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Scaphoid and lunate translation in the intact wrist and following ligament resection: A cadaver study

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Abstract

Purpose—The two purposes of this study were a) to determine the amount of scaphoid and lunate translation that occurs in normal cadaver wrists during wrist motion and b) to quantify the change in ulnar translation when specific dorsal and volar wrist ligaments were sectioned.

Methods—The scaphoid and lunate motion of 37 cadaver wrists were measured during wrist radioulnar deviation and flexion-extension motions using a wrist joint motion simulator. The location of centroids of the bones were quantified during each motion in the intact wrists and after sectioning either two dorsal ligaments along with the scapholunate interosseous ligament or two volar ligaments and the scapholunate interosseous ligament.

Results—In the intact wrist the scaphoid and lunate statistically translated radially with wrist ulnar deviation. With wrist flexion the scaphoid moved volarly and the lunate dorsally. After sectioning either the dorsal or volar ligaments, the scaphoid moved radially. After sectioning the dorsal or volar ligaments, the lunate statistically moved ulnarly and volarly.

Conclusion—These results indicate that measureable changes in the scaphoid and lunate translation occur with wrist motion and change with ligament sectioning. However, for the ligaments that were sectioned, these changes are small and an attempt to clinically measure these translations of the scaphoid and lunate radiographically may be limited. The results support the conclusion that ulnar translocation does not occur unless multiple ligaments are sectioned. Injury of more than the scapholunate interosseous ligament along with either the dorsal intercarpal and dorsal radiocarpal or the radioscapophcapitate and scaphotrapezial ligaments are needed to have large amounts of volar and ulnar translation.

Keywords

Scaphoid translation; lunate translation

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Introduction

Injury to the wrist may include complete or partial rupture of a number of ligaments. Detection of ligament injury may be difficult. A variety of methods have been used to look for any angular or translational changes of the carpal bones that might serve as an indicator of ligament damage. This requires knowledge of the intact carpal bone motion.

In the intact wrist, three dimensional motion of the carpal bones has been reported as a screw displacement axis representation of the motion ^{1,2}, as the angular motion of the bones ^{1,3-6} or as translations between the bones, however the latter has frequently been quantified as a displacement in the direction of the screw axis ⁷. Individual carpal translations in the intact wrist relative to the radius has been reported by Kobayashi et al ⁸. They reported that in wrist extension the carpal bones translated radially; in flexion, the lunate and triquetrum translated radially; and in ulnar deviation, the proximal row translated radially.

In the injured wrist, resultant changes in carpal motion has typically been reported as an angular change of the bone ⁹. However, little is known about the complete 3 dimensional translational motion of the scaphoid and lunate. Instead, most studies have been based on planar radiographs and have focused on describing ulnar translocation (ulnar movement of the carpal bones) ¹⁰⁻¹³ and its causes ¹⁴. Of interest, Robertson et al ¹⁵ have shown that the methods to quantify ulnar translocation are relatively insensitive to angular malalignment of the radiographed forearm. Song et al ¹⁶, using the methods of Gilula and Weeks ¹⁰ quantified ulnar translation of the lunate in perilunate dislocations. A problem with the measurement of ulnar translation of the lunate has been identified by Wollstein et al ¹⁷. They noted that its value varies with radial and ulnar deviation of the wrist because of the normal translation of the proximal carpal row in radioulnar deviation ⁸. The role of various capsuloligamentous structures in providing rotational stability to the carpus was studied by Ritt et al ¹⁸ however they did not report on the individual scaphoid and lunate translational motions. Wiesner et al ¹⁹ examined translational changes with sectioning of a variety of anatomical structures, but also did not report on the individual carpal motions.

The purpose of this study is to better quantify the amount of scaphoid and lunate three dimensional translation in the normal and injured wrist. Clarification of ligamentous injury and subsequent carpal translation may have important clinical consequences and significantly affect our treatment approach.

The two goals of this study were: 1) To determine how much the scaphoid and lunate translate during wrist motion in the intact cadaver wrist, 2) To determine how these translations might change after simulated injury to the wrist.

Methods

The motion of the scaphoid and lunate were measured in 37 fresh frozen cadaver wrists (average age of 67 years, range of 29 to 98; 22 male, 15 female) as each wrist was moved using a wrist joint motion simulator ²⁰. The methodology of this study was similar to that published previously ^{5,6}. Physiological forces were applied to 5 wrist flexor and extensor tendons to cause three types of motions: cyclic radioulnar deviation from 10° radial deviation to 20° ulnar deviation, cyclic flexion-extension from 50° flexion to 30° extension and cyclic dart throw motions. In the dart throw motion, the wrist moved back and forth from 30° of flexion and 10° ulnar deviation to 30° of extension and 10° of radial deviation. Electromagnetic motion sensors (Polhemus Fastrak, Polhemus, Colchester, VT) were indirectly attached to the scaphoid, lunate and radius via carbon fiber rods and acrylic platforms and directly to the third metacarpal, to continuously measure the angular and translational motion of these bones. The axes of wrist flexion-extension and radioulnar

deviation were defined to be in the same plane as, or perpendicular to, the radius and ulna respectively. Zero (neutral) flexion-extension and zero radioulnar deviation correspond to when the third metacarpal is collinear with the ulna.

