SCIENTIFIC ARTICLE

Prediction of Ligament Length and Carpal Diastasis During Wrist Flexion–Extension and After Simulated Scapholunate Instability

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Purpose To determine the role of the carpal ligaments during wrist flexion-extension and to understand whether maintaining integrity of only the dorsal scapholunate ligament (SLL) is adequate for maintaining stability of the scapholunate joint.

Methods This study combined motion analysis and manual digitization of ligament attachment regions to generate predictions of carpal ligament length and implied strain during wrist motion and length changes after simulated ligamentous injury.

Results We modeled 13 ligaments and 22 ligament segments (subportions). We measured ligament length change with respect to wrist angle. A total of 11 segments had minimum stretch or elongation from neutral wrist position over the entire wrist range of motion for any ligament cut condition. The remaining 11 segments had more than 10% stretch in some portion of flexion-extension. In general, ligaments had increased stretch during wrist flexion and after cutting the entire SLL and the dorsal intercarpal ligaments off the scaphoid.

Conclusions Disruption of the membranous and palmar portions of the SLL and the dorsal intercarpal ligament off the scaphoid did not result in the development of an increased 3-dimensional scapholunate gap, as measured by differences in ligament length calculations between the scaphoid and lunate. This may indicate a predynamic instability condition (before clinical signs and x-ray findings) that is stabilized by the dorsal SLL, preventing the increase in the 3-dimensional scapholunate gap. This may also support surgical treatment recommendations, which suggest that repair of the dorsal component only of the SLL will be effective. Disruption of the dorsal intercarpal ligament off the scaphoid or lunate did not result in further significant changes. Therefore, the dorsal SLL has an important role in preventing scapholunate ligament instability.

Clinical relevance These results provide insight into the abnormal kinematics as various ligaments are compromised. *(J Hand Surg 2013;38A:509–518. Copyright © 2013 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Carpal kinematics, simulated active motion, passive motion.

Kinematics of the carpals is complex. Movement of the carpals is mostly determined by articular contact and ligamentous tethers, and not by direct muscular attachments and forces. It is therefore difficult to predict motion of the bones after ligament tears using current imaging and clinical techniques. The term *scapholunate instability* describes a spectrum of clinical conditions, which makes it

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difficult to diagnose mild or moderate sprains not evident on x-rays.[1] Linscheid et al[2] described scapholunate (SL) dissociation and detailed the loss of mechanical linkage between the scaphoid and lunate. Later, Mayfield et al[3] described the progressive stages of perilunate instability. It is believed that carpal instability is more common than previously thought, and that degenerative disease may be the late result of undiagnosed instability.[4]

Scapholunate instability has been described in 3 stages: predynamic, dynamic, and static.[5,6] Few studies have provided insight into what ligaments contribute to these various stages of instability. Short et al[7,8] investigated the stabilizing role of the scaphoid and lunate ligaments. They reported that the SL ligament (SLL) is the primary stabilizer of the joint, and the other ligaments were secondary stabilizers. Meade et al[4] showed that division of the palmar portion of the SLL resulted in minimal radiographic change. Only after the radioscaphocapitate ligament was divided did the SL gap substantially widen. Ruby et al[9] also found that dividing the dorsal capsule and entire SLL resulted in an SL diastasis.

These studies indicate that the SLL and dorsal capsule are important to maintaining stability in the carpus. Viegas et al[10] described additional anatomical information and the role of the dorsal ligaments. The authors determined that these ligaments form a lateral "V" construct to afford indirect stability to the scaphoid. Mitsuyasu et al[11] followed up this research with a biomechanical evaluation and determined that when the dorsal intercarpal ligament (DICL) and the SLL were disrupted from the scaphoid, but the DICL was still attached to the lunate, the result was a flexed posture of the scaphoid and a widened SL gap, but only when the hand was loaded (dynamic instability). When the DICL was also disrupted from the lunate, the result was a flexed posture of the scaphoid, an extended posture of the lunate, and a widened SL gap in the unloaded condition (static instability). The progression of a dynamic to a static deformity is well accepted in the clinical setting. However, before the work of Mitsuyasu et al, there were no detailed anatomic explanations or examples of the causes of and differences between a dynamic and static instability.

The first purpose of this study was to determine the role of the carpal ligaments during normal wrist flexion-extension motion. The second purpose was to determine whether maintaining integrity of only the dorsal SLL was adequate for maintaining stability of the SL relationship.

MATEIRALS AND METHODS

We studied 6 fresh-frozen cadaver upper extremities free from visible or radiographically identifiable deformities or degenerative changes. There were 3 right and 3 left wrists; 5 were male and 1 was female, with an age range of 28 to 59 years. We measured carpal kinematics using previously reported methods.[12,13] Briefly, we placed titanium screws into the dorsal surface of the radius, ulna, scaphoid, lunate, triquetrum, and capitate under fluoroscopic guidance. We glued 2-mm-diameter graphite rods to the head of each screw. At the end of each rod was a triad pin that had three 5-mm-diameter spheres placed in a cruciform arrangement on top. The plastic spheres were coated with 3M reflective tape (St. Paul, MN). We oriented the sphere and rods to ensure that they would not come into contact with each other during full passive flexion-extension of the wrist. The rods were rigidly attached in the bones. The rod weight was approximately 0.8 g and did not flex or vibrate independently (by visual observation). We positioned them to avoid tendons and avoid or minimize tethering of the capsule and/or ligaments. We connected the flexor carpi ulnaris and extensor carpi ulnaris tendons to each other by wires that looped around a freely moving pulley. The flexor carpi radialis and extensor carpi radialis brevis tendons were treated identically. Each loop was weighted with 11.1 N (total across the wrist, 22.2 N, or 10 lb) of weight. One pulley was attached to the radial extensor-flexor pair and the other to the ulnar extensor-flexor pair. These floating pulleys allowed free movement of the tendon pairs during motion and allowed the pairs to move synergistically and approximate normal muscle tone. We placed a 3-mm-diameter metal pin into the medullary canal of the third metacarpal and used it as a guide to move the wrist passively through a flexion-extension motion (minimizing out-of-plane motion). The elbow was fixed in 90° flexion and the forearm in neutral, and the arm was placed on the table for testing (with the humerus parallel to the table). We did not restrict radial and ulnar deviation.

We used a 6-camera optical motion analysis system (Motion Analysis Corp., Santa Rosa, CA) to track the 3 reflective markers for each carpal as the wrist was manually driven through 2 cycles of wrist flexion-extension. Then we tested each wrist in a series of progressive and cumulative disruptions of the intercarpal ligaments. Each sequence simulated our hypothesized series of increasing stages of carpal instability of the wrist. The ligaments were cut through a small incision in the wrist capsule, to simulate a total tear of each ligament. The order of ligament cuts was as follows: (1) membranous portion of the SLL (membranous SLL) and palmar portion of the SLL (pal-