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Dorsal Wrist Extrinsic Carpal Ligament Injury Exacerbates Volar Radiocarpal Instability After Intra-Articular Distal Radius Fracture

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Abstract

Background: Volar radiocarpal instability is often seen after loss of fixation of volar lunate facet fragments. The pathogenesis of post-traumatic volar radiocarpal instability is poorly understood. The purpose of this study was to determine if injury to the dorsal wrist extrinsic carpal ligaments contributes to volar radiocarpal instability. **Methods:** Six matched pairs of cadaveric upper extremities were tested using a dynamic hand testing system. In group 1, the intact wrist, the wrist with a volar lunate facet fracture, and the fractured wrist after 500 cycles of grip were tested. In group 2, in addition to the intact and fractured wrist, the fractured wrist with the dorsal extrinsic carpal ligaments cut and the fractured wrist with the dorsal extrinsic carpal ligaments cut after 500 cycles of grip were also tested. Volar-dorsal displacement of the lunate was measured from 45° wrist flexion to 45° wrist extension in 22.5° increments with the wrist flexors/extensors loaded for each condition. **Results:** Volar lunate translation did not significantly increase after the volar lunate facet fracture alone, and was not evident to a significant extent until the dorsal wrist extrinsic carpal ligaments were cut. Further instability of the lunate occurred after grip cycling only with the dorsal extrinsic capsular ligaments cut. **Conclusions:** Injury to the dorsal wrist extrinsic carpal ligaments exacerbates volar radiocarpal instability. Unrecognized dorsal sided injury may be a contributing factor to why stable fixation of volar lunate facet fragments remains problematic after volar plating of intra-articular distal radius fractures with displaced volar lunate facet fragments.

Keywords: distal radius fracture, volar lunate facet, volar radiocarpal instability, volar carpal subluxation, dorsal radiocarpal ligament, dorsal intercarpal ligament

Introduction

Distal radius fractures are among the most common injuries of the upper extremity. While volar plating can be used to treat most operative distal radius fractures,[1] loss of fixation of the volar lunate facet has been recognized as an important limitation of volar plating in the setting of comminuted intra-articular distal radius fractures.[2,3]

The volar surface of the distal radius is relatively flat, except for the very distal margin which projects volarly approximately 3 mm to form a ridge from which the volar radiocarpal ligaments originate.[4] Additionally, the distal cortical margin of the distal radius also slopes volarly from radial to ulnar in the axial plane. Due to this complex anatomy, standard monoblock volar distal radius locking plates may inadequately support volar lunate facet fragments.[3,4] Volar locking plates have evolved so that the ulnar corner is slightly longer, screws are positioned more distally at the ulnar corner than the radial corner, and screws can be placed at variable angles to lend more support to the volar ulnar corner. Placing volar locking plates more ulnar has also been suggested to provide adequate buttress of volar lunate facet fragments. However, patients with AO B3.3 fractures with a lunate facet fragment less than 15 mm in length remain at risk for failure and may require supplemental fixation even if the volar plate is properly placed.[2] Volar carpal subluxation can occur after loss of fixation of the volar lunate facet.[5,6] If left untreated, this can result in a loss

