Tibio-Talar Augmentation of Deltoid Ligament Repair: A Robotic Investigation of Ankle Stability

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Disclosures: Alex W. Brady (N), Justin R. Brown (N), Alexander R. Garcia (N), Daniel C. Marchetti (N), Wyatt H. Buchalter (N), Amelia H. Drumm (N), Christopher D. Kreulen (5-Arthrex, Wright Medical, Enovis/MedShape, and Sequoia Surgical; 3B-Arthrex, Synthes, MedShape, Zimmer Biomet Holdings, and Medical Device Business Services; 1-Arthrex), Craig T. Haytmanek (5-Stryker, Wright Medical Technology, Steadman Philippon Research Institute (SPRI). SPRI is a a 501(c)(3) non-profit institution supported financially by private donations and corporate support, including Arthrex, DJO, MLB, Ossur, Siemens, Smith & Nephew and XTRE; 3B-Arthrex; 2-Gemini Mountain Medical and Steelhead Surgical), Thomas O. Clanton (3B-Arthrex, Stryker, Wright Medical, BICMD, and SubioMed Inc; 1-Arthrex and Stryker; 5-Steadman Philippon Research Institute (SPRI), Gentleman Orthopedic Solutions and Gemini Mountain Medical)

INTRODUCTION: The deltoid ligament can tear in association with ankle fractures, syndesmotic injuries, or independently. In previous biomechanical research. the optimal surgical treatment for an anterior deltoid tear has been shown to be a repair with a tibiocalcaneal augmentation, with no additional benefit of a tibiotalar augmentation. However, tibiocalcaneal augmentation is technically challenging to perform as there is a risk of damage to neurovascular structures in the medial ankle. Therefore, by testing tibio-talar augmentation first, the purpose of this study is to determine if this simpler surgery is sufficient to stabilize the ankle in the setting of an anterior and complete deltoid tear. Additionally, concerns over loss of range of motion due to over-constraint in plantarflexion and dorsiflexion have been raised with ligament augmentation surgery. The secondary purpose of this study is to determine if these concerns are warranted. We hypothesize that sectioning the deltoid ligaments will substantially heighten ankle laxity in eversion and external rotation, anterior deltoid repair will mitigate laxity but not restore native stability, and incorporation of tibiotalar and tibiocalcaneal augmentations will further improve stability. We hypothesize that none of the surgical treatments will introduce loss of range of motion due to over-constraint.

METHODS: Ten cadaveric ankles were mounted on a six-degrees-of-freedom robotic arm. Each specimen underwent biomechanical testing in nine successive states: 1) Intact, 2) Anterior deltoid cut, 3) Anterior deltoid repair, 4) Repair + tibiotalar augmentation, 5) Repair + tibiotalar + tibiocalcaneal augmentation, 6) Posterior deltoid cut, leaving anterior repair and augmentations intact, 7) Removal of the tibiocalcaneal augmentation 8) Removal of the tibiotalar augmentation 9) Removal of the anterior repair (complete cut state). This study design allowed the comparison of the three treatment options separately in the setting of an anterior tear and a complete tear. Testing consisted of six range of motion tests, measuring how much rotation occurred under a 5-Nm load: 1) Eversion at neutral 2) Eversion at 25° plantarflexion, 3) External rotation at neutral, 4) External rotation at 25° plantarflexion 5) Plantarflexion and 6) Dorsiflexion. 1-factor random-intercepts linear mixed effects statistical models were created to run an ANOVA analysis followed by post-hoc pairwise comparisons between testing states in the setting of an anterior tear and a complete tear.

