Deltoid ligament repair reduces and stabilizes the talus in unstable ankle fractures

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ABSTRACT

Introduction: Treatment of supination external rotation type IV (SER-IV) ankle injuries has focused on reduction and fixation of the fibula and syndesmosis (ORIF), not repair of the deltoid ligament.

Methods: Twenty-one ankles were analyzed with a motion capture system. Uninjured ankles were stressed and compared to ankles with SER-IV injuries, then with ORIF, and finally ORIF and deltoid repair.

Results: After deltoid ligament repair, talar coronal and axial rotation normalized to the uninjured state and were significantly reduced compared to ORIF alone.

Discussion: Deltoid ligament repair after an SER-IV ankle injury can help directly reduce and stabilize the tibiotalar joint.

1. Introduction

Lateral malleolar fractures with associated deltoid ligament injuries are commonly encountered by orthopedic surgeons. Anatomic fixation of these injuries is essential to optimize joint contact pressures and outcomes.¹ Proper reduction and stabilization of these injuries may be deceptively difficult, however, due to the complexity of the tibiotalar and syndesmotic articulations.^{1–5} Efforts have mainly been focused on reduction and stabilization of the fibula and, when necessary, syndesmosis in the setting of these injuries, to indirectly reduce the talus within the mortise.^{6–9} These indirect techniques may, however, be insufficient for restoring the normal position and motion of the talus in all planes of translation and rotation.

Previous anatomic studies have demonstrated the complex, multi-planar role of the deltoid ligament in maintaining the normal tibiotalar relationship.^{2–5} Theoretically, the deltoid ligament's contribution to ankle stability can only be restored acutely with a deltoid ligament repair. With time the ligament may heal without direct repair, but biomechanical function may not be restored if it heals in a lengthened or otherwise abnormal state.

Early clinical studies failed to show a difference when comparing deltoid ligament neglect to repair.^{10–14} These studies were likely underpowered to detect a difference, however. Non-comparative studies

have shown encouraging outcomes with deltoid ligament repair, and newer data has suggested that deltoid ligament repair may have a clinical benefit.^{15–19}

Here we use a cadaveric model to directly test whether talar instability persists after laterally based fixation of unstable ankle injuries, and whether a deltoid ligament repair can prevent this instability.

2. Methods

2.1. Specimen

Twenty one lower limbs from unidentified donors were obtained from a private company source (United Tissue Donors, Norman, OK) and evaluated clinically and radiographically for excluding abnormalities. Exclusion criteria included significant lower limb trauma or surgery and/or severe tibiotalar or subtalar osteoarthritis. No limbs were found to have any of the excluding conditions noted above; all were included in the study and final analysis. The average age of limbs was 63 years old (range 41–73 years old). There were 12 left limbs and nine right limbs. Each limb was disarticulated at the knee joint with care taken to preserve the proximal tibiofibular joint prior to preparation and testing.

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2.2. Testing jig

A material testing machine capable of exerting known axial and rotational forces was utilized for testing (MTS858 Mini-Bionix biaxial material testing machine, MTS Systems Corp, Eden Prairie, MN). Proximally, the lower limbs were attached to a cylindrical cup using two 5 mm fully threaded schanz pins placed at right angles through the tibial plateau; this cup was subsequently secured to the actuator of the material testing machine.

Measurements were taken for each specimen state (see below) with the specimen in three configurations. In the first configuration, the actuator was used to raise the lower limb until the foot hung free above the plate of the material testing machine. The actuator and attached limb were then lowered until the foot contacted the plate of the material testing machine and an axial force of 150 N was registered. Finally, the ankle was placed under 1 Nm of external rotation stress. These conditions were meant to simulate the minor stresses that the ankle would experience during nonweightbearing or touchdown weightbearing, which are our typical weightbearing recommendations following ankle fracture fixation. We did not place higher levels of external rotation stress on the ankles because our deltoid ligament repair is not meant to substantially strengthen or our ankle fixation construct; instead, it is meant to keep the tibiotalar joint reduced in all planes of motion until medial healing has occurred.

In this study, syndesmotic fixation was not performed in order to isolate the effect of deltoid repair on talar position and stability.

2.3. Motion tracking and relative position measurement

An Optotrak optoelectronic 3D motion measurement system (Optotrak Certus, Northern Digital Inc, Waterloo, Ontario, Canada) and custom software (Matlab, MathWorks Inc., Natick, MA) was used to determine relative positioning of the tibia and talus.

Relative positions were tracked using a procedure similar to Switaj et al.²⁰ In this procedure, targets that emit infrared light were attached to 3 mm schanz pins placed in each bone (Fig. 1).