Kinematic data for all 37 wrists were collected for all wrist motions with intact carpal ligaments and again following ligament sectioning. However the computed translational motions of the scaphoid and lunate were not available in all wrists due to computational or methodological problems. Data for all 37 wrists were available when all ligaments were intact for the flexion-extension and radioulnar deviation motions. During the dart throw motion, data was available in only 30 of the intact wrists.

Following wrist testing with intact ligaments, either a set of dorsal or volar ligaments were sectioned. For the volarly sectioned group, the scaphotrapezial, radioscapophcapitate and all components of the scapholunate interosseous ligaments were sectioned. In the dorsally sectioned group, the dorsal intercarpal, dorsal radiocarpal and all components of the scapholunate interosseous ligaments (SLIL) were sectioned. In 19 of the 37 wrists, during wrist flexion-extension and radioulnar deviation, data was collected after the volar ligaments were sectioned. In the volar ligament group of 19 wrists, during the dart throw motion, data was available in only 8 wrists. In 12 of the 37 wrists, during wrist flexion-extension and radioulnar deviation, data was available after the dorsal ligaments were sectioned. In the dorsal ligament group, during the dart throw motion, data was available for 17 of the wrists. The dorsal and volar ligaments and the SLIL were divided as previously described⁹.

After collecting kinematic data for the wrists in the volar and dorsal groups, each wrist was repetitively moved for 1000 cycles of flexion-extension to simulate repeated use of a wrist following injury. Kinematic data of the scaphoid and lunate were again collected during the wrist flexion-extension and radioulnar deviation motions. The computed translational data for the scaphoid and lunate were available for the 19 wrists in the volar group and the 12 wrists in the dorsal group.

After the final kinematic data collection was completed, each specimen was placed into a foam box and encased in expandable polyurethane foam to rigidly immobilize it. Each wrist was then CT scanned at 0.7 mm intervals. Electromagnetic kinematic data were recorded at the time of the CT scan. This combination of data determined the position of each sensor relative to the bone being monitored as well as in helping to construct the three dimensional models as described previously^{6,21}. The CT slices were reconstructed into three dimensional (3D) objects that were animated using the kinematic data. The 3D animated models of each scaphoid and lunate were analyzed in computer aided design software to determine the 3D volumetric centroid position of the scaphoid and lunate during each wrist motion while the wrist ligaments were intact as well as after they were sectioned. During each cycle of a wrist motion, 273 increments of scaphoid and lunate motion were analyzed. Additionally, the minimum distance between the scaphoid and lunate were computed at each increment of wrist motion. Due to how the bones were thresholded in the reconstruction software, this distance represents the cortical to cortical bone distance and not the cartilage to cartilage distance. At the conclusion of the experiment, each specimen was dissected to verify that there was accurate placement of sensors and that there was complete sectioning of the ligaments.

The motion of each centroid was tabulated in 3 directions: radial-ulnar, proximal distal, and dorsal-volar during the wrist motions. At 4 wrist radioulnar deviation positions: a) ten degrees of radial deviation, b) neutral wrist position as the wrist was moving from radial deviation to ulnar deviation, c) 10 degrees of ulnar deviation as the wrist was moving from radial deviation to ulnar deviation and d) at 20 degrees of ulnar deviation, data was

tabulated. At 9 wrist flexion extension positions (50, 40, 30, 20 and 10 degrees of flexion, neutral, 10, 20, and 30 degrees of extension as the wrist was moving from flexion to extension), data was tabulated. For the dart throw motion, data was tabulated at each 10 degree increment of wrist flexion. During the wrist radioulnar deviation motion, the centroidal position at the four wrist radioulnar positions were referenced back to the centroidal position with the wrist in neutral but as the wrist was moving from ulnar deviation to radial deviation. For the flexion-extension motion and the dart throw motions, the centroid positions were referenced to the neutral position with the wrist moving from extension to flexion. By using a neutral reference position as the wrist was moving in the opposite direction as the analyzed data, it was possible to determine if the centroid position was dependent upon which direction the wrist was moving.

