures, especially at the base with greater than 2 mm of displacement, have been regarded as the risk factor for DRUJ instability in distal radius fractures [37] because of its proximity to the deep triangular fibrocartilage complex [32]. However, it still is unclear whether the displaced ulnar styloid fractures cause pain and instability at the DRUJ in patients with distal radius fractures [34, 40, 44]. One study suggested that stable internal fixation of distal radius fractures results in a stable DRUJ after bony healing regardless of the presence of substantially displaced, unrepaired ulnar styloid fractures [39], whereas two studies [15, 35] reported no differences in the wrist function between patients with unrepaired ulnar styloid fractures and those without ulnar styloid fractures. In addition, factors other than ulnar styloid fractures have been investigated only rarely in distal radius fractures for DRUJ instability. Recently widening of the DRUJ gap was identified as a risk factor for DRUJ instability [8].

We therefore tried to identify clinical and radiographic factors associated with DRUJ instability in distal radius fractures.

Patients and Methods

We retrospectively reviewed the data for 256 patients who underwent surgery for unstable, unilateral distal radius fractures in a tertiary trauma center from January 2007 to February 2010. Our indication for surgery was a distal radius fracture that met more than three of the following criteria before reduction: (1) dorsal angulation greater than 20° , (2) radial shortening greater than 5 mm, (3) metaphyseal comminution greater than $\frac{2}{3}$, (4) an articular gap or step-off greater than 2 mm, and (5) ulnar styloid fracture [1, 3, 18]; or one of the following criteria after reduction: (1) dorsal angulation greater than 0° , (2) radial shortening greater than 2 mm, or (3) an articular gap or step-off greater than 2 mm [20, 21]. We excluded 10 patients owing

Fig. 1 A flow chart shows the study cohort.

to inadequate prereduction radiographs, six for a previous history of distal radius fracture, four owing to severe comminution of the sigmoid notch, four because of bilateral distal radius fractures, two for bilateral fractures along with ulnar head/neck fractures, and nine owing to ulnar head/neck fractures. These 35 exclusions left 221 patients (221 wrists) for inclusion (Fig. 1). There were 86 men and 135 women with a median age of 55 years (interquartile range [IQR], 44–63 years). The dominant hand was involved in 95 patients. One hundred forty-six distal radius fractures occurred after a fall from a standing height, 33 fractures occurred from a fall at a height greater than 1 m, 28 fractures occurred from sports-related activities, and 14 fractures were caused by traffic accidents. According to AO/OTA classification [27], 43 fractures were Type A3, four were Type B1, 13 were Type B2, 45 were Type C1, 52 were Type C2, and 64 were Type C3. There were 18 open fractures, with a small open wound on the volar ulnar side in 17 wrists. The ulnar styloid process was fractured in 97 patients. The institutional review board of our hospital granted approval for this study.

Of 221 patients enrolled, 10 had an unstable DRUJ through intraoperative manual testing (see below), and these patients were included in Group I. On surgical exploration, all patients in Group I had triangular fibrocartilage complex avulsion injuries, eight of which were at the fovea of the ulna head (Fig. 2), and two at the volar margin of the sigmoid notch (Fig. 3). Group II consisted of 201 patients with stable DRUJ. Ten patients with an open

Fig. 2A–D A 47-year-old woman sustained a distal radius fracture while mountain climbing. (A) She had an abrasion wound on the radial side and a pinpoint-sized open wound on the ulnar side of the injured wrist. On the prereduction (B) PA and (C) lateral radiographs, ulnar variance was greater than 20 mm. After stable fixation of the fracture, the DRUJ was unstable. (D) During surgical exploration, the triangular fibrocartilage complex was completely avulsed from the fovea of the ulnar head. Arrow = remaining stump of the avulsed triangular fibrocartilage complex at the fovea of the ulnar head, arrowhead = tip of the avulsed triangular fibrocartilage complex, asterisk = ulnar head.

wound at the wrist in Group II underwent surgical exploration of the DRUJ during open wound debridement. No deep triangular fibrocartilage complex injuries were found.