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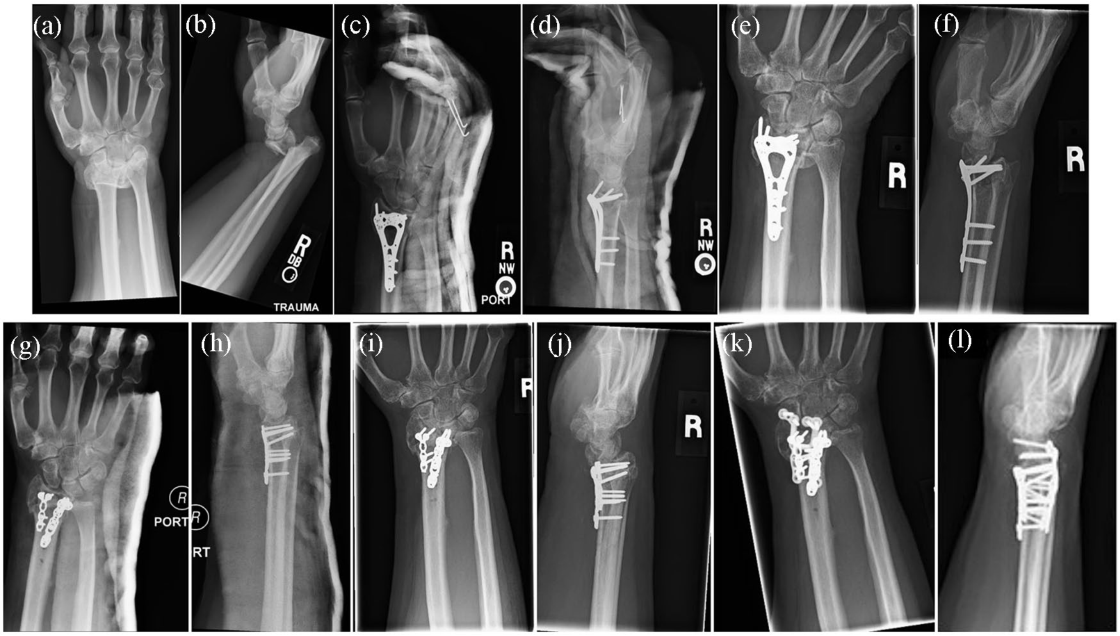

Figure 1. Clinical case implicating the dorsal extrinsic carpal ligaments in volar radiocarpal instability.
Note. (a-b) Initial injury radiographs. (c-d) Initial postoperative radiographs. (e-f) Eight weeks postoperative radiographs show loss of fixation of the volar lunate facet fragment and volar carpal subluxation. (g-h) Initial postoperative radiographs after revision open reduction and internal fixation (ORIF) with fragment specific plates. (i-j) Four weeks s/p revision ORIF radiographs showing continued volar carpal subluxation with apparent maintenance of fixation of the volar lunate facet fragment. (k-l) Four weeks postoperative radiographs after radioscapholunate fusion done through a dorsal approach showing complete disruption of the dorsal radiocarpal ligament and dorsal intercarpal ligament.

of range of motion, arthrosis, and pain.[5] The mechanism for volar carpal subluxation is still not well understood.

A recent clinical case at our institution involved a patient with a comminuted intra-articular distal radius fracture who was initially treated with a volar locking plate. The fixation subsequently failed with loss of fixation of the volar lunate facet (Figure 1). The patient underwent revision surgery with apparent stable fixation of the lunate facet, but continued to have volar carpal subluxation and dysfunction. Ultimately, the patient required reconstruction with a radioscapholunate fusion done through a dorsal approach. Exploration of the dorsal wrist capsule at the time of surgery revealed that the dorsal radiocarpal ligament (DRC) and dorsal intercarpal ligament (DIC) were completely disrupted. These surgical findings implicate the dorsal extrinsic carpal ligaments in post-traumatic volar radiocarpal instability. Therefore, the purpose of this study was to quantify displacement of the lunate in a volar lunate facet fracture model before and after hand grip cycling to determine the role of the dorsal extrinsic carpal ligaments in volar radiocarpal instability. Our hypothesis was that disruption of the DRC and the DIC will significantly increase volar lunate translation and that grip cycling will result in further increases of instability only when the DRC and DIC are transected.

Materials and Methods

Specimen Preparation

Six matched pairs of freshly frozen full upper extremity cadaveric specimens with an average age of 53 years (range 31-67 years) were used in this study. No gross evidence of prior wrist injury or surgery was evident in any of the specimens. The specimens were dissected of all soft tissues proximal to the hand except the wrist capsule, interosseous membrane, and tendon attachments of the flexor carpi ulnaris, flexor carpi radialis, extensor carpi radialis brevis, extensor carpi radialis longis, extensor carpi ulnaris, and flexor digitorum profundus (FDP). The specimens were kept moist with normal saline throughout preparation and testing. The forearm was fixed in neutral rotation (with the humerus positioned vertically and the elbow at 90°). Neutral forearm rotation was defined as the position where the radial styloid/lateral border of the radius was oriented 90° from the horizontal. The forearm was transected 16 cm from the tip of the radial styloid, and potted with plaster of Paris in 2” diameter polyvinyl chloride pipe measuring 6 cm in length. Care was taken to ensure neutral alignment in both the coronal and sagittal planes. Krackow stitches were placed in each individual preserved tendon for subsequent muscle loading. The middle finger extensor tendon was split to allow access to

