Hybrid Fixation Restores Tibiofibular Kinematics for Early Weightbearing After Syndesmotic Injury

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Background: Disruption of the anterior inferior tibiofibular ligament (AITFL), posterior inferior tibiofibular ligament (PITFL), and interosseous membrane (IOM) is a predictive measure of residual symptoms after an ankle injury. Controversy remains regarding the ideal fixation technique for early return to sport, which requires restoration of tibiofibular kinematics with early weightbearing.

Purpose: To quantify tibiofibular kinematics after syndesmotic fixation with different tricortical screw and suture button constructs during simulated weightbearing.

Study Design: Controlled laboratory study.

Methods: A 6 degrees of freedom robotic testing system was used to test 9 fresh-frozen human cadaveric specimens (mean age, 65.1 ± 17.3 years). A 200-N compressive load was applied to the ankle, while a 5-N·m external rotation and a 5-N·m inversion moment were applied independently to the ankle at 0° of flexion, 15° and 30° of plantarflexion, and 10° of dorsiflexion. Fibular medial-lateral translation, anterior-posterior translation, and internal-external rotation relative to the tibia were tracked by use of an optical tracking system in the following states: (1) intact ankle; (2) AITFL, PITFL, and IOM transected ankle; (3) single-screw fixation; (4) double-screw fixation; (5) hybrid fixation; (6) single suture button fixation; and (7) divergent suture button fixation. Repeated-measures analysis of variance with Bonferroni correction was performed for statistical analysis.

Results: In response to the external rotation moment and axial compression, single tricortical screw fixation resulted in significantly higher lateral translation of the fibula compared with that of the intact ankle at 10° of dorsiflexion ($P < .05$). Suture button fixation resulted in significantly higher posterior translation of the fibula at 0° of flexion and 10° of dorsiflexion, whereas divergent suture button fixation resulted in higher posterior translation at only 0° of flexion ($P < .05$). In response to the inversion moment and axial compression, single tricortical screw and hybrid fixation significantly decreased lateral translation in plantarflexion, whereas double tricortical screw fixation and hybrid fixation significantly decreased external rotation of the fibula compared with that of the intact ankle at 15° of plantarflexion ($P < .05$).

Conclusion: Based on the data in this study, hybrid fixation with 1 suture button and 1 tricortical screw may most appropriately restore tibiofibular kinematics for early weightbearing. However, overconstraint of motion during inversion may occur, which has unknown clinical significance.

Clinical Relevance: Surgeons may consider this data when deciding on the best algorithm for syndesmosis repair and postoperative rehabilitation.

Keywords: ankle syndesmosis; tricortical screw; suture button; weightbearing

Ankle injuries are among the most common injuries sustained during sporting activities, accounting for 30% to 45% of all injuries in some sports.[8,27] Isolated disruption of the ligaments of the syndesmosis, the anterior inferior tibiofibular ligament (AITFL), posterior inferior tibiofibular ligament (PITFL), and interosseous membrane (IOM), occurs in 1% to 74% of ankle injuries.[15] Syndesmotic injuries have been shown to be predictive of residual symptoms after an ankle sprain, requiring nearly twice the recovery time of isolated grade III lateral ankle sprains.[5,6]

Despite the usually prolonged recovery time, some studies have shown good clinical outcomes and early return to sports within 6 weeks with early weightbearing at 1 week after surgical fixation of grade III syndesmotic injuries.[11,22] Surgical fixation of unstable, grade III syndesmotic injuries has been shown to significantly reduce the time of return to

