Ulnar Styloid Base Fractures Cause Distal Radioulnar Joint Instability in a Cadaveric Model

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Abstract

Background: The deep portion of the distal radioulnar ligaments (DRUL) inserts on the ulnar fovea and is the most important stabilizer of the distal radioulnar joint (DRUJ). Ulnar styloid base fractures that include the ulnar fovea may cause DRUJ instability. **Methods:** DRUJ stability in pronosupination was evaluated in 12 fresh-frozen upper extremities (4 female) aged 52 to 68 years (mean: 58.8 years) using a custom fixture, which allowed free rotation of the radius around the fixed ulna. Optical motion capture was used to record rotation of the radius with respect to the ulna. Each specimen was subjected to 3 N m of torque in both supination and pronation under 4 conditions: intact, ulnar styloid osteotomy with disruption of the foveal insertion of the DRUL, ulnar styloid fixation, and DRUL transection. Group differences were compared using a 1-way repeated-measures analysis of variance and Tukey multiple comparison post hoc tests. **Results:** When compared with the intact condition, both ulnar styloid osteotomy and DRUL transection significantly increased mean pronation (by 9.40° and 15.21°, respectively) and supination (by 9.05° and 17.42°, respectively) of the forearm. Screw fixation only significantly reduced pronation compared with osteotomy (by 2.62°). Screw fixation did not significantly affect supination. **Conclusions:** Ulnar styloid fractures that disrupt the fovea cause instability of the DRUJ in pronation and supination under 3 N m of torque in a cadaveric model. Screw fixation of ulnar styloid base fractures achieves anatomic reduction; however, it only partially returns rotational stability acutely to the DRUJ and only during pronation.

Keywords: ulnar styloid, triangular fibrocartilage complex, fracture, distal radioulnar joint, instability

Introduction

Distal radius fractures represent approximately 1 in 6 of all fractures and are often (44%-65%) accompanied by fractures of the ulnar styloid.^{10,37} Although ulnar styloid fractures are uncommonly addressed when treating distal radius fractures, there is evidence to suggest that they lead to reduced wrist functional outcomes and to distal radioulnar joint (DRUJ) instability.^{5,14,19,23,27,30,32,38,40} Instability and poor outcomes have been attributed to disruption of the triangular fibrocartilage complex (TFCC) and, more specifically, the deep portion of the distal radioulnar ligaments (DRUL), which inserts in the ulnar fovea and is important in the stability of the DRUJ.^{6,8,11,14,24,37}

Recent studies suggest that untreated ulnar styloid fractures and ulnar styloid nonunions do not affect patient outcomes (including DRUJ instability) in distal radius fractures treated with open reduction and internal fixation (ORIF) of the radius alone.^{2,9,10,28,31,36,39} However, a recent meta-analysis by Wijffels et al³⁷ suggests that much of the clinical literature on styloid fractures does not consistently specify

the level of fracture. This is important because styloid fractures distal to the fovea would not be expected to disrupt the insertion of the DRUL and cause DRUJ instability. Furthermore, May et al¹⁴ in 2002 illustrated that larger, displaced ulnar styloid fractures were more likely to be associated with DRUJ instability than smaller, nondisplaced fractures. Thus, literature that includes smaller styloid fractures that are distal to the fovea may be biased to find no difference in outcomes and DRUJ instability between patients with and without untreated styloid fractures.

A biomechanical study may clarify the impact of ulnar styloid base fractures that include the ulnar fovea on the stability of the DRUJ. For example, Mirarchi et al¹⁶ in 2008

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Table 1. Specimen Demographics.

Specimen	Side	Age, y	Sex	Race	Fixation
1	Right	56	Female	white	Headless compression
2	Right	68	Male	black	Headless compression
3	Right	62	Male	white	Headless compression
4	Right	52	Female	white	Headless compression
5	Left	52	Female	white	Headless compression
6	Right	62	Female	white	Traditional screw
7	Left	62	Male	white	Traditional screw
8	Left	60	Male	white	Traditional screw
9	Left	55	Male	white	Traditional screw
10	Right	55	Male	white	Traditional screw
11	Right	62	Male	white	Traditional screw
12	Right	60	Male	white	Headless compression

Note. Table 1 demonstrates demographic and protocol information for each specimen.

developed a model for isolation of the DRUJ during biomechanical cadaveric testing and illustrated that this model could be used to study the effect of ulnar styloid fractures on DRUJ kinematics. In this small, pilot study of 5 specimens, the authors found decreased ability to produce torque through the DRUJ in pronation and supination in cadavers with ulnar styloid osteotomies versus when the same cadavers were intact.