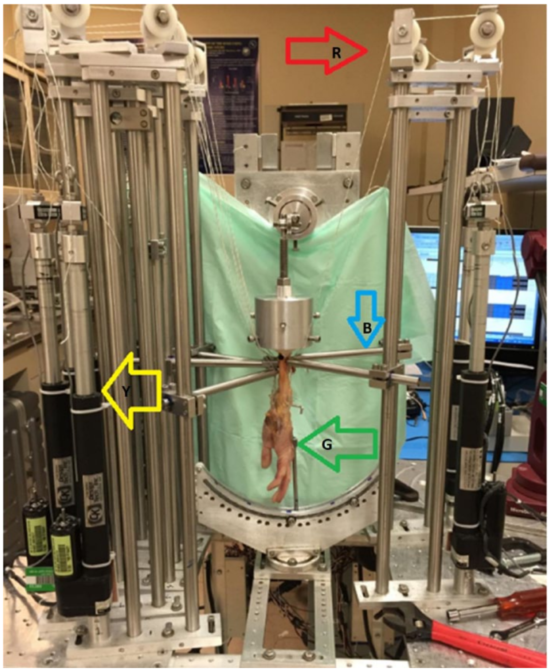

Figure 2. Custom dynamic hand testing system.
Note. Green (G) arrow: cadaveric specimen with rod inserted on the third metacarpal to control wrist position and tracking posts placed in the radius and lunate to calculate displacement of the lunate relative to the radius. *Yellow (Y) arrow*: load cell equipped servomotor actuators controlled by a LabVIEW interface that allows for customized loading sequences to be applied. *Red (R) arrow*: lines connected to tendons for muscle loading. *Blue (B) arrow*: lines connected to the tendons pass through guide rods prior to being attached to the actuators to allow for physiologic lines of pull.

the third metacarpal, and a custom plate was then securely fixed to the third metacarpal in-line with the shaft using two screws. A custom rod was later screwed into the plate and used to control wrist positioning in the jig (Figure 2). The fourth and fifth dorsal wrist extensor compartments were released to access the dorsal wrist capsule. Two tracking posts, which were custom-made from aluminum to minimize their weight effect, were then placed. One was placed in the dorsal aspect of the lunate and another into the dorsal radial shaft 5 cm proximal to the wrist joint. Preliminary studies in this lab have verified the utilization of these tracking posts and have shown that the weight effects of the tracking posts on kinematic measurements were negligible. To ensure that the tracking post in the lunate did not tether the dorsal capsule, a stab incision was made in the capsule where the post was to be placed and was elevated so that the tracking post was firmly seated against the lunate.

Custom Dynamic Hand Testing System

Specimens were tested using a custom dynamic hand testing system designed to obtain carpal kinematic measurements under custom loading protocols (Figure 2). The potted forearm was securely mounted into a custom fixture that simulated 90° of elbow flexion. The rod attached to the third metacarpal was placed in the center of a custom arc plate that allowed for passive wrist flexion and extension. For each specimen, the arc plate was adjusted such that a smooth wrist flexion-extension arc was obtained. For muscle loading, lines attached to the Krackow stitches of each individual muscle tendon were positioned through guide rods to achieve physiologic lines of pull and connected to a load cell (Transducer Techniques, Temecula, CA) equipped servomotor actuators (CK Design Technology, Simi Valley, CA). The actuators were controlled by a LabVIEW (National Instruments, Austin, TX) interface that allowed for application of customized loading sequences. A total of 100 N was applied across the preserved wrist flexors/extensors based on physiologic cross-sectional area (PCSA) ratios of each muscle. Muscle loading remained constant across all wrist positions.

