Scapholunate and Lunotriquetral Ligament Injuries Associated With Distal Radius Fractures: The Effect of Wrist Position and Forearm Rotation During a Fall Onto an Outstretched Hand

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Background/Purpose: The prevalence of scapholunate (SL) and lunotriquetral (LT) ligament injury with distal radius fractures can be as high as 54% and 20%, respectively. This unique in vitro biomechanical model simulated 4 different fall mechanisms: external rotation (ER) with neutral hand position, ER with ulnar deviation (UD), internal rotation (IR) with neutral hand position, and IR with radial deviation (RD) to evaluate if hand position and forearm rotation during a fall can influence whether an LT ligament tear occurs or not.

Methods: Fluoroscopic images, MRI scans, and dual energy x-ray absorptiometry (DEXA) bone mineral density measurements of the wrist were obtained for 48 fresh frozen cadaveric arms. Arms were transected 18 cm proximal to Lister's tubercle and then mounted at 80° of wrist extension and full pronation. In the first set of 24 arms, 8 were mounted perpendicular to the materials testing system (MTS) table top, 8 were RD 10° to 15°, and 8 were UD 10° to 15°. In the second set of 24 arms, 12 underwent 5 N-m of ER, with 6 of the arms perpendicular to the MTS table top and the other 6 UD 10° to 15°. The last 12 arms underwent 5 N-m of IR, with 6 of the arms perpendicular to the MTS table top and the other 6 RD 10° to 15°. The arms were then loaded on an MTS machine and axially displaced 2.5 cm at a compression rate of 5 cm/sec. Postinjury fluoroscopic images and MRI scans of the wrist were obtained and analyzed.

Results: All of the arms sustained a distal radius fracture. Post-test MRI revealed that 17 (35%) of the arms sustained an SL ligament tear, and 16 (33%) sustained an LT ligament tear. Of the 24 arms that did not undergo a rotational force, 5 (21%) sustained an SL or LT ligament tear. In contrast, of the 24 arms subjected to a rotational force, 18 (75%) were found to have either a SL or LT tear (Figure 1).

Discussion: SL and LT ligament tears were found to be associated with distal radius fractures in 75% of arms subjected to a rotational force, whereas only 21% of the arms with a static forearm displayed such an injury. Further investigation is needed to determine if a specific fall pattern is associated with an SL or LT tear.

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Significance: Practitioners should maintain a high suspicion of SL or LT injury in patients who sustain a distal radius fracture after a fall onto an outstretched hand, particularly when forearm rotation is involved.

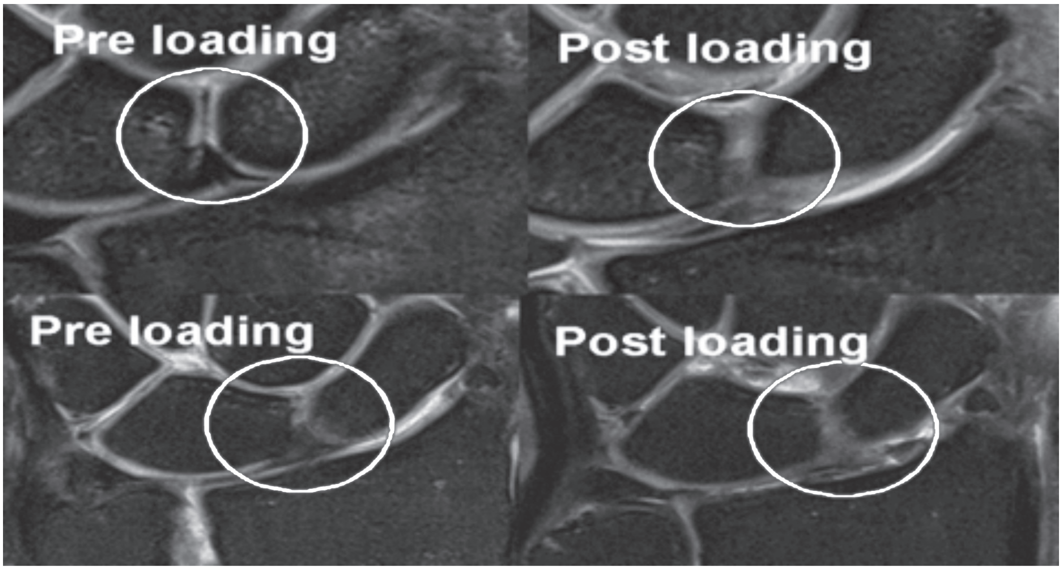

Fig. 1 ER arms with intact SL preloading had 50% tears (top); 75% of those with preexisting tears progressed (bottom).