A digitizing probe was then used to determine the position of metal fiducial markers placed on the surface of each bone and to digitize the surface of the tibia and talus at the level of the plafond. During the experiments, the 3D motion measurement system was used to determine the position of the markers. The relative and absolute positions

Fig. 1. Testing set up with specimen mounted in a material testing machine. Note the green, infrared-emitting flags mounted in the tibia and talus.

Fig. 2. Comparison of an ankle specimen before and after creation of the SER4 deltoid equivalent injury model. Please note that under minimal loading (1 Nm of external rotation stress) the injury model ankle demonstrates significant widening of the medial clear space.

of each bone, including changes in coronal rotation, axial rotation, coronal translation and sagittal translation, were then calculated in the custom Matlab software using the position of the targets and the previously digitized bony surfaces.

2.4. Specimen states

The first specimen state tested was the intact state. Subsequently, an injury model was created, specifically a supination external rotation 4-type (SER4) fibular fracture with a deltoid ligament injury (Fig. 2).

The fibula fracture was anatomically repaired and the ankles were tested again (open reduction internal fixation/ORIF state). Finally, the deltoid ligament was repaired and the ankles were tested a final time (open reduction internal fixation/ORIF + deltoid ligament repair state) (Fig. 3).

2.5. Specimen preparation

A direct lateral approach was made for fibular injury creation. A curvilinear approach was made medially to access the medial tibia, medial malleolus, deltoid ligament, talar dome and talar neck for target and fiducial marker placement and deltoid ligament injury creation. All major ligamentous and tendinous structures aside from the deltoid ligament were preserved.

To generate the injury condition the superficial and deep components of the deltoid ligament were isolated and sharply released from the medial malleolus. Subsequently, an oblique osteotomy was made in the fibula at the level of the plafond to simulate an SER4-type fibular

Fig. 3. Comparison of an ankle specimen after creation of the ORIF state and then subsequently after creation of the ORIF + deltoid ligament repair state. Please note that under a hanging condition, the talus demonstrates significantly increased eversion in the ORIF state.

fracture. Finally, the AITFL, PITFL and IOL fibers anchoring the osteotomized fibula to the tibia were released, completing the SER4 ankle fracture model. To confirm that the injury was successfully created, 1 Nm of external rotation stress was applied to each ankle; the medial clear space was noted to widen under direct visualization and under fluoroscopy (OEC 9900, GE Healthcare, Chicago, IL) (Fig. 2).

Subsequently, the fibular osteotomy was repaired anatomically with a predrilled six hole 3.5 mm 1/3 tubular plate to generate the ORIF state (Ankle Fracture Management System, Arthrex Inc, Naples, FL, USA). Finally, the deltoid ligament was repaired as detailed below to generate the ORIF + deltoid ligament repair state (Fig. 3).

2.6. Deltoid ligament repair

A 2 mm transosseous sagittal plane drill hole was made at the origin of the superficial deltoid ligament on the medial malleolus. A suture was placed through this tunnel (#2 fiberwire, Arthrex Inc, Naples, FL, USA). A free needle was used to pass the anterior and posterior limbs of the suture through the anterior and posterior aspects of the confluent deltoid ligament insertion on the talus. The suture ends were pulled tight and tied over the top of the deltoid insertion site without additional reduction maneuvers.

2.7. Statistics

The bony surfaces of the intact limb were digitized with the foot resting on the baseplate of the material testing machine under nominal axial load (less than 10 N) to set the baseline position of the ankle (0 mm translation, 0° rotation). For each condition (hanging, 150 N axial force, and 1 Nm external rotation stress configurations for the intact, ORIF, and ORIF + deltoid ligament repair states) the following measurements were taken in comparison to the baseline measurements: 1. Tibiotalar coronal rotation, 2. Tibiotalar axial rotation, 3. Tibiotalar sagittal translation, 4. Tibiotalar coronal translation.

Data was analyzed using repeated-measures ANOVA testing with a Bonferroni correction using Systat software (Systat, Chicago, IL). Changes in position in the ORIF and ORIF + deltoid ligament repair states were compared to the baseline measurements taken from the intact ankle.

3. Results

3.1. Injury creation

For each specimen, the creation of an SER4 ankle fracture was confirmed radiographically and visually with an external rotation stress test; in each specimen the medial clear space was noted to widen significantly after creation of the injury state as described above.

3.2. Positional measurements

Compared to the intact state, the ORIF state exhibited a significant increase in talar eversion with respect to the tibia when hanging. Additionally, there were significant axial rotation differences between the intact and ORIF states. The ORIF state exhibited a significant increase in talar internal rotation with axial loading, and a significant increase in external rotation with external rotation stress compared to the intact state. All of these rotational/translational issues were corrected in the ORIF + deltoid ligament repair state (Table 1).

There were no significant differences any of the specimen states with respect tibiotalar sagittal translation or tibiotalar coronal translation.