The aim of this study was to elucidate the kinematic effects of ulnar styloid fractures on the stability of the DRUJ using a cadaveric, biomechanical model. Our primary hypothesis is that large ulnar styloid base fractures that include the ulnar fovea cause DRUJ instability. Our secondary hypotheses are that fixation of ulnar styloid base fractures restores DRUJ stability and that open laceration of the DRUL causes equivalent DRUJ instability when compared with styloid base fractures.

Materials and Methods

Twelve fresh-frozen cadaveric upper extremities including two-thirds of the humerus with intact elbow, forearm, wrist, and hand were included in the final analysis of this study. The cadavers were aged at time of death 52 to 68 years (mean: 58.8 years); 8 were male, and 4 were female (Table 1). Prior to experimentation, a shuck test in neutral forearm rotation was performed by the first author (T.S.P.) on each specimen as described by Lindau et al¹² to rule out gross DRUJ instability. Gross instability was defined as the ability of the examiner to displace the ulna out of the sigmoid notch to the

point perching. The specimens were also inspected with fluoroscopy to rule out abnormalities such as DRUJ and/or radio-carpal arthritis, evidence of previous wrist trauma, and ulnar positivity with or without ulnocarpal arthritis due to a high correlation of these findings with TFCC injury.^{12,15,25,26,33} One specimen was screened out prior to testing due to the presence of a distal radius plate indicating prior wrist trauma.

Previous studies have demonstrated that various subparts of the DRUL become taut in extremes of pronation and supination establishing that the DRUJ has an important role in rotational forearm stability.^{1,4,11,24,29} Other biomechanical studies have exploited this to demonstrate DRUJ instability by measuring the production of torque by a cadaveric wrist in pronation and supination.¹⁶ Simply put, if it is true that the DRUL is important in limiting extremes of forearm rotation at the DRUJ and it is true that the DRUL inserts at the ulnar fovea, then it would follow that an ulnar styloid base fracture that disrupts the fovea should cause incompetence of this important checkrein to forearm rotation.

Each cadaver was individually secured to a custom test fixture (Figure 1) that was designed to rigidly fix the humerus and the ulna in 90° of elbow flexion allowing for free rotation of the radius. A free, threaded pin was placed in the distal one-third of the radial shaft to accept weights for the application of pronation and supination torque. The same pin and weights were used for each specimen and bicortical placement was confirmed on fluoroscopy. Furthermore, the test fixture was built on a tilting platform that was adjusted throughout experimentation to keep the pin parallel to the floor. This ensured that the same amount of torque was applied to each specimen. Marker clusters were rigidly secured to the distal radius and ulna via threaded K-wires to monitor 3-dimensional rotation of the radius with respect to the ulna via optical motion capture (Optotrak; Northern Digital Inc, Waterloo, Ontario, Canada) with sub-millidegree accuracy. Marker clusters were also affixed to the fixture and to the humerus as controls.

DRUJ instability was assessed by the application of 3 N m of torque in both supination and pronation under 4 sequential experimental conditions: intact, ulnar styloid osteotomy, ulnar styloid fixation, and DRUL transection (Table 2). Thus, each intact specimen acts as its own control. All specimens were preconditioned in both pronation and supination with 3 N m of torque for 90 seconds prior to data collection, to stress the tested ligaments and prevent creep from resulting in spurious results. Torque of 3 N m was selected as it fell within the range of torques produced during active pronosupination in both male and female subjects¹³; 3 N m would be comparable to opening a tight jar or using a screwdriver, activities that might provoke symptoms in patients with DRUJ instability. However, it is substantially less than the peak torques of ~12 N m and ~6 N m that healthy male and female subjects are capable of generating during maximal effort.¹³

Figure 1. Experimental fixture.

Note. A cadaver specimen in the experimental fixture with 3 N m of torque applied in pronation from two vantage points (a and b). Note the LED markers in clusters attached to the radius, ulna, fixture base, right fixture tower, and humerus. Also note that the fixture base rotates, allowing the entire apparatus to be tilted to the left or right to ensure the torque pin is always horizontal. There are 2 stabilizing threaded pins in the humerus and 1 in the ulna (with an affixed marker) to stabilize the arm in 90° of elbow flexion allowing for free rotation of the radius about the ulna.

Table 2. Experimental Data.

