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The Critical Size of Ulnar Styloid Fragment for the DRUJ Stability

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Abstract

Background Ulnar styloid fractures can be associated with clinically significant instability of the distal radioulnar joint (DRUJ). However, the exact fragment size that results in DRUJ instability is unknown.

Purpose The objective of this study was to determine the critical size of an ulnar styloid fracture that would result in a significant increase in DRUJ translation and forearm rotation.

Methods Eight cadaveric specimens were used to investigate the effects of three different ulnar styloid fracture sizes on DRUJ instability: tip fracture, base fracture, and a fracture including the fovea. Forearm rotation and dorsopalmar DRUJ translation were measured after each sequential increase in fracture size.

Results Relative to the uninjured state, a significant increase in forearm rotation and dorsopalmar translation was found for all three fractures. However, the fovea fracture showed a statistically significant increase in forearm rotation compared with all other fracture types and a statistically significant increase in total dorsopalmar translation compared with the tip fracture.

Conclusion In this study, ulnar styloid fractures involving the fovea resulted in significantly greater DRUJ instability comparted to tip and base fractures alone. This study provides important biomechanical data regarding the critical size of ulnar styloid fractures that result in DRUJ instability and may aid in the surgical decision-making algorithm in these patients.

Keywords
- distal radioulnar joint
- distal radioulnar ligaments
- distal radius fracture
- TFCC
- ulnar styloid fracture

The distal radioulnar joint (DRUJ) is the articulation between the ulnar head and sigmoid notch, a shallow concavity of the distal radius. The joint is mainly stabilized by soft tissue that allows for some degree of physiologic dorsopalmar (DP) translation (5.4 mm in supination and 2.8mm in pronation[1]). DP translation is increased in cases of DRUJ instability commonly accompanying wrist trauma.[2] In the clinical setting, instability is assessed with the ballottement test, which has been shown to be the most accurate clinical test for DRUJ instability.[3] Distal radius fractures are the most frequent fractures of the upper extremity. In certain cases, the fracture extends into the DRUJ causing instability.[4] Distal radius fractures with associated DRUJ instability are often associated with pain and wrist dysfunction and may lead to DRUJ arthritis.[5,6]

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Ulnar styloid fractures (USF) accompany 51 to 65% of distal radius fractures.[4,7] The consequence of an USF is controversial. There is some evidence suggesting that it is associated with poor wrist functional outcome with remaining DRUJ instability.[8,9] In clinical studies, USF are addressed surgically only in 10% of cases when treating distal radius fractures.[2] Indications for ulnar styloid fixation are not well defined. In contrast, other studies have suggested that distal radius fractures treated with open reduction and internal fixation (ORIF) of the radius alone leaving the USF untreated, do not affect patient reported outcomes, even when styloid nonunion occurs.[10–12]

The triangular fibrocartilage complex (TFCC) inserts at the ulnar head, ulnar styloid, and the fovea. The deep portion of the distal radioulnar ligaments (DRUL)[13,14] serve as the primary stabilizer of the DRUJ.[15] The biomechanical properties of the DRUJ may be altered if the insertion of the DRUL is violated by a fracture of the ulnar styloid.[2,16,17] In a clinical study, May et al[2] showed that large, displaced USFs were more likely to be associated with DRUJ instability than smaller, nondisplaced fractures. Small and distal USFs were shown to have no effect on DRUJ stability with similar clinical outcomes in patients with and without untreated styloid fractures.[11] In a meta-analysis, Wijffels et al found that most clinical studies on USF do not clearly specify the level of fracture, which diminishes the comparability between the studies. Recently, two biomechanical cadaveric studies have shown that basal USF caused DRUJ instability.[17,18] However, none of these studies compared different fragment sizes or evaluated DP translation of the DRUJ.[3] The aim of this study was to investigate the influence of USF size on DRUJ stability by measuring forearm rotation as well as DP translation in a cadaveric model. Our hypothesis was that a USF involving the deep insertion of the DRUL would lead to a significant increase of the DP translation.

Materials and Methods

Specimen Preparation

Eight fresh-frozen cadaveric forearms were tested. The forearms were macroscopically intact and had no history of trauma. Specimens included five males and three females with an overall mean age of 66.4 years old (range: 60–77). The humerus was amputated above the elbow, potted in PVC pipe using plaster, and fixed to the pipe with orthogonal screws. The soft tissue was removed from the forearm preserving the interosseous membrane, TFCC, DRUJ capsule, extensor carpi ulnaris (ECU), ECU subsheath, extensor retinaculum, and pronator quadratus (PQ). The origins of the ECU and PQ were cut, and sutures were attached to the tendons for muscle loading.