DRUJ instability was examined during surgery. With the patient in the supine position, general or regional anesthesia was administered and sterile draping was performed. Before gowning, the contralateral normal DRUJ was examined by the surgeon (BCK) as the normal reference for the injured wrist. With the patient's elbow in 90° flexion and forearm in neutral rotation, the surgeon firmly grabbed the distal end of the radius with one hand and tried to passively translate the distal ulna in the dorsal and volar directions with the other hand [16]. The same stress test

was repeated with the patient's forearm in supination and pronation. The DRUJ of the injured wrist was examined in the same manner after stable fixation of the distal radius fracture. The stability of the DRUJ in the injured wrist was assessed by comparison with the normal wrist because the amount of joint relaxation varies among individuals [10], and was categorized as no instability, moderate instability (increased translation of the DRUJ with firm end), or severe instability (increased translation without firm end). Because the dorsoulnar fragments might be a cause of DRUJ instability without a triangular fibrocartilage complex injury [6], we fixed them with one or two K-wires (1.4 mm) under arthroscopic guidance.

Fig. 3A–E A 52-year-old man sustained an open fracture of the distal radius. **(A)** The open wound was present at the volar ulnar side of the wrist. The ulnar variance was greater than 1 mm, and bony fragments (arrow) were observed in front of the volar margin of the sigmoid notch on the **(B)** PA and **(C)** semisupinated views of the wrist

radiographs and on **(D)** the CT scan. **(E)** These fragments were attached to the avulsed deep part of triangular fibrocartilage complex, ie, the volar distal radioulnar ligament. A forceps is holding one of the fragments (arrowhead).

Surgical exploration of the DRUJ and repair of the deep triangular fibrocartilage complex was performed for patients with moderate or severe DRUJ instability. Exposure of the DRUJ was performed using a volar approach as previously described [4]. Briefly, the capsule of the DRUJ was reached through an interval between the ulnar neurovascular bundle and finger flexors. The capsule was opened by making a transverse incision. A Freer elevator was inserted into the space between the ulnar head and the triangular fibrocartilage complex to more clearly observe the foveal insertion of the deep part of the triangular

fibrocartilage complex. Any injury to the deep triangular fibrocartilage complex was recorded and repaired with a 1.8-mm suture anchor (Mitek, Westwood, MA, USA) except for that in a 70-year-old woman with a low activity level and with nondominant hand involvement. The DRUJ was pinned with two 1.6-mm wires in five patients. Surgical exploration of the DRUJ also was performed for patients with open wounds at the wrist as an adjunct to wound debridement. One hundred sixty-three distal radius fractures were treated by mini-open and/or arthroscopically assisted reduction and fixation with K-wires, or K-wires

and external fixators. Fifty-eight distal radius fractures were treated by open reduction and internal fixation. No ulnar styloid fractures were repaired.

After surgery, a sugar tong or long arm splint was applied with the forearm in neutral or 30° supination for 6 weeks for all patients with DRUJ instability. Physiotherapy for edema control and finger motion was started on the day of surgery. Active and passive motion of the wrist was initiated under the supervision of the surgeon 6 weeks after surgery for 10 times per session and three sessions per day. For patients with a stable DRUJ, the same hand and wrist physiotherapy regimen was used. However, wrist physiotherapy was started at different times per fixation methods. Patients treated by K-wire pinning or K-wires and external fixation wore a sugar tong or removable splint, respectively, for 6 weeks and then began wrist physiotherapy. Patients treated by ORIF wore a removable splint for 2 weeks and started wrist physiotherapy thereafter. All patients in Group I and 186 patients (88%) in Group II were followed for more than 6 months. In Group I, one patient whose triangular fibrocartilage complex rupture was not repaired had symptomatic DRUJ instability, however, she declined to undergo surgical reconstruction. In Group II, no patients had DRUJ instability.