All specimens were tested in positions of 45° of wrist flexion to 45° of wrist extension in 22.5° increments. These increments were measured by placing a digital goniometer flat on the rod attached to the third metacarpal plate and moving the rod accordingly. Within this tested range of motion, impingement of the lunate tracking post on the radius never occurred and would only be evident in extreme wrist extension. For each testing condition, a 1 N preload was applied to the wrist flexors/extensors and the wrist was placed and locked in the desired position. The wrist flexors/extensors were then fully loaded and kinematic measurements were taken by digitizing the tracking post positions using a 3D digitizer (MicroScribe, Revware Inc., Raleigh, NC). The wrist flexors/extensors were unloaded back to preload and loaded to their final load again to obtain repeat kinematic measurements. After the second kinematic trial, the wrist was unloaded and the next position/condition was tested in a similar fashion. The average of the two kinematic trials was used in the final analysis. A local coordinate system was established such that radial-ulnar translation occurred along the x-axis, proximal-distal translation occurred along the y-axis, and volar-dorsal translation occurred along the z-axis.

Volar Lunate Facet Fracture Model and DRC/DIC Sectioning

Following testing of the intact wrist, an isolated volar lunate facet fracture was created. Although isolated volar lunate facet fractures are not commonly seen, the fracture model is meant to simulate a multi-fragment distal radius fracture that has otherwise been well-fixed with loss of fixation of the volar lunate facet. A notch on the volar aspect of the distal radius between the lunate and scaphoid facets could be readily palpated and was used to define the width of our fragment. Beginning from this notch and extending

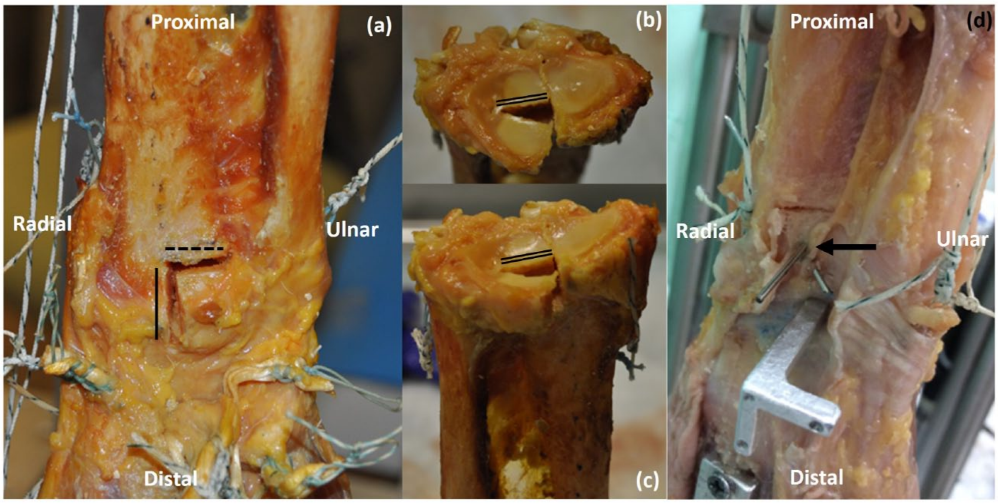

Figure 3. Volar lunate facet fracture model.
Note. (a) *Black line*—a vertical osteotomy in the sagittal plane was made starting from the notch between the scaphoid and lunate facet extending 15 mm proximally. This osteotomy exited out the dorsal cortex. *Dashed line*—a transverse osteotomy in the axial plane was started from the proximal extent of the vertical osteotomy and continued ulnarly. This osteotomy also exited out the dorsal cortex to create an en-bloc fracture fragment. (b) and (c) *Double line*—an additional transverse osteotomy in the coronal plane was made starting from the undersurface of the fracture fragment and exiting at approximately 50% of the lunate facet creating a volar and dorsal fracture fragment. (d) The dorsal fragment was reduced using a pointed reduction clamp and pinned in place using two crossing 1.62 K-wires (black arrow).