Testing Setup

Using a custom testing system, the humerus was fixed horizontally, the elbow locked in 90 degrees with a metal elbow-spanning bridge plate, and the forearms were mounted vertically on the dorsal second and third metacarpal bone (►Fig. 1). The radius and metacarpals were fixed together using an external fixator to maintain their anatomic relationship and eliminate carpal motion. Additional screw fixation was placed in the distal carpal row between the fifth metacarpal bone and trapezium. This procedure isolated the movement of the DRUJ by separately securing the ulna to the

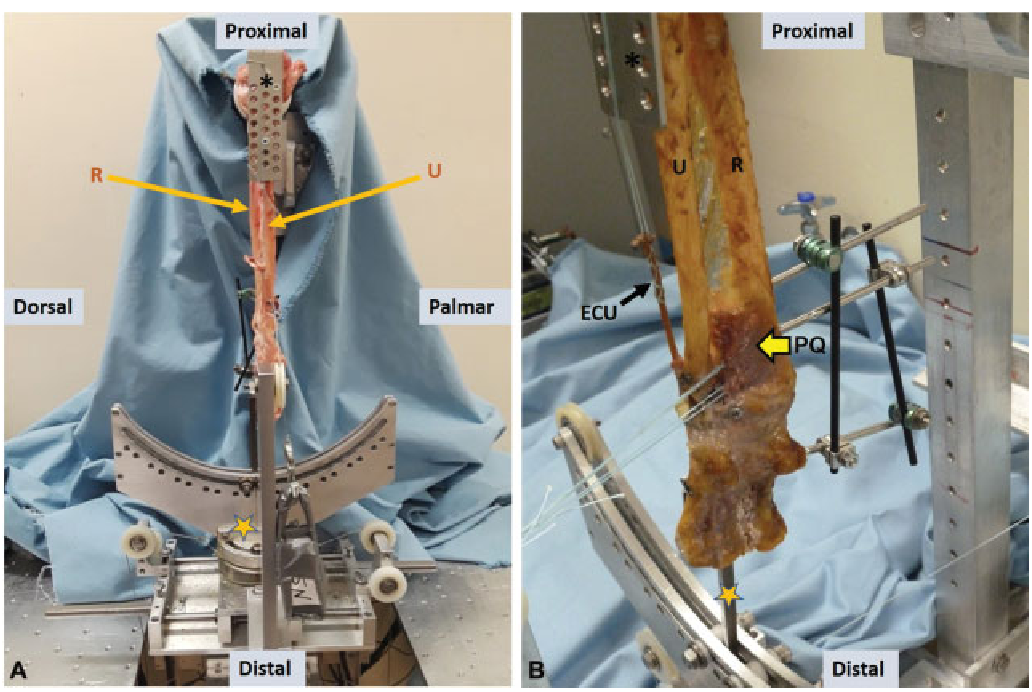

Fig. 1 (A) Custom forearm-testing apparatus capable of rotational and translational movement. *The humerus is fixed horizontally and the elbow is secured in 90 degrees of flexion with a plate. ★: On the lower mobile part, the metacarpal bones are fixed. Load is applied with weights attached to pulleys. (B) Detail of the testing setup. The muscles were loaded to simulate residual muscle tension. ECU, extensor carpi ulnaris tendon; PQ, pronator quadratus; R, radius; U, ulna.

humerus and the radius to the carpus. The lower part of the testing system allowed translation of the DRUJ in a DP direction and rotation of the forearm by attaching weights on the base of the apparatus to induce the movement. The center of rotation was defined as the center of the ulnar head. The translational and rotational movement could be independently locked to allow for isolated analysis of motion in each plane. To simulate the residual tension of stabilizing muscles, 5 N weights were loaded on the ECU and PQ.

