Deciphering Wrist Dynamics: Unraveling the Impact of Scapholunate Ligament Injuries On Wrist Stability, Kinetics, and Treatment Options in Orthopaedics Practice

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Introduction: The human wrist is one of the body's most complex joints, providing a wide range of motion in different planes. The scapholunate ligament (SLL) is one of the primary stabilizers of the Scapholunate joint and one of the most commonly injured intercarpal ligaments.
A few cadaveric studies have been published that examine wrist kinematics, particularly the alterations in wrist movement following SLL injuries. Our study, however, concentrates on the intracarpal and radiocarpal region following post-SLL rupture, incorporating a finite element (FE) model.
Our hypothesis suggests that a tear of the SLL results in atypical deviations within the carpal joint, thereby altering joint angles and, in turn, influencing the contact pressures, which may predispose the joint to early arthritis.
Through experimental testing and virtual simulation, this study aims to investigate the intricate wrist SL joint behavior responses caused by both partial and full tears of the SL ligament and provide insight into changes in anatomical bone instability and contact stress propagation for different grip loading conditions.

Method: Eight wrist specimens' Contact pressure and movement were tracked with sensors attached to the scaphoid and lunate bones. A total of 72 ligaments were modeled using linear spring elements (SPRING) between the bony structures with stiffness values ranging between 10 and 350 N/mm.
Cartilages were modeled using the two-parameter Mooney Rivlin hyperelastic model.
The FE model is a patient-specific three-dimensional (3D) reconstructed wrist joint from computed tomography (CT) images, employed to replicate wrist kinematics and investigate pressure distribution. Friedman test with pairwise comparisons used to determine differences in movement and contact pressure among conditions

Result: The movement of the scaphoid and lunate bones significantly varied with ligament conditions, showing increased scapholunate displacement in X (distal-proximal) directions and a decrease in Y (medial-lateral) directions for complete tears. Lunate and scaphoid angles significantly shifted from flexion to extension and extension to flexion when moving from a fully intact or partially torn ligament to a fully torn ligament, respectively (Table 1). The proximal movement was observed in all groups, with significant Radial deviation of the scaphoid and lunate found when the ligament is damaged (Fig. 1). While all groups moved toward the volar direction in the z-direction, showing significant disparities, notably, the full tear group had the least volar movement ($p < 0.05$). A rise in contact area was noted in both wrist and fingers in the presence of a ligament tear; statistical significance was not established. Conversely, only finger pressure exhibited a statistically significant decrease in the presence of a scapholunate ligament tear. The findings, confirmed by finite element analysis, accurately replicated scaphoid and lunate movements from the experiments, with peak radiocarpal pressure significantly differing between intact and fully torn ligaments (Fig. 2) ($P < 0.05$).

Discussion: Damage to SLL significantly alters wrist joint stability, particularly affecting the movement and rotation of the scaphoid and lunate bones. These injuries lead to radial deviation and proximal displacement of the scaphoid and lunate bones, accompanied by a shift in contact area towards the radial side. The untreated condition could potentially lead to early arthritis; thus, there is a need to intervene as early as possible. Our study has several limitations, including the static loading conditions, the use of cadaveric models failing to incorporate dynamic fluidity, and the choice of mesh density to represent the geometries of the wrist structures.

Significance/clinical relevance: Our experimental results validate the radial deviation that occurs with SLL injury, and they were further validated through finite element analysis, suggesting its potential utility in clinical decision-making and treatment selection in the future. The model is a patient-specific 3D reconstructed wrist joint using CT images from the patient, which allows us to investigate the extent of the injury and the possible patient-specific treatment available.

Scapholunate Gap	Fully Intact	Partial Tear	Full Tear	P-value
X Coord	-0.29 ± 0.34 [a]	0.17 ± 0.41 [b]	0.36 ± 0.66 [b]	<0.05
Y Coord	0.95 ± 0.37 [a]	0.11 ± 0.10 [b]	0.26 ± 0.14 [c]	<0.05
Z Coord	-2.30 ± 1.06 [a]	-1.35 ± 0.87 [b]	-1.03 ± 0.62 [c]	<0.05
Angle	**Fully Intact**	**Partial Tear**	**Full Tear**	**P-value**
Lunate	-15.7 ± 17.9 [a]	-20.4 ± 7.9 [a]	5.17 ± 5.32 [b]	<0.05
Scaphoid	27.3 ± 16.3 [a]	-37.0 ± 19.9 [b]	-25.5 ± 12.3 [c]	<0.05

Table 1. Comparative Analysis of Scapholunate Distance and Angle Following Loading Initiation for Each Ligament Case.

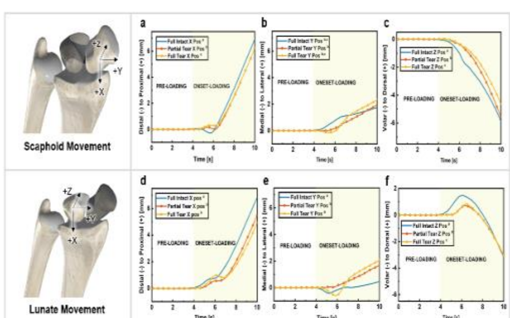

Fig. 1. Total Scaphoid and Lunate Movement. (a)-(c) depict the scaphoid movement in the X, Y, and Z directions, respectively, while (d)-(f) illustrate the lunate movement in the X, Y, and Z directions. Each y-axis represents a distinct anatomical direction over time, with superscript letters alongside each group legend indicating significant differences, denoted by varying letters.

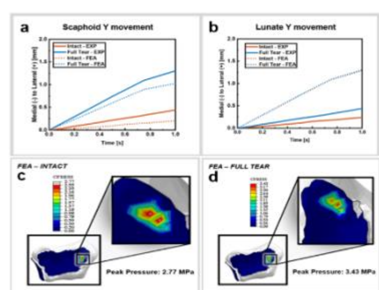

Fig. 2. FEA results in comparison with experimental measurements: (a) Scaphoid differential in displacement along the Y axis; (b) Lunate differential in displacement along the Y axis; (c) Radiocarpal contact pressure for intact scapholunate ligament condition and (d) Radiocarpal contact pressure for complete tear scapholunate ligament condition.