proximally, a 15 mm vertical osteotomy in the sagittal plane was made using a microsagittal saw (Figure 3a). The vertical osteotomy was completed dorsally and distally into the articular surface of the radius. A transverse osteotomy in the axial plane was made from the proximal extent of the vertical osteotomy to the ulnar border of the radius (Figure 3a). This osteotomy also exited dorsally to create an en-bloc fracture fragment. The fracture fragment was then translated volarly to expose its undersurface. Another transverse osteotomy in the coronal plane was made at the undersurface of the fragment extending intra-articularly, effectively splitting the lunate facet into a volar and dorsal fracture fragment (Figure 3b). The last osteotomy exited the articular surface about halfway through the lunate facet. The dimensions of the fracture fragments were based on the findings that fracture lines for the volar lunate facet fragment are more likely to extend into the region between the short and long radiolunate ligament attachments and the center of the sigmoid notch between the volar and dorsal radioulnar ligaments.[7] The dorsal fracture fragment was reduced and held provisionally using a pointed reduction clamp. The fragment was then pinned in place with two crossing 1.62 mm k-wires. The k-wires were then cut short to ensure that they wouldn't interfere with the specimen or testing (Figure 3d). No fixation of the volar fragment was performed and the volar fragment was left unreduced to mimic what would occur with loss of fixation of the volar lunate facet. In order to simulate injury of the DRC and DIC, both ligaments were completely excised in line with the ligament using an 11-blade scalpel (Figure 4).

Hand Grip Cycling

Oftentimes, volar radiocarpal subluxation is not seen at the initial time of injury and is recognized after an injured wrist has been immobilized for a period of time.[6] To simulate this situation, hand grip was applied by cyclically loading the four heads of the FDP based on PCSA with the wrist fixed in 22.5° of extension for 500 cycles. The total applied force with loading of the wrist flexors/extensors and the four heads of FDP was 165 N. To better isolate the effect of grip cycling, the specimens were divided into two groups such that grip cycling occurred after the fracture alone for group 1, and after both the fracture and dorsal extrinsic capsular ligaments were sectioned in group 2. Thus, in group 1, measurements were taken on the intact wrist, the wrist with a volar lunate facet fracture, and the fractured wrist after 500 cycles of grip. In group 2, the tested conditions included the intact and fractured wrist, the fractured wrist with the DRC and DIC cut, and the fractured wrist with the dorsal extrinsic capsular ligaments cut after 500 cycles of grip were tested. Each group was comprised of one specimen from each matched pair.

Measurements and Statistical Analysis

After testing was complete, the lunate was disarticulated with the tracking post still in place, and the geometry of the lunate relative to the tracking post was obtained. These data were then used to reconstruct a surface rendering of the lunate in Rhino 3D (McNeel & Associates, Seattle, WA). From this rendering, the volume centroid of the lunate was