A Microscribe 3DLX (Revware Inc., Raleigh, NC) was used to digitally measure the locations of four screw-markers placed on the distal forearm. This digitizer records the three-dimensional coordinates of any selected point relative to a reference coordinate system. Distances and relationships between the points were then calculated. The screw-markers were located 1 cm proximal to the base of the ulnar styloid on the ulnar side, 1 cm radial to the ventral border of the sigmoid notch, and 1 cm radial to the dorsal border of the sigmoid notch. The latter two markers were used to calculate the center of the sigmoid notch and used to measure the relative amount of movement between the center of the sigmoid notch and the center of rotation at the ulnar fovea. The final screw-marker was placed on the radial styloid.

Measurements

DRUJ instability was quantified by measuring forearm rotation and DP translation. Rotation was measured in degrees of pronation and supination and DP translation in millimeters. Neutral forearm rotation was defined as the position in which the DRUJ axis was aligned with the axis of the humerus.

When testing forearm rotation, DP translation was fixed in a neutral position by simultaneously loading 15 N of dorsal and 15 N of palmar load. Pronation and supination were then tested with 1 Nm of torque. Total forearm rotation was calculated from the sum of pronation and supination.

When measuring DP translation, forearm rotation was fixed in one of three forearm rotations including neutral, full pronation, and 90 degrees of supination. Dorsal and palmar translation were measured as the difference from a neutral position and after 15N of translational load was applied. For each of the three fixed rotations, DP translation was calculated as the sum of dorsal and palmar translation.

After testing was completed for all conditions (see below), measurements and observations were taken for the width of the ulnar head, length, and width of the sigmoid notch, amount of ulnar variance, Tolat classification, amount of arthritis, and the presence or absence of the distal oblique bundle.

Conditions

Four conditions were tested sequentially: intact (►**Fig. 2**), tip fracture, base fracture, and fovea fracture. Fractures (►**Fig. 3**) were created using an osteotome to cut 70% of the fracture width, then completing the final 30% by levering the fragment distally. This technique avoided detachment of soft tissue structures by the osteotome.

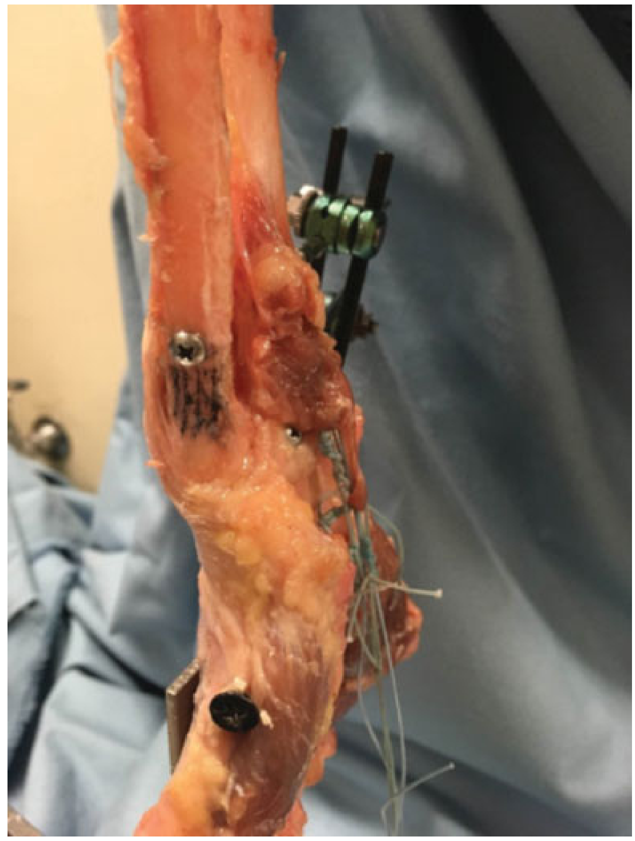

Fig. 2 Intact condition. The appearance of the forearm prior to the execution of fractures. Note the external fixator that connects the distal radius to the metacarpal bones.

Tip Fracture

The tip fracture (►**Fig. 4**) was performed at 84% of the length of the styloid (marked with the help of the Microscribe) between the insertion of the superficial (starting at 87%) and

Fig. 3 Schematic drawing of different ulnar styloid conditions in a wrist X-ray: orange line, tip fracture at 84% of the styloid; black line, base fracture; red line, fovea fracture.