One of us (BKS) evaluated the true posteroanterior (PA) and lateral images of all 221 patients. The extensor carpi ulnaris groove criterion was used to identify true PA radiographs, in which a longitudinal line that crosses the midpoint of the ulnar styloid should be observed medial to the extensor carpi ulnaris groove [22]. The scaphopisicapitate criterion was used to identify true lateral radiographs, in which the volar cortex of the pisiform should be seen between the volar cortex of the scaphoid tuberosity and that of the capitate head [30]. We measured radial inclination, radial length, dorsal tilt, and ulnar variance for all 221 patients using the central longitudinal axis of the radius, as previously described [19]. The interobserver and intraobserver agreement of these radiographic parameters reportedly is greater than 0.7 [5, 19]. When measuring ulnar variance, radial length, and radial inclination, the dorsal margin of the sigmoid notch was used as a reference point for dorsally displaced distal radius fractures, and the volar margin of the sigmoid notch was used for volarly displaced distal radius fractures (Fig. 4). All measurements were made with semiautomated image analysis software installed in the picture archiving and communications system (PACS; PiViewStar; Infinitt, Seoul, Korea), which inserted line drawings and calculated lengths and angles after an observer manually determined reference points on the periphery. Radiographic measurements using semiautomated software and digital images reportedly provide better interobserver reliability and intraobserver reliability than those with hands and conventional films [5, 11].

Patients in Group I (with DRUJ instability) and Group II (without DRUJ instability) were compared for age, gender, side of the injury, involvement of the dominant hand, mode of injury, fracture type (AO/OTA), coexisting ulnar styloid fracture, presence of an open wound, and radiographic indices, using the Mann-Whitney test for continuous variables and Fisher's exact test for categorical variables. We then calculated relative risk and the 95% CI of each variable associated with a *p* value less than 0.05 between groups. For convenience we converted ulnar variance into a dichotomous variable (ulnar variance ≥ 6 mm or not) based on the result from the analysis of the receiver operating characteristics curve, in which the use of 6 mm of ulnar variance as the cut-off point gave the highest accuracy in differentiating between groups [29].

A post hoc power analysis was performed with the Mann-Whitney test for continuous variables and Fisher's exact test for categorical variables as a model for our study, assuming an occurrence rate of 4.5% for the DRUJ instability. To calculate sample sizes for radiographic parameters, we used a 95% tolerance limit [19] for each parameter as a meaningful difference. For continuous variables, sample sizes of two, four, four, and 11 in Group I, and 32, 80, 94, and 243 in Group II were necessary to achieve a statistical power of 80% to assess radial length, radial inclination, ulnar variance, and dorsal tilt respectively. For categorical variables, sample sizes of 27 in Group I and 570 in Group II were necessary to achieve a statistical power of 80% for assessment of the rate of high-energy injury.

Results

An open wound was present in a greater percentage ($p < 0.001$) of patients in Group I versus Group II, eight of 10 versus 10 of 211 (4.5%), respectively (Table 1). The ulnar variance on the prereduction radiograph was greater ($p < 0.001$) in Group I versus Group II, 9 mm (IQR, 7–13 mm) versus 4 mm (IQR, 2–5 mm). Likewise, an ulnar variance of 6 mm or greater was more prevalent ($p < 0.001$) in Group I versus Group II, eight of 10 versus 34 of 211 (16%). A high-energy injury showed a trend ($p = 0.09$) toward greater occurrence in Group I. The incidence of a coexisting ulnar styloid fracture was similar ($p = 0.75$) between groups whether the base was involved or it was displaced greater than 2 mm.

The presence of an open wound and ulnar variance of 6 mm or greater increased the risk of having DRUJ instability even after stable fixation of distal radius fractures (Table 2). The presence of an open wound in a patient with a distal radius fracture increased the probability ($p < 0.001$) of DRUJ instability by 45-fold (95% CI,

Fig. 4A–D One of two reference points, the volar (*) or dorsal (▲) margin of the sigmoid notch, may be used for measurement, as shown in these (A) PA and (B) lateral radiographs. In a dorsally displaced fracture of the distal radius, the dorsal margin of the sigmoid notch is used for measuring ulnar variance, radial inclination, and radial length, and in a volarly displaced fracture, the volar margin of the sigmoid notch is used for these measurements, as shown on these (C) PA and (D) lateral radiographs. RL = radial length, RI = radial inclination, UV = ulnar variance, DT = dorsal tilt.