Changes in the translational positions of the scaphoid and lunate centroids for the intact wrist were statistically analyzed by using a one way repeated measures ANOVA at $p < .05$. Two factor, repeated measures ANOVAs were used to examine changes in the centroid position after the ligaments were sectioned with one factor being wrist angle and the other factor being whether the ligaments were sectioned or intact. A Bonferroni correction for multiple comparisons was used for the comparison of the main effects. Two factor repeated measure ANOVAs were used to examine changes in the minimum distance between the scaphoid and lunate with one factor being wrist angle and the other factor being the integrity of the ligaments.

Results

Translation of the scaphoid and lunate volumetric centroids

In the intact wrist, the translational position of the scaphoid centroid was statistically different at the different wrist positions for all 3 wrist motions in the radial-ulnar ($p < .007$), dorsal-volar ($p < .006$) and distal-proximal ($p < .001$) directions. The same was seen for the lunate ($p < .001$) except there was no statistical change in the distal-proximal centroid location during any wrist motion ($p > 0.124$) and there was no change in the dorsal-volar location ($p > 0.437$) during the wrist radioulnar deviation motion. The largest of the centroid changes occurred during wrist radioulnar deviation. In 20 degrees of ulnar deviation, the scaphoid moved radially 3.1 mm and the lunate 3.0 mm (figure 1). During wrist flexion-extension, the scaphoid and lunate centroids moved in opposite directions (figure 2), with the lunate moving dorsally and the scaphoid moving volarly in wrist flexion.

After the dorsal ligaments were sectioned (dorsal group), the only statistical change in the scaphoid centroid position was in the radial-ulnar direction ($p = 0.034$) during the wrist flexion-extension motion (figure 3). After the volar ligaments were sectioned (volar group), the only statistical change in the scaphoid centroid position was also in the radial-ulnar direction ($p = 0.043$) during the dart throw motion.

Statistical changes in the lunate centroid position were observed after the dorsal ligaments were sectioned a) during wrist flexion-extension in the radial-ulnar direction ($p = 0.008$, figure 3) and the dorsal-volar direction ($p = 0.014$), b) during wrist radioulnar deviation in the dorsal-volar direction ($p = 0.017$, figure 4) and c) during the dart throw motion in the dorsal-volar direction ($p < .001$). Of interest during wrist flexion-extension, after the dorsal ligaments were sectioned, the scaphoid statistically moved radially and the lunate statistically moved ulnarly (figure 3). After the volar ligaments were sectioned, the lunate centroid position changed a) during wrist flexion-extension in the radial-ulnar direction ($p = 0.008$) and in the distal-proximal direction ($p = .002$), b) during wrist radioulnar deviation, in the dorsal-volar direction ($p = 0.023$, figure 4) and c) during the dart throw motion in the dorsal-volar direction ($p = .045$).

After 1000 cycles of repetitive motion, there were no additional statistical changes in scaphoid centroid translation in either the dorsal or volar groups. However for the lunate, there were either greater statistically significant changes (dorsal group, figure 3) or new statistical changes in the centroid position (volar group). The exceptions were that the lunate no longer had a statistical change in the distal-proximal translation in the volar group during wrist flexion-extension and in the dorsal group during wrist radioulnar deviation.

Minimum distance (gap) between the scaphoid and lunate

The minimum distance between the scaphoid and lunate in the intact wrists was available in 34 of the wrists for both wrist flexion-extension and radioulnar deviation. In the intact wrists, during wrist flexion-extension the distance varied from 2.6 mm at neutral to 3.0 mm at 50 degrees of flexion. During radioulnar deviation, the distance varied from 2.3 mm at 10 degrees of radial deviation to 3.4 mm at 20 degrees of ulnar deviation. However, these changes were not statistically significant.

After sectioning the ligaments and 1000 cycles of wrist motion, there was a statistical increase in the gap during wrist flexion-extension (figure 5) and during wrist radioulnar deviation (figure 6) regardless of whether the dorsal or volar ligaments had been sectioned ($p < 0.008$).

Discussion

These results indicate that the centroids of the scaphoid and lunate do translate with wrist motion, especially radially during ulnar deviation. These results compare well with Craig and Stanley²² who analyzed radiographs of 52 wrists, showing there is ulnar translation of the scaphoid as the wrist moves from ulnar to radial deviation. In our study at 20 degrees of ulnar deviation, the centroid the scaphoid moved radially 3.1 mm and the lunate 3.0 mm (figure 1). In the dorsal-volar direction, the centroid of the entire scaphoid moved volarly 1.6 mm at 50 degrees of flexion (figure 2) whereas the centroid of the lunate moved dorsally 1.6 mm at 50 degrees of flexion (figure 2). Since the scaphoid is an oblong bone, the centroid of its volume would be expected to move volarly with flexion.

One limitation of this study is that it is an in vitro study and may not be directly comparable to in vivo kinematics. Also, the influence of lunate type on scaphoid and lunate kinematics was not investigated. Galley et al²³ have shown wrists with a type I lunate have greater scaphoid translation with radial deviation. Another limitation is that the study did not include an examination of the role of the short and long radiolunate ligaments.