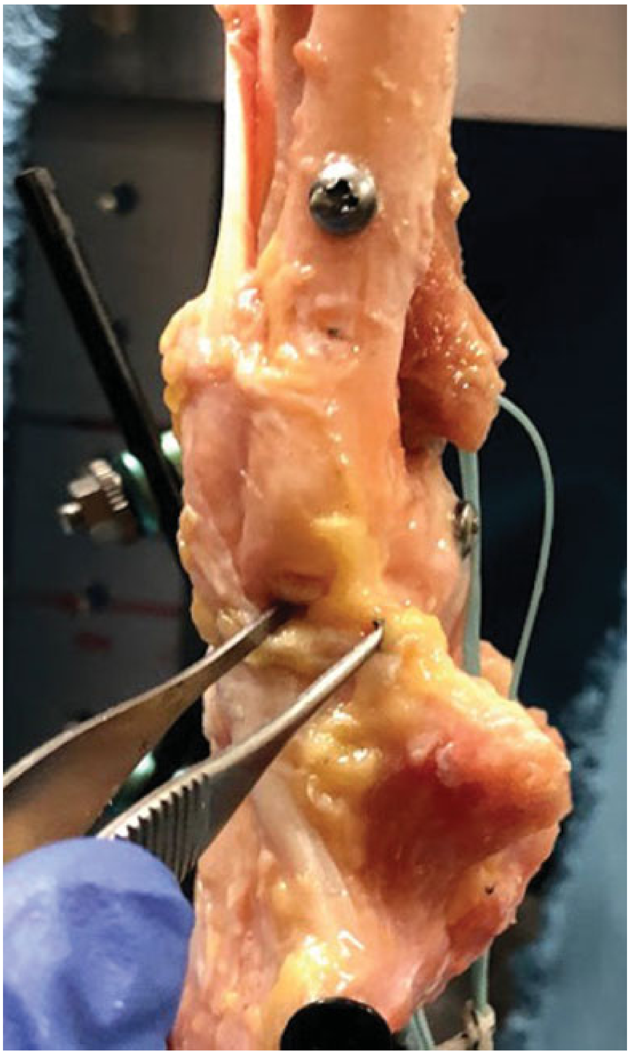

Fig. 4 The tip fracture of the ulnar styloid was created at 84% of the styloid length.

the deep DRUL (ending at 81%) of the styloid, as assessed in a prior study by Maniglio et al.[19] The length was measured with a caliper from the initial point of styloid curvature to the most distal end of the styloid process. The fracture was made from the ulnar to radial side perpendicular with the long axis of the ulna.

Base Fracture

The base fracture (►**Fig. 5**) was performed parallel to the tip fracture at the height of the ulnar fovea. The site of the base fracture was determined by palpating gradually from proximal to distal with a needle aimed from the palmar to dorsal side, as to avoid piercing the ECU tendon. The ability of the needle to pass entirely through without getting stuck against bone indicated that the needle reached the fovea. The base fracture was executed by making a fissure parallel with the tip fracture and aiming toward the inserted needle as the endpoint.

Fovea Fracture

The fovea fracture (►**Fig. 6**) was made from the ulnar to radial side starting at the base of the styloid and ending 2 to 3 mm radial to the fovea that was determined with the help of the inserted needle.

Statistical Analysis

Descriptive statistics with means and standard errors were used. A repeated measures analysis of variance was used to compare the between subject effect of fracture and the within subject effect of forearm position using IBM SPSS Statistics Version 27. If a statistical difference was identified, pairwise comparisons were performed using a Bonferroni correction for multiple comparisons. The *p*-value was set at 0.05 to designate statistically significant differences.

Results

The biometrical measurements of the cadaveric specimens are listed in ►**Table 1**.

Based on the Tolat[20] classifications, five specimens were type one, three specimens were type two, and none were type three.

Rotation

For each condition, the mean pronation was lower than supination ($p < 0.01$ for all fracture conditions) (►**Fig. 7**).