10.3–196.7). An ulnar variance of 6 mm or greater on the prereduction radiograph increased the probability ($p < 0.001$) of DRUJ instability by 17-fold (95% CI, 3.8–77.4). The probability of DRUJ instability in this study cohort was 55% for patients having both factors and 0% for those without any of them (Table 3).

Discussion

DRUJ instability is an important cause of ulnar-sided wrist pain after bony healing of distal radius fractures [9, 25, 40]. The factors associated with this injury, however, rarely

have been studied. Because of its anatomic proximity to the triangular fibrocartilage complex, fracture of the ulnar styloid at its base has been postulated to cause DRUJ instability [12, 28, 33, 37]. However, well-designed studies consistently denied the association between symptomatic DRUJ instability and the ulnar styloid fracture in distal radius fractures [15, 35, 39, 44]. Recently widening of the DRUJ gap was identified as an independent risk factor for DRUJ instability in distal radius fractures [8]. In this study, we tried to identify clinical and radiographic factors associated with DRUJ instability in distal radius fractures.

There are several limitations to this study. First, subjectivity might be introduced in the evaluation of DRUJ

Table 1. Comparisons between Group I and Group II

Factors	Group 1 (n = 10)	Group 2 (n = 211)	p value
Age*	52 (34–60)	55 (44–63)	0.42
Gender (M:F)	5:5	81:130	0.52
Injury side (R:L:BL)	6:4	96:115	0.65
Dominant hand	6	89	0.21
High-energy injury	6	68	0.09
AO type			0.78
A3	3	40	
B1	0	4	
B2	0	13	
C1	1	44	
C2	2	50	
C3	4	60	
Ulnar styloid fracture	5	92	0.75
Ulnar styloid base fracture	1	49	0.3
Ulnar styloid displaced ≥ 2 mm	0	38	0.22
Open fracture	8	10	< 0.001
Radial length (mm)	12 (6–15)	9 (6–11)	0.11
Radial inclination (°)	21 (9–24)	19 (13–23)	0.82
Ulnar variance (mm)	9 (7–13)	4 (2–5)	< 0.001
Dorsal tilt (°)	18 (8–37)	12 (2–23)	0.2

*Continuous variables are presented as median (interquartile range); BL = bilateral; High-energy injury is defined as a mode of injury other than a fall from standing height.

Table 2. Relative risk for DRUJ instability

Factors	Relative risk	95% CI	p value
Open fracture	45.1	10.3–196.7	< 0.001
Ulnar variance ≥ 6 mm	17	3.8–77.4	< 0.001

DRUJ = distal radioulnar joint.

Table 3. Probability of DRUJ instability

Factors combined	Group I	Group II	Probability
Open fracture and ulnar variance ≥ 6 mm	6	5	0.55
Open fracture and ulnar variance < 6 mm	2	8	0.29
Closed fracture and ulnar variance ≥ 6 mm	2	29	0.06
Closed fracture and ulnar variance < 6 mm	0	172	0.00

DRUJ = distal radioulnar joint.

instability because only clinical assessment was performed. However, no gold standard for diagnosing DRUJ instability has been established. The clinical assessment methods we

used also were used in multiple previous studies [8, 16, 26, 36, 42]. Furthermore, physical evaluation methods correlate with intraoperative findings better than CT and show higher interobserver reliability in the assessment of DRUJ instability [8, 16, 36, 42]. Second, we could not use more advanced statistical methods like logistic regression analysis because the number of observations available as a dependent variable was insufficient. Instead, we calculated the relative risks and confidence intervals to assess the effect of clinical and radiographic factors on DRUJ instability in distal radius fractures.