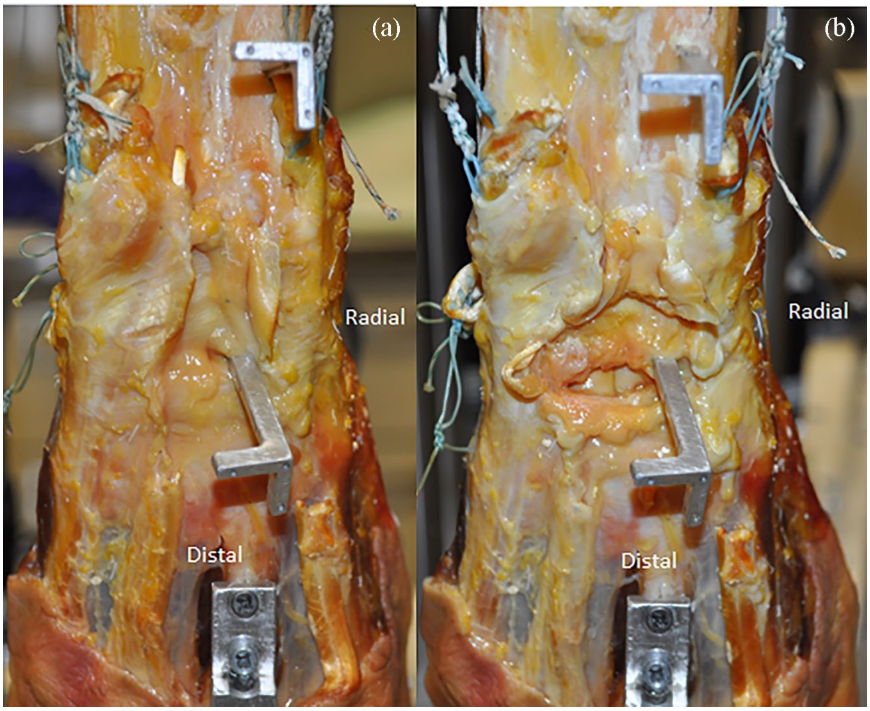

Figure 4. DRC and DIC sectioning.
Note. (a) Dorsal view of intact wrist with tracking posts. (b) Dorsal view of the wrist after DRC and DIC sectioning. DRC = dorsal radiocarpal ligament; DIC = dorsal intercarpal ligament.

determined. The changes in position of the lunate relative to radius at each testing position were calculated for each condition using the volume centroid. To simplify data presentation, only volar-dorsal translation is being reported. Statistical comparisons were performed using repeated measures analysis of variance with a Tukey's post-hoc test with a *P*-value lesser than .05 indicating significance.

Results

Translation of the lunate in the intact state ranged from 1.00 mm of volar translation at 45° of extension to 0.88 mm of dorsal translation at 45° of flexion. After the fracture, translation ranged from 1.51 mm of volar translation at 45° of extension to 0.48 mm of dorsal translation at 22.5° of flexion. Creation of the volar lunate facet fracture alone did not have a significant effect on volar-dorsal translation of the lunate at any wrist position ($P > .19$) (Figure 5). Significant increases ($P < .001$) in volar translation of 208% (0.59-1.82 mm) at 22.5° of wrist extension and 124% (1.00-2.24 mm) at 45° of wrist extension were noted after the DRC and DIC ligaments were cut (Figure 5). Hand grip cycling after the volar lunate facet fracture alone provided no additional significant effect ($P > .10$) on volar-dorsal lunate translation (maximum volar translation of 1.52 mm at 45° of extension and maximum dorsal translation of 0.08 at 22.5° of flexion). While hand grip cycling after both the volar lunate facet fracture and sectioning of the dorsal extrinsic capsular ligaments did not significantly further increase ($P > 0.43$) volar-dorsal translation at 22.5° (1.82-2.27 mm) and 45° (2.24-2.40 mm) of wrist extension, there were significant increases ($P < .02$) in volar lunate translation of 2467% (-0.06-1.42 mm) at neutral, 374% (-0.31-0.85 mm) at 22.5° of wrist flexion, and 162% (-0.74-0.46 mm) at 45° of wrist flexion relative to the pre-cycling condition (Figure 5).

Discussion

The findings of this study provide information on the pathogenesis of radiocarpal instability after intra-articular distal radius fractures with volar lunate facet fragments and suggest that volar radiocarpal instability is exacerbated after injury to the dorsal extrinsic carpal ligaments.

After the simulated fracture alone, there were no significant differences in volar-dorsal lunate translation at any wrist position. Significant increases in volar lunate translation were not noted until the DRC and DIC ligaments were sectioned. Various studies have suggested that inadequate fixation of volar lunate facet fragments of the distal radius may result in volar radiocarpal subluxation post-operatively.[5,6] It has generally been thought that volar radiocarpal subluxation results from the loss of bony stability as well as the functional avulsion of the short radiolunate ligaments.