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Biomechanical Analysis of Far Proximal Radial Shaft Fracture Fixation
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Background/Purpose: Fractures of the proximal radius pose a unique challenge in obtaining proximal fixation without disrupting ligamentous complexes of the elbow or limiting forearm rotation. Metaphyseal bone available for screw purchase is limited proximally by the annular ligament and medially by the bicipital tuberosity. We hypothesize that orthogonal plating with lower-profile mini-fragment plates will reduce the problems of impingement with forearm rotation while providing equal or greater construct stiffness and strength than traditional 3.5-mm plates.

Methods: In 5 fresh cadaver elbows, a transcondylar 2.0-mm horizontal reference wire was inserted through the elbow and a second parallel wire inserted through the radial styloid with the forearm fully supinated. Through a volar approach preserving all soft-tissue structures, with the arm in full supination, 2.0-mm, 2.4-mm, 2.7-mm, and 3.5 mm plates were applied to the volar surface of the proximal radius. The forearm was ranged through an arc of pronosupination without and then with implants. Impingement was observed when pronation of the radius led to contact with a one millimeter wire resting on the volar/radial surface of the ulna. Next, 11 matched pairs of formalin-fixed, human cadaveric radii were harvested and stripped of soft-tissue attachments. Bone mineral density for each group was 0.632 g/cm^2. A transverse osteotomy was created 2 cm distal to the bicipital tuberosity. Group 1 (G1) was affixed with a 5-hole 3.5-mm nonlocking plate with 2 bicortical screws proximal to the osteotomy and 3 bicortical screws distal; group 2 (G2), a 10-hole 2.0-mm nonlocking plate volarly and a 2.0-mm plate radially, both with 3 bicortical screws proximal and distal to the osteotomy; and group 3 (G3), a 2.4-mm plate volarly and a 2.0-mm plate radially. Specimens were loaded and stiffness measured for bending in 3 different planes: with the volar plate in tension band mode (TB), 90° out-of-plane mode (OOP), and on the compression side (CS). Next, torque stiffness (TQ) was measured and the constructs were loaded to failure. Groups were compared by multiple comparison analysis of variance.

Results: All specimens exhibited 90° of supination and a mean of 71° of pronation. There was no impingement observed with the 2.0-mm plate. The 2.4-mm plate construct reduced pronation by 19.5%; the 2.7-mm plate, by 43.7%; and the 3.5-mm plate, by 60.3%. In torsion, there were no significant (NS) differences in stiffness between any of the constructs. In bending stiffness, there was NS difference between G1 and G3 in TB or CS, but in OOP, G3 was greater than G1 (P <0.05). In TB and OOP, G2 constructs were less than G1 (P <0.0001 and 0.005), and G3 (P <0.001 and 0.0001). In CS, G2 was not significantly different from G1.

Conclusion: Orthogonal plating with low-profile 2.4-mm and 2.0-mm plates in the proximal radius is at least as stiff as a single 3.5-mm plate while avoiding significant mechanical impingement with forearm rotation.

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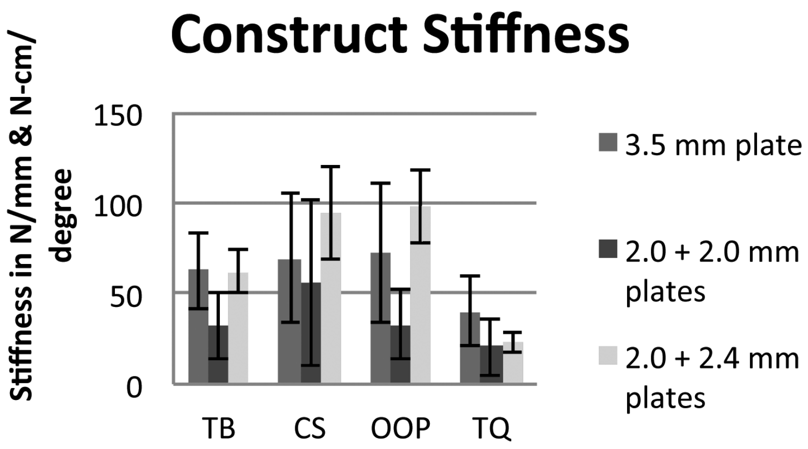