We found an increased positive ulnar variance of 6 mm or greater and an open wound at the wrist increased the risk of DRUJ instability even after stable fixation of distal radius fractures in our patients. Few studies investigate the factors associated with DRUJ instability in the setting of distal radius fractures. Lindau and Aspenberg found no radiographic parameters associated with DRUJ instability [24], but Fujitani et al. [8] reported that widening of the DRUJ gap was the only risk factor for DRUJ instability. These discrepancies between studies arise from differences in study setting. First, methods of measurement for radiographic parameters are different. Fujitani et al. measured ulnar variance as a distance from the volar margin of the sigmoid notch to the tip of the ulnar head, regardless of the direction of fracture displacement [8]. This method is likely to give an underestimation of ulnar variance, because the dorsal margin of the sigmoid notch is more proximally located than the volar one in fractures with dorsal tilt greater than 0°. However, we used the volar or dorsal margin of the sigmoid notch based on the direction of fracture displacement in measuring ulnar variance. We think this method represents the longest distance from the fovea of the ulnar head to the sigmoid notch (Fig. 4) and would be more sensitive in revealing the difference in ulnar variance between groups. Our finding is consistent with those of previous biomechanical studies that showed an increase in ulnar variance greater than 5 mm resulted in DRUJ instability and triangular fibrocartilage complex rupture [7, 31, 38]. Second, variables chosen for examination differed among studies. The DRUJ gap and open wound were not examined as a variable in our study or that of Fujitani et al. [8], resulting in different conclusions. Third, sample sizes for DRUJ instability in the above-mentioned studies are so small that they may include only a unique set of samples not representative of the entire population with DRUJ instability with distal radius fractures.

We found that all the patients with DRUJ instability (n = 10) had a deep triangular fibrocartilage complex avulsion from the fovea of the ulnar head or the sigmoid notch, whereas patients without DRUJ instability who underwent surgical exploration of the DRUJ (n = 10) did

not show any deep triangular fibrocartilage complex avulsions. The triangular fibrocartilage complex has been regarded as the most important stabilizer of the DRUJ [2, 17]. The triangular fibrocartilage complex, especially the deep part, plays a major role in dorsopalmar and rotational stability of the DRUJ [2, 13, 14, 41, 43], and to be related to DRUJ instability and subsequent pain after distal radius fractures [23, 24]. Fujitani et al. observed a deep triangular fibrocartilage complex tear from the fovea of the ulnar head in all patients with DRUJ instability [8]. Our finding supports the importance of the deep triangular fibrocartilage complex for DRUJ stability in distal radius fractures.

We found the presence of an open wound increased the risk of DRUJ instability in distal radius fractures. Given that open wounds usually are related to a high-energy injury, it seems likely that a high-energy injury would act as a confounding factor correlating with an open wound and DRUJ instability. However, the presence of high-energy injuries was similar between the groups, perhaps owing to an insufficient number of patients. Further study with adequate power is necessary to assess the role of a high-energy injury regarding DRUJ instability in distal radius fractures. We found a stable DRUJ in 45% of patients having an open wound and ulnar variance of 6 mm or greater observed on the prereduction radiograph. This suggests that these factors are not specific despite being sensitive. Thus, DRUJ instability should be judged by manual testing rather than by these factors.

Patients with DRUJ instability had a greater rate of open wounds and more positive ulnar variance observed on prereduction radiographs than patients without DRUJ instability with distal radius fractures. An open wound and positive ulnar variance of 6 mm or greater on prereduction radiographs were risk factors of DRUJ instability in the setting of distal radius fractures. Thus, patients with these factors should be evaluated carefully for coexisting DRUJ instability.