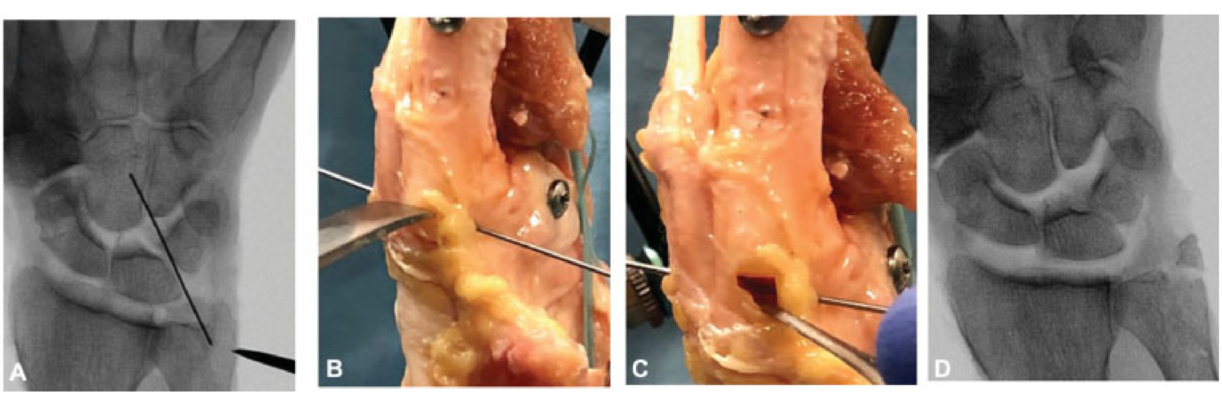

Fig. 5 Base fracture condition. (**A** and **B**) Radiological image and picture before the osteotomy: a needle was inserted into the fovea and used as the endpoint for the fracture. (**C**) The inserted needle became visible once the fracture was executed through the fracture line. (**D**) Anteroposterior radiological image after the osteotomy performance.

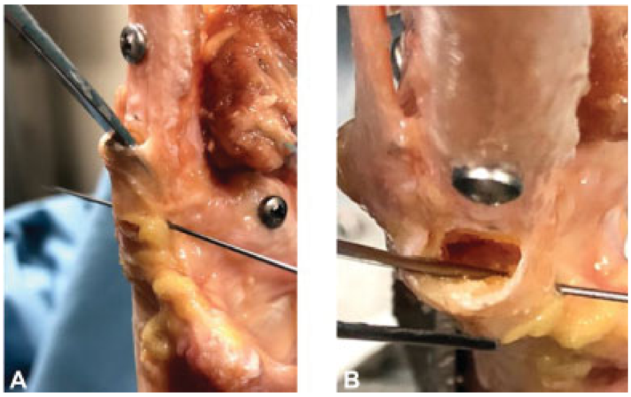

Fig. 6 (**A**) Fovea fracture condition performed with a chisel and the help of a marking needle. (**B**) The ending point for the fracture was 2 to 3 mm radial to the inserted needle.

The mean pronation was 65.4 degrees in intact forearms, 69.4 degrees after a tip fracture, 70.2 degrees after a base fracture, and 71.1 degrees after a fovea fracture. There were no significant differences found in pronation with increasing fracture size ($p > 0.7$ for all comparisons). The mean supination was 105.5 degrees in intact forearms, 112.1 degrees after a tip fracture, 114.1 degrees after a base fracture, and 119.4 degrees after a fovea fracture. In supination, statistical significance was found between the base fracture when compared with the intact condition ($p = 0.039$). There was a significant increase in supination following the fovea fracture compared with all other fracture conditions (vs. intact $p = 0.003$; vs. tip fracture $p = 0.014$; vs. base fracture $p = 0.037$). In total rotation, statistical significance was found between the intact condition (170.9 degrees) and the tip fracture (181.5 degrees; $p = 0.002$), base fracture (184.3 degrees; $p = 0.001$), and fovea fracture (190.5 degrees; $p < 0.001$) as well as between the tip fracture and fovea fracture ($p = 0.002$) and the base fracture and fovea fracture ($p = 0.011$).

DP Translation

For each condition, the mean DP translation was the greatest in neutral and the lowest in pronation (►**Fig. 8**). For each

Table 1 Anatomical measurements with standard error in brackets

Anatomical measurements		
Ulnar head	DP	18.0 mm (±0.7)
	Proximal to distal	10.2 mm (±0.5)
Sigmoid notch	DP	14.8 mm (±0.6)
	Proximal to distal	9.5 mm (±0.3)
Ulnar variance		+0.4 mm (±0.6)
Average size of ulnar tip fragment (at 84%)		2.6 mm (±0.7)
Presence of DOB		37.5%
Presence of minor degenerative changes		62.5%

Abbreviations: DOB, distal oblique bundle; DP, dorsopalmar.