There were no significant differences between the intact state and the ORIF + deltoid ligament repair state for any of the conditions tested (Table 1).

Table 1

Talar motion relative to the tibia.

Coronal Rotation (degrees, eversion is positive)					
	Intact	ORIF	Injury p-value	ORIF + Deltoid Repair	Repair p-value
Hanging	−2.6	1.8	0.002	−4.8	0.6
150 N	−0.8	2.4	0.5	1.9	1
1 Nm	0.4	1.4	1	−0.4	1
Axial Rotation (degrees, external rotation is positive)					
Hanging	1	−2.6	0.07	−0.3	1
150 N	4.6	1.3	0.04	5.2	1
1 Nm	5.8	10.8	0.03	4.3	0.7
Sagittal Translation (mm, anterior is positive)					
Hanging	0.4	−1.1	0.9	0.7	1
150 N	0.6	1.8	1	2	1
1 Nm	3.4	6.3	0.2	3.5	1
Coronal Translation (mm, lateral is positive)					
Hanging	1.1	0	0.3	2	1
150 N	3.7	3.5	1	8.2	0.3
1 Nm	1.6	5.2	0.6	8.2	0.09

4. Discussion

Lateral malleolar fractures with associated deltoid ligament injuries can be deceptively difficult to reduce anatomically due to the complexity of the ankle joint. Even minor malreductions can significantly alter joint contact pressures, leading to the development of posttraumatic arthritis.¹ Most recent literature regarding ankle fractures has focused on reduction of the fibular fracture and the syndesmosis, with relatively little attention paid to the deltoid ligament.^{6–9}

While laterally based fixation is certainly critical for restoring stability in these injuries, it cannot restore the functionality of the deltoid ligament. This was demonstrated in an interesting cadaveric study by LaMothe, which showed that after a combined syndesmotic and deltoid ligament injury, joint contact forces remained abnormal even after anatomic reduction of the syndesmosis.²¹ Other cadaveric studies have more directly demonstrated the important role that the deltoid ligament plays in maintaining normal tibiotalar alignment and kinematics.^{2–5} Earl showed that joint contact areas were decreased by 43% and peak cartilage pressures were increased by 30% after sectioning of the deltoid ligament.² Watanabe and Rasmussen independently defined the multiplanar stability provided by the deltoid ligament; Watanabe, in particular, found that the deltoid ligament is responsible for up to 80% of the rotational stability of the talus in an unloaded ankle.^{4,5}

In spite of these findings, deltoid ligament repair has not traditionally been considered an integral part of treating fibular fractures with deltoid ligament injuries. This is, in part, due to early studies on the subject which found no benefit to routine deltoid ligament repair.^{11–14} Stromsoe, in particular, randomized patients to deltoid ligament repair versus no repair, and failed to find a difference in outcomes.¹³

More recent data, however has suggested that there may be benefit to deltoid ligament repair.^{17,19} Zhao compared ankle fractures with deltoid ligament injuries treated with laterally based fixation only to those treated with the addition of a deltoid ligament repair.¹⁸ The deltoid ligament repair group had a significantly decreased medial clear space on healing, and in the case of AO type C fractures, a significant decrease in overall malreductions. In a similar study, Woo additional found improved functional outcomes in the deltoid ligament repair group at an average of 17 months follow up.¹⁷

Noncomparative studies have demonstrated good outcomes with deltoid ligament repair in the setting of an unstable ankle fracture, including in professional football players.^{10,18} Additionally, there have even been published reports of deltoid ligament repair adequately

substituting for a syndesmotic screw when a syndesmotic injury is present.^{15,16}

Our study adds to the growing body of literature emphasizing the importance of the deltoid ligament in the setting of ankle fractures. After open reduction internal fixation of the fibula fracture in an SER4 deltoid equivalent injury model, the talus still exhibited significant instability in coronal and axial rotation under the minor stresses that are expected to occur in the early postoperative period. Following deltoid ligament repair, these abnormal talar movements were eliminated, and there were no significant differences in tibiotalar position or movement in any plane of motion compared to the intact ankles.

Weaknesses of this study include those intrinsic to cadaveric studies. For one, cadaveric tissue behaves differently from living tissue in terms of mechanical properties and response to loading. Additionally, the injury model we created is artificial, and may not be a perfect representation of the soft tissue damage associated with an organic injury. Furthermore, we subjected the specimens to in line axial and pure external rotation forces only, which did not account for the varied and variable forces experienced by the ankle.

5. Conclusion

In a cadaveric model of an SER IV ankle fracture with deltoid ligament disruption, deltoid ligament repair after fibular fixation restored the position and stability of the talus in all planes of motion when compared to the intact state. This was not achieved with fibular fixation alone.

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Declarations of interest

None.

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