RESULTS:
The anterior tear significantly increased ankle laxity compared to native in all tests: external rotation at neutral (+2.8°, $p<0.0001$), at 25° (+2.4°, $p=0.0002$), eversion at neutral (+2.1°, $p=0.0019$), at 25° (+5.6°, $p<0.0001$). The complete tear significantly increased ankle laxity compared to native in all tests (all $p<0.0001$): external rotation at neutral (+6.9°), at 25° (+7.2°), eversion at neutral (11.6°), at 25° (+12.0°). In the setting of the anterior tear, an anterior repair restored native ER at neutral and 25° and eversion at neutral but remained significantly more lax at 25° plantarflexion (+2.9°, $p=0.0007$). In the setting of a complete tear, the anterior repair failed to restore native stability in any test. The tibiotalar augmentation showed no significant differences from the anterior repair in any test either in the setting of an anterior or complete deltoid tear. The addition of the tibiocalcaneal augmentation restored native external rotation and eversion stability at neutral and 25° plantarflexion, both in the setting of an anterior tear and a complete tear, showing significant improvements over the tibiotalar augmentation. No significant reductions in range of motion were found for any surgical state in any test compared to native.

DISCUSSION: The tibiotalar augmentation showed no significant improvement over a suture repair in the setting of an anterior or complete deltoid tear. The addition of a tibiocalcaneal augmentation showed significant improvement over the tibiotalar augmentation, restoring native stability in eversion and external rotation in the anterior tear and complete tear models. When these augmentations were tested in the reverse order, previous research showed that the tibiocalcaneal augmentation demonstrated significant improvement over the anterior repair, and the addition of tibiotalar augmentation demonstrated no significant change. Therefore, the optimal treatment in the setting of an anterior or complete deltoid tear was a suture repair plus a tibiocalcaneal augmentation. While this surgery may be technically challenging, it has a strong stabilizing effect on the ankle joint, and future research is necessary to further improve the safety and simplicity of this technique.

CLINICAL RELEVANCE: Nonoperative management of deltoid ligament tears may lead to persistent changes in ankle biomechanics and poor patient outcomes. Deltoid ligament repair with augmentation might hasten rehabilitation, reduce stiffness, and facilitate earlier resumption of pre-injury activity.

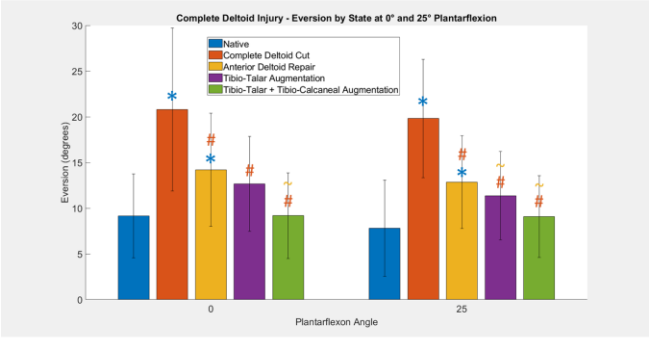

Figure 1. Eversion by injury/repair state at 0º and 25º of plantarflexion. (*) indicates significantly different from native; (#) indicates significantly different from deltoid injury; (~) indicates significantly different from deltoid repair

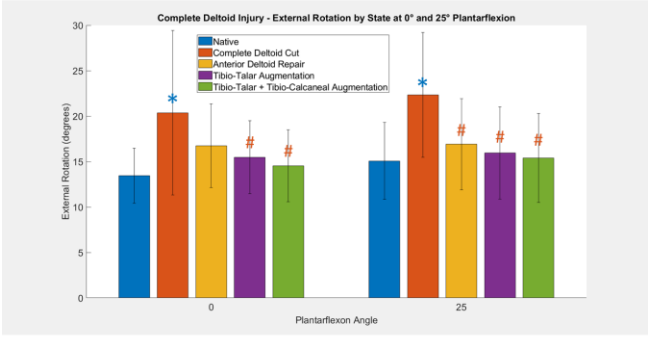

Figure 2. External Rotation by injury/repair state at 0º and 25º of plantarflexion. (*) indicates significantly different from native; (#) indicates significantly different from deltoid injury