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Δ OTA Grant

No Difference in Fatigue Failure Between Nonlocked and Locked Interlocking Screws of Intramedullary Nails in Proximal Tibia Fractures

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Background/Purpose: The optimal type of fixation for proximal tibia fractures is still controversial. The fixation with intramedullary nailing usually fails with backing out of interlocking screws. In order to improve fixation failure, a new nail has been designed with interlocking screws being locked into the nail. The goal of this study is to compare the in situ fatigue strength of a new locking intramedullary nail (LN) with proximal fixed-angle interlocking screws to standard nonlocked (not fixed-angle) nails (NLN) in proximal tibia comminuted extra-articular fractures.

Methods: 6 pairs of fresh-frozen osteoporotic cadaveric tibias (age: 68.7 ± 4.6 [standard deviation] years; T-score: –2.7 ± 1.1) were used. One tibia from each pair was fixed with an LN while the contralateral side was fixed with a nonlocked nail (NLN). A gap model was created simulating a proximal tibia extra-articular severely comminuted fracture (OTA Type 41-A3.3). Specimens were cyclically loaded under compression, simulating the single leg stance phase of gait. Testing was conducted initially cycling between 100 N and 335 N (50% of average body weight) of compression. Every 20,000 cycles, the peak compression was increased by 10% of average body weight. Every 2500 cycles, localized gap displacements were measured with a 3-dimensional motion tracking system and planar x-ray images of the proximal tibia were taken. The two groups were compared using the following metrics: axial stiffness, failure load, number of cycles to failure, and mode of failure. To allow for mechanical settling, initial metrics were calculated at 2500 cycles. A paired *t* test (P <0.05) was used to determine statistical significance for all metrics.

Results: There were no significant differences in any metrics used to compare the LN and NLN. There was a difference in mode of failure with the LN failing primarily by the proximal screws cutting out the bone and the NLN failed primarily by the proximal screws backing out.

Nail Type	Initial Axial Stiffness (@2500 cycles)	Axial Stiffness (Just Before Failure)	Gap Subsidence (Medial, Lateral)	Failure Load	Cycles to Failure
LN	1244 ± 266 N/mm	1026 ± 292 N/mm	0.76 ± 0.44mm, 0.90 ± 0.50mm	1140 ± 310 N	212,500 ± 54,475
NLN	1172 ± 146 N/mm	928 ± 292 N/mm	1.14 ± 0.91mm, 1.10 ± 1.21mm	954 ± 256 N	180,000 ± 38,438

Conclusion: The results of this study suggest that while there is a trend for longer fatigue life, fixed-angle proximal locking screws of intramedullary nails for proximal fixation do not result in statistically different fatigue life when compared with the standard nail (NLN) in a comminuted, extra-articular proximal tibia fracture model.

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Is Overdrilling of Cortical Screws an Appropriate Surrogate for Osteoporosis in Biomechanical Testing?

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Background/Purpose: To simulate osteoporotic conditions, some authors have used a larger screw predrill in healthy bone by overdrilling 0.3 mm smaller than the major diameter in an attempt to decrease fixation strength and replicate failure modes of poor bone. However, use of this model has not been validated and all previous testing used plated constructs. The purposes of this study were to quantify the effect of overdrilling cadaveric bone on screw pull-out strength (POS) and stiffness and to evaluate the failure modes of construct testing using this method in surrogate bone models.

Methods: Matched pairs of human cadaveric femora and composite surrogate tibiae and femora were used for this study. *Phase One:* Cadaveric femoral shafts at progressive distances from the trochanteric tip received bicortical 3.5-mm or 4.5-mm screws orthogonal to bone. Screws were inserted after either a normal predrill based on manufacturer recommendation or an overdrill that was 0.3 mm smaller than screw major diameter (n = 40). Femora were resected into 40-mm segments. POS was measured using ASTM F543 standard testing. Tensile stiffness was also measured during pull-out. *Phase Two:* A comminuted metadiaphyseal fracture (OTA 41-A3) was simulated by creating a 1-cm proximal gap in composite tibiae. Two groups (n = 6 each) were plated with lateral proximal tibia plates using 3.5-mm locked or nonlocking diaphyseal screws after oversized screw predrills. The constructs were loaded in fatigue to 214 N using offsets both proximally and distally. *Phase Three:* A comminuted supracondylar fracture (OTA 33-A3) was simulated by creating a 2-cm gap in composite femora. Two groups (n = 6 each) were plated with lateral proximal femur plates with 4.5-mm locked or nonlocking diaphyseal screws after oversized screw predrills. The constructs were loaded in fatigue to 890 N using a 7° angle from the anatomic axis to the mechanical axis in the medial-lateral plane. Paired Student *t* tests were used in all phases.