subsequent fracture condition, the mean DP translation increased in neutral rotation. The mean DP translation in neutral was 6.8 mm in intact forearms, 7.8 mm after tip fracture, 8.6 mm after base fracture, and 10.0 mm after fovea fracture. There was a statistically significant increase in translation compared with the intact specimen for each fracture condition ($p = 0.003$ for tip fracture; $p < 0.001$ for both base and fovea fracture). There was also a statistically significant increase in translation following fovea fracture compared with the tip fracture ($p = 0.010$). In supination, a statistically significant increase in translation was found only between the fovea fracture to the intact condition (5.8 mm; $p = 0.036$). The mean DP translation in pronation did not change significantly between different conditions ($p = 0.99$ for all comparisons).

Discussion

This study evaluated the effect USF fracture size on DRUJ stability, as measured by forearm rotation and DP translation

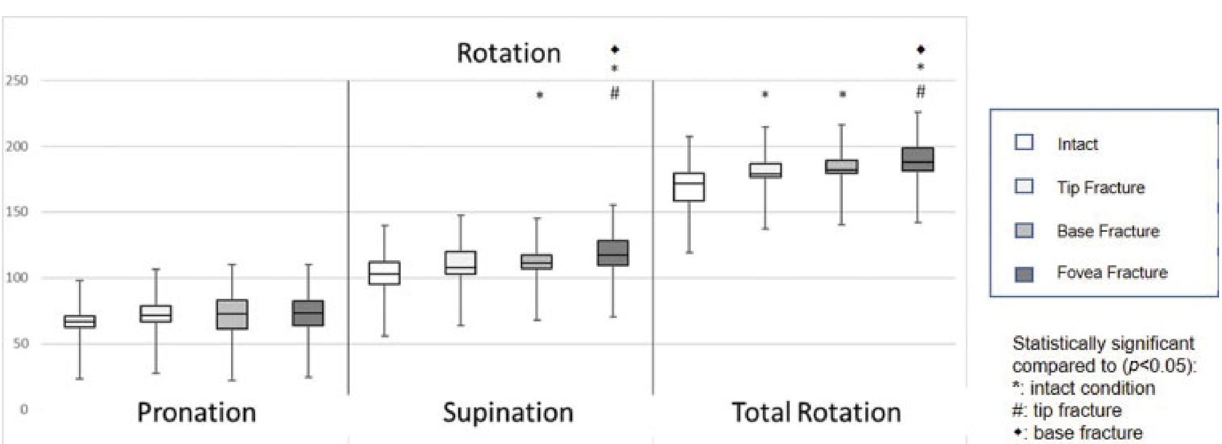

Fig. 7 Boxplot of the average pronation, supination, and total forearm rotation for each ulnar styloid fracture condition.