Experiment	Condition 1	Condition 2	Mean difference	95% CI of difference	P value
Pronation					
	Mean angle (degrees)				
(1) Intact vs (2) Osteotomy	91.0 ± 14.7	100.4 ± 17.5	9.40*	5.41 to 13.40	<.001
(1) Intact vs (3) Fixed	91.0 ± 14.7	97.8 ± 17.5	6.79*	2.31 to 11.27	.004
(1) Intact vs (4) DRUL Transection	91.0 ± 14.7	106.2 ± 21.6	15.21*	5.67 to 24.76	.003
(2) Osteotomy vs (3) Fixed	100.4 ± 17.5	97.8 ± 17.5	-2.62*	-4.35 to -0.88	.004
(2) Osteotomy vs (4) DRUL Transection	100.4 ± 17.5	106.2 ± 21.6	5.81	-1.14 to 12.77	.112
(3) Fixed vs (4) DRUL Transection	97.8 ± 17.5	106.2 ± 21.6	8.43*	2.12 to 14.74	.009
Supination					
	Mean angle (degrees)				
(1) Intact vs (2) Osteotomy	129.8 ± 22.3	138.9 ± 22.7	9.05*	2.71 to 15.39	.006
(1) Intact vs (3) Fixed	129.8 ± 22.3	137.8 ± 22.1	8.01*	2.05 to 13.97	.009
(1) Intact vs (4) DRUL Transection	129.8 ± 22.3	147.2 ± 26.2	17.42*	8.91 to 25.93	<.001
(2) Osteotomy vs (3) Fixed	138.9 ± 22.7	137.8 ± 22.1	-1.05	-2.74 to 0.65	.298
(2) Osteotomy vs (4) DRUL Transection	138.9 ± 22.7	147.2 ± 26.2	8.37*	0.71 to 16.02	.031
(3) Fixed vs (4) DRUL Transection	137.8 ± 22.1	147.2 ± 26.2	9.41*	2.59 to 16.24	.008

Note. Table 2 illustrates mean range of motion ($\pm$ 1 standard deviation) and differences for each condition in maximum pronation and supination.

CI = confidence interval; DRUL = distal radioulnar ligament.

*Statistical significance: $P < .05$.

The styloid osteotomy was performed with a sagittal saw and osteotome under fluoroscopy, freeing the foveal insertion of the DRUL (Figures 2 and 3). A longitudinal incision along the extensor carpi ulnaris/flexor carpi ulnaris interval was deepened to complete the ulnar styloid osteotomy, with minimal disruption of the surrounding soft tissues. Styloid fixation was performed with either a mini (3.5 mm)

headless compression screw (Figure 2) (6 cadavers) or a fully threaded, bicortical, headed 2.0-mm screw (Figure 3). Fluoroscopy was used to confirm anatomic alignment both before and after stress. Volar and dorsal DRUL transection was performed with a scalpel under direct visualization by sweeping the blade within the distal sigmoid notch from dorsal to volar until all soft tissue was transected up to the

Figure 2. Headless compression screw specimen.

Note. Fluoroscopic images of a cadaveric specimen during the intact (a), osteotomized (b), and fixed (c) portions of the experiment. Note in Figure 2b that the osteotomy is carefully performed to include the ulnar fovea. Also note in Figure 2c that this specimen was reduced and fixed with a mini headless compression screw. The threaded pin seen in the distal radius is attached to LED markers for optical motion capture.

proximal carpal row. Notably, the hardware was left in the ulnar styloid during testing of the DRUL lacerated cadavers to keep the styloid fixed.

The motion capture system was used to record the maximum pronation and maximum supination of the radius with respect to the ulna with the applied 3 N m of torque in static position. This was repeated with each cadaver sequentially in each of the 4 conditions. The motion capture system was referenced to each individual cadaver prior to testing to isolate rotation measurements in 1 plane. This was done by using the motion capture system's software to define the x-axis as perpendicular to and the z-axis as parallel to the radius and ulna in neutral forearm rotation (Figure 4). This allowed the y-axis to be defined as perpendicular to these 2 axes and parallel to the humerus. To capture pure rotation of the radius about the ulna prior to testing, it was ensured that the motion capture system was only detecting rotation around the z-axis. If the motion capture system detected rotation around either of the other 2 axes, the cadaver was re-referenced until this was cor-

rected. Each rotation measurement was calculated with neutral forearm rotation defined as "0°."

Group differences in maximum pronation and supination were compared using a 1-way repeated-measures analysis of variance and a Tukey multiple comparison post hoc test. Statistical significance was defined as $P < .05$. Prior to final data analysis, no differences were found among cadavers fixed with a headless compression screw and those fixed with a headed screw; thus, these 2 data sets were combined. Instability of the DRUJ was defined as a statistically significant increase in pronosupination of the radius under standard torque when compared with the intact state.