Results: *Phase One:* Overdrilling the screw pilot hole decreased the POS of 3.5-mm screws by 53% (P <0.001), and 4.- mm screws by 76% (P <0.001). There were no differences in tensile stiffness for 3.5-mm (P = 0.67) or 4.5-mm screws (P = 0.25) when comparing the normal predrill to the overdrilled condition. *Phase Two:* All constructs failed via plate fracture near the gap. There were no differences in construct fatigue life (nonlocked: 97,935 cycles; locked: 98,886 cycles; P >0.64). *Phase Three:* All constructs failed via plate fracture near the gap. There were no differences in construct fatigue life (nonlocked: 66,496 cycles; locked: 67,195 cycles; P >0.57).

Conclusion: This study indicates that overdrilling healthy bone decreases screw POS, but does not affect tensile stiffness and may not mimic the failure modes of plated osteoporotic constructs seen clinically. Nonlocked constructs in poor quality bone have been reported to fail at the screw to bone interface, or by angular collapse from loosening, neither of which was observed in our findings. Additional work is needed to validate the overdrill model prevalent in the literature.

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Finite Element Analysis of the Distal Femur: Fracture Motion Predicts Clinical Callus

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Background/Purpose: The biomechanical environment is theorized to affect bone healing; however, the optimal environment is poorly defined and surrogates are often studied in place of fracture gap motion. Finite element analysis (FEA) has successfully modeled the mechanical behavior of orthopaedic implants. We hypothesized that FEA-predicted fracture gap motion would predict callus formation in a clinical series of distal femur fractures following locked plating.

Methods: A 3-dimensional FEA model of a comminuted distal femur fracture treated with locked plating was developed to analyze fracture gap motion under single limb stance. The model allowed variation of plate material and bridge span to simulate constructs from 64 clinical cases that had been assessed for callus formation at 6, 12, and 24 weeks. Multivariate linear regression analysis assessed the effects of vertical motion and horizontal motion on callus formation. We then selected the "optimal construct" from the clinical case series based on the findings of the regression analysis. Student's *t* test was performed for statistical comparison of callus formation at 6, 12, and 24 weeks between this "optimal construct" and all others.

Results: Substituting titanium for stainless steel approximately doubled both horizontal and vertical motion, while increasing bridge span dramatically increased horizontal motion (shear) with a much lesser effect on vertical motion. Multivariate regression analysis demonstrated vertical motion promoted callus formation with a trend at 6 weeks ($P = 0.08$) and statistical significance at 12 and 24 weeks ($P < 0.05$). Shear was found to inhibit callus formation with a trend at 12 weeks ($P = 0.08$) and statistical significance at 24 weeks ($P < 0.05$). These results predicted that short titanium constructs (maximizing vertical relative to horizontal motion) would be associated with greater callus formation among constructs in the clinical case series. This was found to be true as short titanium constructs had greater callus at all time points ($P < 0.05$).

Discussion/Conclusion: FEA-predicted 3-dimensional gap motion was predictive of callus formation in a clinical case series of distal femur fractures. Predicted vertical motion was associated with increasing callus while predicted shear was associated with decreasing callus. Titanium constructs produced greater vertical motion, promoting callus formation. Increasing bridge span dramatically increased shear at the fracture, inhibiting callus formation. Future implant design and surgical fixation strategies should consider optimizing 3-dimensional fracture gap motion rather than optimizing surrogate measures such as axial stiffness.