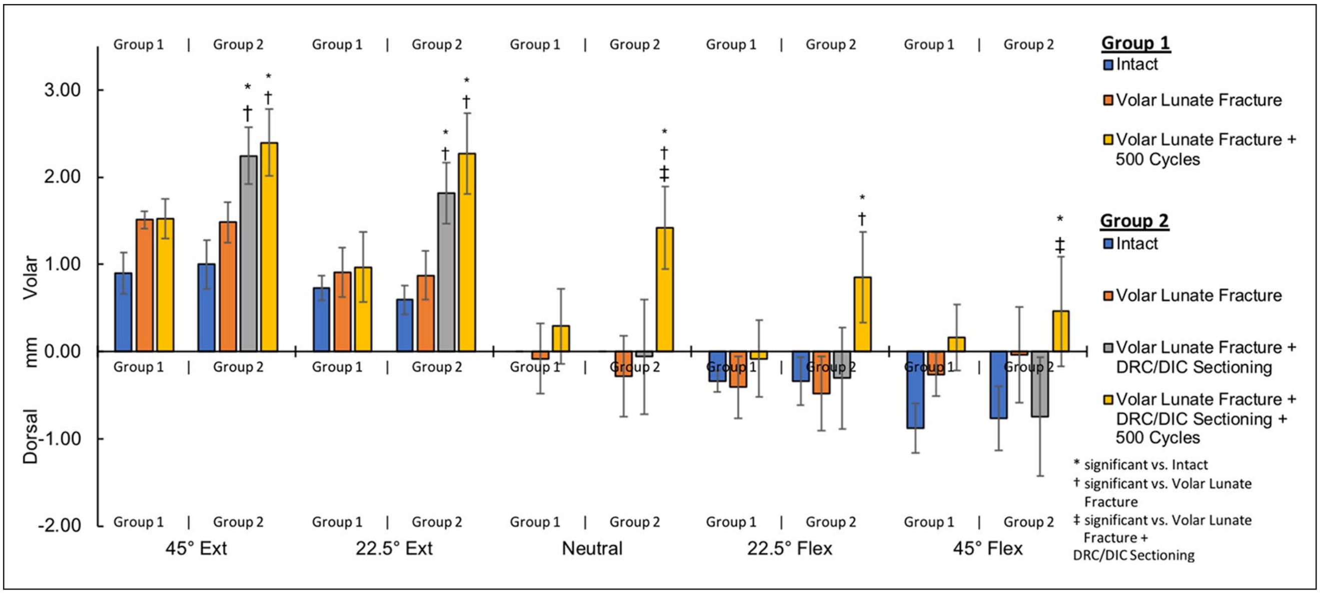

Figure 5. Volar-dorsal translation for both groups and each wrist position of extension (Ext) and flexion (Flex).
Note. DRC = dorsal radiocarpal ligament; DIC = dorsal intercarpal ligament.

However, our results suggest that soft tissue injury to dorsal side of the wrist capsule may be a significant contributing factor in the pathogenesis of volar radiocarpal subluxation as well, which has not yet been previously reported.

Hand grip cycling provides additional compressive loads across the wrist which may attenuate secondary restraints. Clinically, this may occur in patients treated with early motion protocols. In this study, grip cycling after the fracture alone had minimal effect on lunate translation, whereas cycling after both the fracture and dorsal extrinsic capsular ligaments were sectioned resulted in increased volar lunate translation, especially in the neutral and wrist flexion positions where reversal of translation direction occurred. These findings suggest that in the setting of the fracture alone, radiocarpal instability will be less likely to occur because the lunate is still tethered to its attachments to the dorsal capsule. These attachments would limit attenuation of any secondary soft tissue structures. However, when injury to the dorsal ligaments is present, increased translation of the lunate may attenuate secondary stabilizing structures and result in volar radiocarpal instability. Therefore, unrecognized injury to the dorsal extrinsic carpal ligaments may be a significant contributing factor to post-traumatic volar carpal instability. Volar lunate translation after cycling with the dorsal extrinsic capsular ligaments sectioned would cause the volar lunate facet to experience increased load. In addition to the inherent complex anatomy of the volar portion of the distal radius, this finding may help to explain why fixation of volar lunate facet fragments after volar plating of comminuted intra-articular distal radius fractures remains problematic.