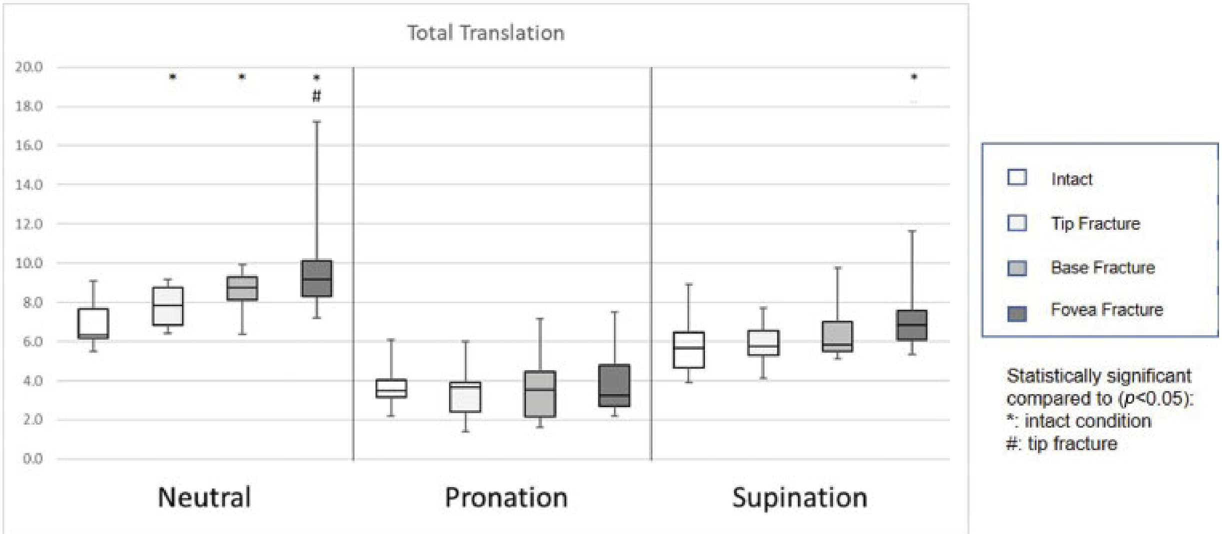

Fig. 8 Boxplot of the average total dorsal–palmar translation for different forearm rotations in neutral, pronation and 90 degrees of supination.

of the DRUJ. Fractures of the tip, base, and fovea all resulted in increased rotational instability compared with the intact condition. The fovea fracture further increased rotation compared with the other two fracture types. DP translation of the DRUJ also increased with all fractures compared with the intact condition in neutral rotation, and fractures involving the fovea increased translation relative to the tip fracture. DP translation in supination only increased after USF involving the fovea.

Various studies have suggested that untreated USFs do not significantly affect clinical outcomes, particularly in patients treated with ORIF for a distal radius fracture.[10–12] In contrast, Oskarsson et al[21] showed that USFs were a valid predictor of DRUJ instability in patients with conservatively treated distal radius fractures and that they were associated with greater loss of wrist function. DRUJ instability after radius fractures is associated with pain, wrist dysfunction and may lead to DRUJ arthritis.[5,6] Another clinical study investigating the outcome of distal radius fractures demonstrated a positive correlation between USF and DRUJ instability, showing that large basal USF and/or displaced fractures were associated with increased likelihood of DRUJ instability.[2] However, the definition of different USF types in these studies is often unclear and rarely based upon anatomical factors. This makes them difficult to compare and may contribute to the controversy in literature.

The ulnar fovea has previously been described as the primary attachment site of the TFCC, where fibers of the deep DRUL inserting in a fan-shaped manner near the base of the ulnar styloid.[13,14] A more complex footprint of the DRUL has been described more recently,[19,22] but the main insertion remains in the region of the ulnar fovea. To our knowledge no previous biomechanical study has assessed DRUJ instability in translation with different fragment sizes of the ulnar styloid even though the ballottement test, a test for translational stability, was found to be the most accurate clinical test for DRUJ instability.[3]

The results of this study suggest that all USFs have the potential to cause DRUJ instability, but that the greatest effect on DRUJ-stability is seen with fractures involving the fovea. These findings are strengthened by the relatively modest magnitude of force needed to translate the DRUJ. Nevertheless, translational forces acting on human subjects may differ than those used in this study.

In addition to translational stability, the TFCC provides rotational guidance for pronation and supination due to its close relationship to the forearm rotational axis.[23,24] In this study, forearm rotation significantly increased in all fracture conditions compared with the intact condition. These findings confirmed the results of Pidgeon et al and Mirarchi et al that showed a consistent and significant increase in rotational instability after a basal USF,[17,18] but goes even further differentiating other fracture heights. We found a significant increase in all fractures compared with the intact condition with a gradual increase of total forearm rotation correlating with increasing fracture size and a USF involving the fovea resulting in the largest amount of forearm rotation. This increase in rotational instability in fovea fractures was significantly higher when compared with the other two fracture types.

This study should be interpreted in the context of several limitations. Passive translation forces and torques used in our study may affect the DRUJ differently than active forces produced by in the in vivo state, which could limit the applicability of the study in clinical practice. Additionally, the USFs in this study were simulated with osteotomy in cadaveric specimens that may not fully account for additional soft tissue injuries that can occur in patients with wrist trauma (i.e., ligamentous injuries, capsule tears, TFCC lesions). Lastly, as a biomechanical study, this study represents only time-zero fracture characteristics and cannot assess the influence of fracture healing on the outcome. Therefore, its application to clinical decision making is limited and will need to be confirmed with further clinical studies.

Conclusions

In this study, all sizes of USF resulted in an increase in DRUJ instability. However, USFs involving the fovea demonstrated significantly greater instability compared with tip and base fractures, suggesting that this fracture subtype should raise even higher suspicion for DRUJ instability in the clinical setting. These findings provide important biomechanical data regarding the critical size of a USF fragment resulting in DRUJ instability and may aid in the surgical decision-making algorithm for patients with these injuries.