A post hoc power study demonstrated that a sample size of 37 arms was more than enough to have 90% power with 95% confidence to show changes in scaphoid and lunate centroid translational changes at 50 degrees of flexion and 20 degrees of ulnar deviation with the wrist ligaments intact. With ligament sectioning, and thus fewer specimens, the available number of specimens were sufficient to have 70% power and 95% confidence for most of the lunate motions but none of the scaphoid motions. Only with less power and confidence were there enough samples for the changes in the scaphoid motions.

Following simulated ligamentous injury, statistical changes in the centroid position occurred primarily in the radial-ulnar direction for the scaphoid but in both the radial-ulnar and dorsal-volar directions for the lunate. The ulnar (and volar) direction is the logical direction of translation of the carpus considering the normal anatomy of the distal radius surface. For this reason, this direction of movement may be associated with many ligamentous wrist injuries. In this study, the lunate moved ulnarly (figure 3) and volarly (figure 4) supporting

the potential value of two dimensional radiographic measurements such as those performed by Song et al.¹⁶

However the individual scaphoid and lunate translational changes after simulated injury were relatively small and perhaps not easily detectable using a radiographic method as might be used by a surgeon as an initial screening method. Perhaps if precise neutral wrist angle positions could be achieved in the injured and contralateral wrists, planar radiographic methods will be of use in measuring individual scaphoid and lunate translations.

After simulated injury the scaphoid centroid moved radially (figure 3). The combined lunate ulnar motion and the scaphoid radial motion resulted in the increase in the gap between the cortical surfaces of the bones (figure 5). The magnitudes are not quite equivalent since the centroid translations were measured at a different location in the bones than where the gap was measured. The combined scaphoid and lunate translation (or the gap between the bones, figure 5) can be a valuable indicator (as it already is) of scapholunate ligament injury due to the gap magnitude being readily visible and that a gap is detectable during much of a wrist motion.

Since the measured carpal bone translations were relatively small, these results support those of Viegas et al.²⁴ that ulnar translocation does not occur unless multiple ligaments are sectioned. They found sectioning of the radioscaphocapitate and long radiolunate ligaments or either the dorsal ulnar lunate or palmar ulnar lunate ligament alone, cannot cause volar and ulnar translocation. Thus a majority of both the dorsal and volar ligaments need to be sectioned to produce this form of instability. The present study comes to the same conclusion. Statistically significant changes in the motion of the lunate centroid and scaphoid centroid occurred following ligament sectioning, however the magnitude of these changes was small, at most 2 mm (figure 3). Neither initial sectioning of the dorsal ligaments plus the SLIL or sectioning the volar ligaments plus the SLIL result in ulnar translocation. Injury of more than the SLIL along with either the radioscaphocapitate and scaphotrapezium or the dorsal intercarpal and dorsal radiocarpal ligaments is needed to have large amounts (greater than 2 mm) of volar and ulnar translations. Therefore, clinical evidence of ulnar translocation warrants concern that a majority of the dorsal and volar ligaments have been damaged.

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Figure 1. Centroid motion of the scaphoid and lunate in the intact wrist, in the radial-ulnar direction, during wrist radioulnar deviation. The scaphoid and lunate both moved radially as the wrist moved into ulnar deviation.

Figure 2. Centroid motion of the scaphoid and lunate in the intact wrist, in the dorsal-volar direction, during wrist flexion-extension. The lunate moved dorsally and the scaphoid moved volarly as the wrist moved into flexion.

Figure 3.

Changes in the scaphoid and lunate centroid positions from the corresponding intact location, in the radial-ulnar direction, during wrist flexion-extension, after the dorsal ligaments and SLIL were sectioned. The scaphoid moved radially and the lunate moved ulnarly, especially as the wrist flexed. The “initial change” in displacement is just after the ligaments were sectioned whereas the displacement “after 1000 cycles” is the response after repetitively flexing and extending the wrist for 1000 cycles after the ligaments were sectioned.

Figure 4. Changes in the lunate centroid positions from the corresponding intact location, in the dorsal-volar direction, during wrist radioulnar deviation, after the dorsal ligaments and the SLIL were sectioned and after the volar ligaments and the SLIL were sectioned.

Figure 5.

The minimum cortical to cortical bone distance between the scaphoid and lunate during wrist flexion-extension, in the intact wrist, after the dorsal ligaments and SLIL were sectioned and after the volar ligaments and SLIL were sectioned.

Figure 6. The minimum cortical to cortical bone distance between the scaphoid and lunate during wrist radioulnar deviation, in the intact wrist, after the dorsal ligaments and SLIL were sectioned and after the volar ligaments and SLIL were sectioned.