References

1. Abbaszadegan H, Jonsson U, von Sivers K. Prediction of instability of Colles' fractures. *Acta Orthop Scand*. 1989;60:646–650.
2. af Ekenstam F, Hagert CG. Anatomical studies on the geometry and stability of the distal radio ulnar joint. *Scand J Plast Reconstr Surg*. 1985;19:17–25.
3. Aro HT, Koivunen T. Minor axial shortening of the radius affects outcome of Colles' fracture treatment. *J Hand Surg Am*. 1991;16:392–398.
4. Bain GI, Pourgiezis N, Roth JH. Surgical approaches to the distal radioulnar joint. *Tech Hand Up Extrem Surg*. 2007;11:51–56.
5. Bozentka DJ, Beredjiklian PK, Westawski D, Steinberg DR. Digital radiographs in the assessment of distal radius fracture parameters. *Clin Orthop Relat Res*. 2002;397:409–413.
6. Cole DW, Elsaidi GA, Kuzma KR, Kuzma GR, Smith BP, Ruch DS. Distal radioulnar joint instability in distal radius fractures: the role of sigmoid notch and triangular fibrocartilage complex revisited. *Injury*. 2006;37:252–258.
7. Fraser GS, Ferreira LM, Johnson JA, King GJ. The effect of multiplanar distal radius fractures on forearm rotation: in vitro biomechanical study. *J Hand Surg Am*. 2009;34:838–848.
8. Fujitani R, Omokawa S, Akahane M, Iida A, Ono H, Tanaka Y. Predictors of distal radioulnar joint instability in distal radius fractures. *J Hand Surg Am*. 2011;36:1919–1925.
9. Geissler WB, Fernandez DL, Lamey DM. Distal radioulnar joint injuries associated with fractures of the distal radius. *Clin Orthop Relat Res*. 1996;327:135–146.
10. Giannoulis FS, Sotereanos DG. Galeazzi fractures and dislocations. *Hand Clin*. 2007;23:153–163, v.
11. Grainger AJ, Duryea J, Elliott JM, Genant HK. The evaluation of a new digital semi-automated system for the radiological assessment of distal radial fractures. *Skeletal Radiol*. 2002;31:457–463.
12. Hauck RM, Skahen J 3rd, Palmer AK. Classification and treatment of ulnar styloid nonunion. *J Hand Surg Am*. 1996;21:418–422.
13. Haugstvedt JR, Berger RA, Nakamura T, Neale P, Berglund L, An KN. Relative contributions of the ulnar attachments of the triangular fibrocartilage complex to the dynamic stability of the distal radioulnar joint. *J Hand Surg Am*. 2006;31:445–451.
14. Kihara H, Short WH, Werner FW, Fortino MD, Palmer AK. The stabilizing mechanism of the distal radioulnar joint during pronation and supination. *J Hand Surg Am*. 1995;20:930–936.
15. Kim JK, Koh YD, Do NH. Should an ulnar styloid fracture be fixed following volar plate fixation of a distal radial fracture? *J Bone Joint Surg Am*. 2010;92:1–6.
16. Kim JP, Park MJ. Assessment of distal radioulnar joint instability after distal radius fracture: comparison of computed tomography and clinical examination results. *J Hand Surg Am*. 2008;33:1486–1492.
17. Kleinman WB. Stability of the distal radioulnar joint: biomechanics, pathophysiology, physical diagnosis, and restoration of function. What we have learned in 25 years. *J Hand Surg Am*. 2007;32:1086–1106.
18. Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. *J Bone Joint Surg Am*. 1986;68:647–659.
19. Kreder HJ, Hanel DP, McKee M, Jupiter J, McGillivray G, Swiontkowski MF. X-ray film measurements for healed distal radius fractures. *J Hand Surg Am*. 1996;21:31–39.
20. Lafontaine M, Delince P, Hardy D, Simons M. [Instability of fractures of the lower end of the radius: apropos of a series of 167 cases] [in French]. *Acta Orthop Belg*. 1989;55:203–216.
21. Leung F, Ozkan M, Chow SP. Conservative treatment of intra-articular fractures of the distal radius: factors affecting functional outcome. *Hand Surg*. 2000;5:145–153.
22. Levis CM, Yang Z, Gilula LA. Validation of the extensor carpi ulnaris groove as a predictor for the recognition of standard posteroanterior radiographs of the wrist. *J Hand Surg Am*. 2002;27:252–257.
23. Lindau T, Adlercreutz C, Aspenberg P. Peripheral tears of the triangular fibrocartilage complex cause distal radioulnar joint instability after distal radial fractures. *J Hand Surg Am*. 2000;25:464–468.
24. Lindau T, Aspenberg P. The radioulnar joint in distal radial fractures. *Acta Orthop Scand*. 2002;73:579–588.
25. Lindau T, Hagberg L, Adlercreutz C, Jonsson K, Aspenberg P. Distal radioulnar instability is an independent worsening factor in distal radial fractures. *Clin Orthop Relat Res*. 2000;376:229–235.