Ethical Approval
Ethical approval for this study was obtained from Institutional Review Board of VA Hospital Long Beach UCI.

Funding
None.

Conflict of Interest
M.Z. reports that he works as a Consultant & Designer for Medacta and received nonfinancial support from Angiocrine Biosciences. The remaining authors do not have any conflict of interest.

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References

1 Pirela-Cruz MA, Goll SR, Klug M, Windler D. Stress computed tomography analysis of the distal radioulnar joint: a diagnostic tool for determining translational motion. J Hand Surg Am 1991; 16(01):75–82
2 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(06):965–971
3 Moriya T, Aoki M, Iba K, Ozasa Y, Wada T, Yamashita T. Effect of triangular ligament tears on distal radioulnar joint instability and evaluation of three clinical tests: a biomechanical study. J Hand Surg Eur Vol 2009;34(02):219–223
4 Stoffelen D, De Smet L, Broos P. The importance of the distal radioulnar joint in distal radial fractures. J Hand Surg [Br] 1998;23 (04):507–511
5 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
6 Wijffels MM, Keizer J, Buijze GA, et al. Ulnar styloid process nonunion and outcome in patients with a distal radius fracture: a meta-analysis of comparative clinical trials. Injury 2014;45(12): 1889–1895
7 Geissler WB, Freeland AE. Arthroscopic management of intra-articular distal radius fractures. Hand Clin 1999;15(03):455–465, viii viii
8 Baradaran A, Moradi A, Sadeghi R, Ebrahimzadeh MH. Do we underestimate the predictive value of the ulnar styloid involvement in distal radius fractures? A systematic review and meta-analysis of clinical studies. J Hand Surg Eur Vol 2017;42(06): 642–645
9 Wysocki RW, Ruch DS. Ulnar styloid fracture with distal radius fracture. J Hand Surg Am 2012;37(03):568–569
10 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(09): 1595–1602
11 Souer JS, Ring D, Matschke S, Audige L, Marent-Huber M, Jupiter JBAOCID 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(04):830–838
12 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(01): 102–107
13 Ishii S, Palmer AK, Werner FW, Short WH, Fortino MD. An anatomic study of the ligamentous structure of the triangular fibrocartilage complex. J Hand Surg Am 1998;23(06): 977–985
14 Nakamura T, Yabe Y, Horiuchi Y. Functional anatomy of the triangular fibrocartilage complex. J Hand Surg [Br] 1996;21 (05):581–586
15 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 (07):1086–1106
16 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(05): 712–720
17 Pidgeon TS, Crisco JJ, Waryasz GR, Moore DC, DaSilva MF. Ulnar styloid base fractures cause distal radioulnar joint instability in a cadaveric model. Hand (N Y) 2018;13(01):65–73
18 Mirarchi AJ, Hoyen HA, Knutson J, Lewis S. Cadaveric biomechanical analysis of the distal radioulnar joint: influence of wrist isolation on accurate measurement and the effect of ulnar styloid fracture on stability. J Hand Surg Am 2008;33(05): 683–690
19 Maniglio M, Lin CC, Flueckiger R, Zumstein MA, McGarry MH, Lee TQ. Ulnar footprints of the distal radioulnar ligaments: a detailed topographical study in 21 cadaveric wrists. J Hand Surg Eur Vol 2020;45(09):931–938
20 Tolat AR, Stanley JK, Trail IA. A cadaveric study of the anatomy and stability of the distal radioulnar joint in the coronal and transverse planes. J Hand Surg [Br] 1996;21(05):587–594
21 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(6-7):341–344
22 Shin WJ, Kim JP, Yang HM, Lee EY, Go JH, Heo K. Topographical anatomy of the distal ulna attachment of the radioulnar ligament. J Hand Surg Am 2017;42(07):517–524
23 Kataoka T, Moritomo H, Omokawa S, Iida A, Murase T, Sugamoto K. Ulnar variance: its relationship to ulnar foveal morphology and forearm kinematics. J Hand Surg Am 2012;37(04):729–735
24 Yuan C, Zhang H, Liu H, Gu J. Does concomitant ulnar styloid fracture and distal radius fracture portend poorer outcomes? A meta-analysis of comparative studies. Injury 2017;48(11): 2575–2581