The most pertinent findings of this study came from the volar-dorsal translation data and therefore translation in the radial-ulnar and proximal-distal directions were not reported. There were no clear trends or significant differences evident between conditions in terms of radial-ulnar translation. This is not an entirely unexpected finding as the radioscaphocapitate ligament was not violated in our injury model. Data in the proximal-distal direction showed significant proximal translation after the fracture was created. Sectioning of the dorsal ligaments alone did not result in significantly increased proximal translation. Grip cycling resulted in increased proximal translation regardless of dorsal ligament sectioning, but the effect was larger after dorsal ligaments were cut. Clinically, this proximal migration may contribute to the displacement of the volar lunate facet fragment. These trends in the proximal-distal translation data were similar to those in the volar-dorsal translation data and the decision was made not to report proximal-distal translation to simplify the data.

Injury to the scapholunate interosseous ligament (SLIL), the lunotriquetral interosseous ligament (LT), and the triangular fibrocartilage complex after distal radius fractures have been reported arthroscopically.[8-12] Richards et al[11] reported an incidence of partial or complete injury to any one of those ligaments to be as high as 98% after distal radius fractures and Geissler et al[9] found that a higher incidence of injury to these ligaments was found in fracture patterns with volar lunate facet fragments. None of these studies reported DRC or DIC ligament injury as these ligaments are difficult to visualize with standard dorsal wrist arthroscopy portals. While volar portals can be utilized to visualize the DRC,[13] this practice is not yet commonplace. Based on the findings of this study, concomitant injury to the DRC and DIC ligaments significantly increases volar radiocarpal instability in the setting of intra-articular distal radius fractures and further investigation regarding the true incidence of DRC or DIC injury after distal radius fractures is warranted.

Beck et al[2] reported that among patients who maintained reduction of the volar lunate facet, carpal translation preoperatively was 4.5 mm and among patients who lost reduction, carpal translation was 6 mm. The magnitude of volar translation of the lunate seen in this study is approximately 2.5 mm, and there are various reasons why the magnitude of displacement may have been smaller than is seen clinically. First, the only soft tissues that were disrupted in our model were the DRC and DIC. Injury to other ligaments commonly associated with intraarticular distal radius fractures, such as the SLIL or LT, would likely increase the magnitude of displacement. Furthermore, our model created a fairly large fracture fragment and although no fixation was used, the fragment may have been inherently stable due to its large size and shape. Additionally, we did not investigate the effect of different loads across the wrist and greater loads would likely cause more displacement. Despite these limitations, the focus of this study was not to determine the magnitude of translation of the lunate after a volar lunate facet fracture but to determine if injury to the dorsal ligaments resulted in more translation, which our model was able to demonstrate.

There are several other limitations of this study. As with all cadaveric biomechanical studies, this study was limited by the lack of *in vivo* soft tissue support, post-mortem soft tissue changes, and repeated testing and manipulation of a specimen. The number of wrist positions and applied muscle loads tested were limited. The DRC and DIC ligaments were sectioned at the same time, and the effect of isolated DRC and DIC sectioning is unknown. Furthermore, testing after stable fixation of the volar lunate facet fragment was not performed and the dorsal ligaments were never cut prior to creation of the fracture. Therefore, the effect of sectioned dorsal ligaments in the presence of a stable volar lunate facet is unknown. Other variables which may contribute to radiocarpal instability after volar lunate facet fractures such as injury to other soft tissue structures (SLIL, LT, the oblique band of the distal interosseous membrane) and the size of the fracture fragment were not investigated. Despite these limitations, this study provides important information in the pathogenesis of volar radiocarpal instability and may be useful to clinicians that treat complex distal radius fractures involving the volar-ulnar lunate facet. Based on this data, surgeons should consider the possibility of dorsal sided soft tissue injury when encountering patients with volar carpal subluxation after a distal radius fracture. Treatment of these complex injuries may require dorsal capsular repairs or supplemental fixation such as a dorsal spanning plate.

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Ethical Approval

This study was approved by our institutional review board.

Statement of Human and Animal Rights

This study was waived approval by the IRB committee at our institution as it is a cadaveric basic science study and does not involve humans or animals.

Statement of Informed Consent

Informed consent was obtained when necessary.

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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