Results

When compared with the intact condition, ulnar styloid osteotomy significantly increased mean pronation (9.40°; 95% CI, 5.41 to 13.40) ($P < .001$) and supination (9.05; 95% CI, 2.71 to 15.39) ($P = .006$) of the forearm (Table 2).

Figure 3. Headed screw specimen.

Note. Fluoroscopic images of a cadaveric specimen during the intact (a), osteotomized (b), and fixed (c) portions of the experiment. Note in Figure 3b that the osteotomy is carefully performed to include the ulnar fovea. Also note in Figure 3c that this specimen was reduced and fixed with a headed screw (2.0 mm). The threaded pin seen in the distal radius is attached to LED markers for optical motion capture.

Screw fixation after osteotomy modestly reduced pronation (-2.62° ; 95% CI, -4.35 to -0.88) ($P = .004$) (Table 2). However, screw fixation did not significantly reduce supination (-1.05° ; 95% CI, -2.74 to 0.65) ($P = .298$). Screw fixation did not fully restore the normal constraints to pronosupination. After screw fixation, there was significantly more pronation (6.79° ; 95% CI, 2.31 to 11.27) ($P = .004$) and supination (8.01° ; 95% CI, 2.05 to 13.97) ($P = .009$) than there had been in the intact condition.

DRUL transection significantly increased both mean pronation (15.21° ; 95% CI, 5.67 to 24.76) ($P = .003$) and mean supination (17.42° ; 95% CI, 8.91 to 25.93) ($P < .001$) when compared with the intact condition (Table 2). Furthermore, in pronation, DRUL transection resulted in significantly more mean rotation than the screw fixation condition (8.43° ; 95% CI, 2.12 to 14.74) ($P = .009$), but it did not increase rotation when compared with the osteotomized condition (5.81° ; 95% CI, -1.14 to 12.77)

($P = .112$). In supination, however, DRUL transection resulted in significantly more rotation than both the fixed condition (9.41° ; 95% CI, 2.59 to 16.24) ($P = .008$) and the osteotomized condition (8.37° ; 95% CI, 0.71 to 16.02) ($P = .031$).

Discussion

The importance of ulnar styloid fractures is controversial. Although fractures of the distal portion of the ulnar styloid are likely of minimal consequence, ulnar styloid base fractures that include the fovea have a theoretical risk of causing DRUJ instability.^{11,24} The deep portion of the DRUL, which inserts at the ulnar fovea near the base of the ulnar styloid, is the primary stabilizer of the DRUJ.^{7,11,17,20-22,24,34,35} Thus, ulnar styloid base fractures that include this foveal insertion would be expected to remove the stabilizing effect of the deep DRUL and thereby cause DRUJ instability.

Figure 4. Optical motion capture axes.

Note. Figure 4 demonstrates the axes defined for the optical motion capture system to calculate rotation superimposed on a sawbones upper extremity fixed to the experimental fixture. Rotation of the radius around the ulna was recorded as rotation about the z-axis. There was no appreciable rotation around the y-axis or x-axis.

We hypothesized that osteotomies of the ulnar styloid that include the fovea would cause instability of the DRUJ in cadavers, defined as increase in pronosupination of the radius with respect to a fixed ulna under a standard torque. Our testing demonstrated a consistent and significant increase in pronosupination of the radius with respect to the ulna after osteotomy (Table 2). These results suggest that ulnar styloid base fractures including the fovea have potential to cause DRUJ rotational instability. Our findings are augmented by the relatively modest amount of torque needed to demonstrate them (3 N m) compared with the maximum amount of torque achievable actively in human subjects (~12 N m and ~6 N m in male and female, respectively).¹³

Secondarily, we hypothesized that fixation of the ulnar styloid osteotomies would return stability to the DRUJ. The results of our study were mixed with regard to this postulation. In pronation, there was a statistically significant (though modest) decrease in rotation of the radius in the fixed condition compared with the osteotomized condition, and there was a significant increase in rotation of the radius

in the DRUL transection condition compared with the fixed condition suggesting improvement of DRUJ stability after screw fixation (Table 2). In supination, there was also a significant increase in rotation of the radius in the DRUL transection condition compared with the fixed condition. However, there was no significant difference when comparing the osteotomized and fixed conditions in supination. Furthermore, in both pronation and supination there was significantly more rotation in the fixed condition when compared with the intact condition, suggesting residual DRUJ rotational instability despite fixation.