26. Lindau T, Runnquist K, Aspenberg P. Patients with laxity of the distal radioulnar joint after distal radial fractures have impaired function, but no loss of strength. *Acta Orthop Scand*. 2002;73:151–156.
27. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, Prokuski L, Sirkin MS, Ziran B, Henley B, Audige L. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. *J Orthop Trauma*. 2007;21(10 suppl):S1–S133.
28. May MM, Lawton JN, Blazar PE. Ulnar styloid fractures associated with distal radius fractures: incidence and implications for distal radioulnar joint instability. *J Hand Surg Am*. 2002;27:965–971.
29. Metz CE. Basic principles of ROC analysis. *Semin Nucl Med*. 1978;8:283–298.
30. Metz VM, Wunderbaldinger P, Gilula LA. Update on imaging techniques of the wrist and hand. *Clin Plast Surg*. 1996;23:369–384.
31. Moore TM, Lester DK, Sarmiento A. The stabilizing effect of soft-tissue constraints in artificial Galeazzi fractures. *Clin Orthop Relat Res*. 1985;194:189–194.
32. Nakamura T, Takayama S, Horiuchi Y, Yabe Y. Origins and insertions of the triangular fibrocartilage complex: a histological study. *J Hand Surg Br*. 2001;26:446–454.
33. Oskarsson GV, Aaser P, Hjall A. Do we underestimate the predictive value of the ulnar styloid affection in Colles fractures? *Arch Orthop Trauma Surg*. 1997;116:341–344.
34. Roysam GS. The distal radio-ulnar joint in Colles' fractures. *J Bone Joint Surg Br*. 1993;75:58–60.
35. Sammer DM, Shah HM, Shauver MJ, Chung KC. The effect of ulnar styloid fractures on patient-rated outcomes after volar locking plating of distal radius fractures. *J Hand Surg Am*. 2009;34:1595–1602.
36. Scheer JH, Hammerby S, Adolfsson LE. Radioulnar ratio in detection of distal radioulnar joint instability associated with acute distal radius fractures. *J Hand Surg Eur Vol*. 2010;35:730–734.
37. Shaw JA, Bruno A, Paul EM. Ulnar styloid fixation in the treatment of posttraumatic instability of the radioulnar joint: a biomechanical study with clinical correlation. *J Hand Surg Am*. 1990;15:712–720.
38. Shen J, Papadonikolakis A, Garrett JP, Davis SM, Ruch DS. Ulnar-positive variance as a predictor of distal radioulnar joint ligament disruption. *J Hand Surg Am*. 2005; 30:1172–1177.
39. Souer JS, Ring D, Matschke S, Audige L, Marent-Huber M, Jupiter JB; AOCID Prospective ORIF Distal Radius Study Group. Effect of an unrepaired fracture of the ulnar styloid base on outcome after plate-and-screw fixation of a distal radial fracture. *J Bone Joint Surg Am*. 2009;91:830–838.
40. Stoffelen D, De Smet L, Broos P. The importance of the distal radioulnar joint in distal radial fractures. *J Hand Surg Br*. 1998; 23:507–511.
41. Stuart PR, Berger RA, Linscheid RL, An KN. The dorsopalmar stability of the distal radioulnar joint. *J Hand Surg Am*. 2000; 25:689–699.
42. Tay SC, Tomita K, Berger RA. The “ulnar fovea sign” for defining ulnar wrist pain: an analysis of sensitivity and specificity. *J Hand Surg Am*. 2007;32:438–444.
43. Ward LD, Ambrose CG, Masson MV, Levaro F. The role of the distal radioulnar ligaments, interosseous membrane, and joint capsule in distal radioulnar joint stability. *J Hand Surg Am*. 2000; 25:341–351.
44. Zenke Y, Sakai A, Oshige T, Moritani S, Nakamura T. The effect of an associated ulnar styloid fracture on the outcome after fixation of a fracture of the distal radius. *J Bone Joint Surg Br*. 2009;91:102–107.