

Rotational Kinematics of Scapholunate Injury and Fixation: A Biomechanical Analysis Using Euler Angles

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INTRODUCTION:

Scapholunate (SL) ligament injuries disrupt normal carpal kinematics, leading to progressive radiocarpal and midcarpal arthritis, pain, and instability, and often require surgical fixation. The purpose of this study was to determine if augmentation through the reduction and association of the scaphoid, capitate, and lunate (RASCL) with a temporary scaphocapitate (SC) screw would decrease SL rotation under cyclic loading. While the RASL procedure can restore anatomic alignment of the carpus, the most common complication is SL joint widening. We hypothesized that RASCL would confer greater rotational stability than RASL alone. In addition, we analyzed axis-specific motion of the scaphoid following scapholunate interosseous ligament (SLIL) disruption to determine whether pathological rotation primarily occurs in the medial-lateral (x), proximal-distal (y), or pronosupination (z) axis. We report rotational findings across SLIL-intact, SLIL-injury, RASL, and RASCL conditions.

METHODS:

Twelve fresh-frozen cadaveric upper extremities (age range 33-64) without evidence of upper extremity injury were harvested via transradial amputation. Specimens were mounted on a custom jig positioned to grasp a bar attached to an Instron testing system and axial compressive force was applied, simulating clenched-fist grip. Each specimen underwent cyclic transcarpal axial loading at 150 Newtons (N), 200 N, and 250 N for 20 cycles under four conditions: SLIL-intact, SLIL-injury, RASL, and RASCL models.

The SLIL-injury model was created by sharply transecting the entire SL ligament as well as the portion of the dorsal intercarpal ligament ulnar to the most ulnar aspect of the scaphoid. Reflective infrared (IR) markers were rigidly affixed to the scaphoid, lunate, and capitate; real-time motion was tracked via a Vicon motion capture system, and rotational kinematics were measured for each condition. The primary outcome—net three-dimensional rotational displacement (°)—was defined as the root mean square of the Euler angles across x, y and z axes. Repeated measures ANOVA tests (RM-ANOVA) with Sidak post hoc correction were performed for each force level to assess differences among conditions; statistical significance was defined as $p < 0.05$.

To identify the predominant axis of pathological motion following SLIL injury, we compared axis-specific rotation (x, y, or z) between SLIL-intact and SLIL-injury conditions. Paired t-tests were used to determine statistically significant differences, with significance set at $p < 0.05$.

RESULTS:

One specimen was excluded as a statistical outlier using the ROUT method ($Q=0.1$). At 150 N, RM-ANOVA demonstrated significant differences in Euler angle means between SL-intact and SL-injury ($p=0.019$) and SL-injury and RASCL ($p=0.045$). At 200 N and 250 N, significant differences were observed between SL-intact and SL-injury ($p=0.017$, $p=0.041$), SL-injury and RASL ($p=0.010$, $p=0.023$), and SL-injury and RASCL ($p=0.008$, $p=0.030$). No significant difference was observed between SL-injury and RASL at 150 N, nor between SL-intact, RASL, and RASCL conditions at any force level.

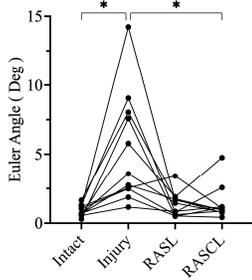
Scaphoid z-axis rotation was significantly greater in the SL-injury compared to SL-intact condition at all force levels (150 N: $p=0.013$; 200 N: $p=0.040$; 250 N: $p=0.036$). No significant differences were found in x- or y-axis rotation at any force level.

DISCUSSION AND CONCLUSION:

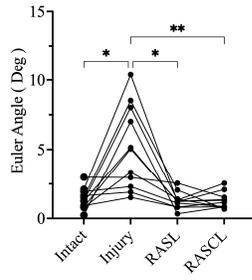
This study investigates scapholunate rotational kinematics using Euler angles to compare SLIL-intact, SLIL-injured, RASL, and RASCL conditions. RASCL consistently demonstrated significant reductions in SL rotation compared to the injury state across all force levels. No significant differences were found between RASL and RASCL, supporting their

biomechanical validity in reducing SL rotation. Notably, pathological scaphoid motion was predominantly observed in the z-axis (pronosupination), suggesting that rotational control in this axis may be a critical target for fixation strategies.

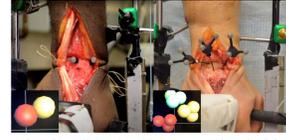
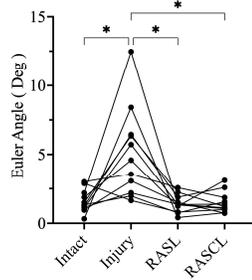
Scapholunate Rotation at 150N



Scapholunate Rotation at 200N



Scapholunate Rotation at 250N



Specimens with embedded IR markers and clusters to capture real time motion gripping Instron rig crossbar. Vicon software allows 3D recreation (inset) of both static and dynamic motion to measure St, distasis (left) and SL angulation (right).