There are a couple of possible explanations for our findings regarding single-screw fixation. First, the production of the osteotomized ulnar styloid with a sagittal saw and osteotome may have damaged the DRUL. We believe this is unlikely considering the saw was used only to start the osteotomy and the fracture was completed gently with the osteotome. More likely, with only a single point of fixation the ulnar styloid fragments were allowed to rotate around the screw when torqued causing inadequate stabilization of

DRUJ. In vivo, most surgeons would avoid this problem by immobilizing patients after ulnar styloid fixation until healing occurs.

Our third hypothesis was that transection of the DRUL would cause an equivalent destabilization of the DRUJ when compared with ulnar styloid osteotomy. Again, the results of our study were mixed with respect to this prediction. In both pronation and supination, DRUL transection caused significantly more rotation of the radius when compared with the intact condition (Table 2). In pronation, there was no significant difference between osteotomized forearms and those undergoing DRUL transection; however, in supination DRUL transected forearms demonstrated increased rotation compared with those osteotomized.

One explanation for this finding is laceration of the distal oblique bundle (DOB) of the interosseous membrane during DRUL transection.¹⁸ As described above, the technique for DRUL laceration involved inserting a scalpel into the sigmoid notch from dorsal to volar and transecting all of the tissue between the radius and ulna up to the carpal bones. It is possible that this caused laceration of the DOB, which inserts just proximal to the sigmoid notch on the radius and assists with DRUJ stability. In addition, our technique for DRUL sectioning certainly disrupted the wrist capsule which is a secondary stabilizer of the DRUJ. Thus, our results with respect to DRUL transection may overstate a pure DRUL injury and more accurately model a combined injury to the DRUL, the wrist capsule, and possibly the DOB. Furthermore, given the sequential nature of the study, DRUL testing was dependent on the stability of the repaired ulnar styloid. Because screw fixation only partially restored stability to the DRUJ, DRUL laceration testing functionally measured instability at 2 points: the DRUL laceration and the incompletely stabilized foveal insertion of the DRUL. Thus, it is logical that DRUL laceration demonstrated more DRUJ instability than osteotomy alone.

Our study has numerous limitations. First, as a cadaveric, biomechanical study, its application to clinical decision making is limited and will need to be confirmed with further studies in vivo. Second, active torque produced by an individual may affect the DRUJ differently than passive force used in our study, which could limit the real-world applicability of the study. Third, a more robust form of fixation that resists rotation of the styloid fragment, such as a tension band, may have improved our results. Fourth, using a single form of fixation for all specimens rather than using either a headless compression screw or a standard screw would have limited variability among specimens. Finally, while our study did demonstrate increased rotational instability in the DRUJ in osteotomized specimens, it is unclear in this cadaver study whether this instability is clinically relevant.

Several studies have suggested that ulnar styloid fractures cause DRUJ instability and may negatively impact

outcomes in patients with concomitant distal radius fractures.^{3,5,14,23,27,30,32,38-40} May et al¹⁴ demonstrated in a study of 166 distal radius fractures that all patients with associated DRUJ instability had ipsilateral ulnar styloid fractures and that large base fractures and displacement of the ulnar styloid were significant risk factors for such instability. Furthermore, Oskarsson et al²³ illustrated in a study of 158 patients treated nonoperatively for distal radius fractures that ipsilateral ulnar styloid fractures were a better predictor of fracture instability than intra-articular extension and were associated with significantly greater loss of wrist mobility and grip strength. Such data have lead many authors to conclude that large ulnar styloid fractures should be addressed surgically.^{5,19,27,30,38} Our data support these findings.

On the contrary, multiple studies have suggested that untreated ulnar styloid fractures do not significantly affect clinical outcomes, particularly in patients with ipsilateral distal radius fractures treated with ORIF.^{2,9,10,28,31,36,37,39} Unfortunately, many of these studies do not appropriately distinguish ulnar styloid base fractures that include the fovea from more distal fractures, making their respective conclusions unclear. For example, Buijze and Ring,² Wijffels and Ring,³⁶ and Zenke et al³⁹ defined base fractures as the proximal half of the styloid, while Souer et al³¹ defined base fractures as involving 75% of the styloid. None of these definitions ensure inclusion of the insertion of the DRUL at the ulnar fovea in the fracture fragment. Our findings suggest that these studies cannot reliably rule out ulnar styloid base fractures as a cause for DRUJ instability due to their liberal definition of the base of the ulnar styloid. Future investigations should be performed that properly define ulnar styloid base fractures as including the ulnar fovea.

Authors' Note

All data can be accessed by contacting the corresponding author.

Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

This article presents data obtained solely from cadaveric specimens without collection of identifying information; therefore, no informed consent was required.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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