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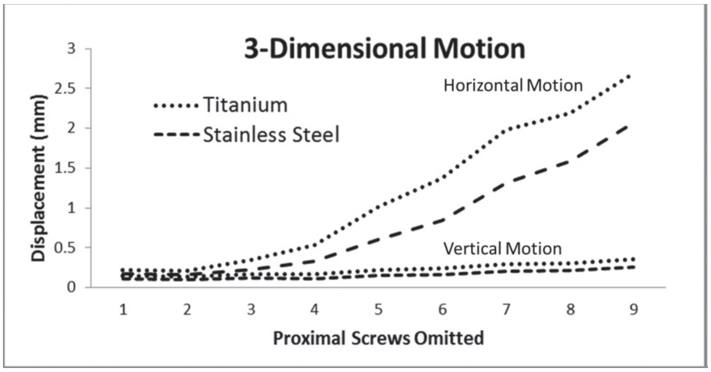

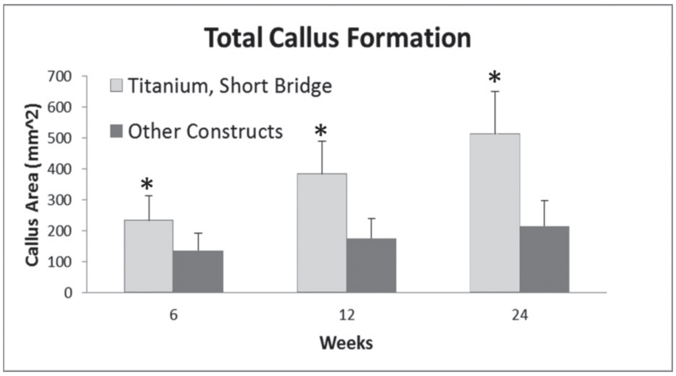

PAPER ABSTRACTS

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The Minimal Screw Length for Tricortical Syndesmosis Fixation in Ankle Fracture: A Cadaveric Study

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Background/Purpose: Syndesmotic injuries of the ankle commonly occur via an external rotation force applied to the ankle joint. The effects of the screw length for single tricortical syndesmosis fixation of a syndesmotic injury can be assessed by evaluating the 3-dimensional kinematic behavior of the tibiofibular diastasis. Previous studies have explored the differences of 3 versus 4 cortices showing no difference between both fixation methods. To our knowledge no study has shown the kinematic behavior using a biomechanical study of single tricortical screw fixation with varied lengths. The specific aim of this study was to determine the minimal tricortical syndesmosis screw length for tibiofibular syndesmosis reduction fixation.

Methods: 15 fresh-frozen cadaveric lower extremities used for testing. A specially designed apparatus was used to stabilize the specimen and rotate the ankle joint in 25° of internal rotation and 35° of external rotation for 9 cycles in each direction. Three stages were tested: intact (Stage I), injury (Stage II), and fixation (Stage III). For Stage III, fixation was accomplished with a single 3.5-mm cortex metallic syndesmosis screw with 3 different predetermined screw lengths. Group I was fixed with threads less than 35% across the width of the metaphysis of the tibia after syndesmotic fixation 4 cm proximal to the plafond; Group II was fixed with the screw threads between 35% and 65% across the width of the metaphysis of the tibia after syndesmotic fixation; and Group III was with the screw threads juxtaposing the far cortex of the tibia after syndesmotic fixation (>65% across the width of the metaphysis of the tibia). Axial loading, torque, rotational angle, and 3-dimensional syndesmotic diastasis readings were recorded.

Results: Our torque results indicated that after the deltoid, anterior tibiofibular ligament, and interosseous ligaments were sectioned, the foot lost 74% and 61% torsional strength compared to the intact specimen for the foot externally rotated 35° and internally rotated 25°, respectively. However, there was no statistically significant difference detected in foot torsional strength between the 3 groups of screw fixation specimens and simulated injury specimens for either foot rotations. The torque of the three groups when externally rotated 50° was found not significantly different between each group (Group I: 9 ± 5 Nm; Group II: 8 ± 3 Nm; Group III: 13 ± 5 Nm). However, 2 fractures of the fibula were detected for Group I, 3 were detected for Group II, and 4 were detected for Group III.

Conclusion: This study supports the hypothesis that there is no significant difference in stability between different screw length constructs for tricortical syndesmosis screw fixation. This study shows that fixation of the distal tibiofibular sydesmosis with differing screw lengths did not provide a difference in torque applied to the syndesmosis. Fixation did not

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provide a difference in torque from sectioned ligaments to fixation in our study. Therefore, it is advised that patients should not bear weight in the period necessary for ligaments to heal.

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