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play by 3 weeks compared with that of nonsurgical management.[7,21] A variety of surgical fixation constructs can be used to stabilize the syndesmosis, including single tricortical or quadricortical screw fixation, suture button fixation, or a combination of these constructs.[1,26] Suture button fixation has potential advantages over screw fixation, such as allowing for physiological tibiofibular motion while maintaining reduction, decreasing the need for implant removal, and allowing earlier rehabilitation.[17] Further, divergent suture button fixation has the theoretical advantage of controlling tibiofibular motion in 2 planes, especially in the sagittal plane, which has been an issue with single suture button constructs in some previous biomechanical studies.[2] Regardless of which fixation method is used, anatomic reduction of the syndesmosis is critical in order to achieve good functional outcomes after surgery.[18,25] Although studies have shown that suture button fixation may lead to a more accurate reduction of the syndesmosis and earlier weightbearing and return to activity compared with that of tricortical screw fixation, no data are available regarding the effectiveness of the fixation techniques for stabilizing the syndesmosis for early weightbearing.[16,24]

Because aggressive rehabilitation is being used in an attempt to allow athletes to return to sports faster, it is important to determine which fixation method is able to restore native distal tibiofibular kinematics for early weightbearing. Thus, the purpose of this study was to quantify tibiofibular kinematics after syndesmotic fixation using different tricortical screw and suture button fixation constructs compared with those of the intact ankle during simulated weightbearing. Although several biomechanical studies have investigated tibiofibular kinematics after syndesmotic fixation, there is still no consensus regarding which fixation construct best restores tibiofibular kinematics. This is partly attributable to the fact that not all of the commonly used fixation constructs have been directly compared within the same study, as is done in this study. It was hypothesized that constructs with only 1 transverse plane of fixation (single screw, single suture button) would not be able to restore tibiofibular motion to that of the intact ankle, whereas constructs with multiple transverse planes of fixation (double screw, hybrid, divergent suture button) would overconstrain tibiofibular motion.

METHODS

A 6 degrees of freedom robotic testing system (model FRS2010; MJT) was used to test 9 fresh-frozen human cadaveric ankle specimens (tibial plateau to toe) (5 specimens from the Anatomy Gifts Registry and 4 specimens from Research for Life) with a mean age of 65.1 ± 17.3 years (range, 26-88 years). Each specimen was examined radiographically and manually before testing to exclude specimens with fractures, osteoarthritis, or previous ligamentous instability. Specimens were stored at –20°C and thawed at room temperature for 24 hours before testing. A skin incision (~10 cm) was made along the lateral aspect of the fibula, and superficial dissection along the anterior and posterior borders of the fibula was performed to visualize the AITFL, PITFL, and IOM. Both holes that were required to implement the fixation constructs were predrilled under fluoroscopic guidance in the intact ankle at 0° of flexion to avoid malreduction of the fibula after transection of the syndesmotic ligaments. The distal hole was drilled approximately 2 cm above the plafond using a 2.8-mm drill bit to standardize the positioning of the fixation and ensure an anatomic reduction of the syndesmosis during fixation.[10] The drill bit was angulated 30° anteriorly, with the use of a goniometer, to follow the trajectory of the distal tibiofibular joint (Figure 1A). A 4-hole one-third tubular plate was secured to the distal fibula after drilling of the distal-most hole, with the second most distal hole of the plate lined up with the drilled hole. Then, a proximal hole was drilled, using a 2.8-mm drill bit angulated 30° anteriorly, in the third most distal hole of the plate (Figure 1B).

The subtalar joint was fused under fluoroscopic guidance using 2 wood screws through a minimal anterior arthrotomy along the anterior aspect of the talus. Fusion of the subtalar joint was necessary to precisely control tibiotalar joint motion and apply forces in a repeatable manner. After the skin and subcutaneous tissues on the posterior calcaneus were removed, posterior calcaneus was potted in an epoxy compound (Bondo; 3M), and the potting material was rigidly fixed to the upper end plate of the robotic manipulator through a universal force-moment sensor (IP60 [SI-660-60]; ATI Delta) using a custom-made aluminum clamp (Figure 2A). The tibia was rigidly mounted to the lower plate of the robotic testing system, while the full length of the fibula was maintained and fibular motion was unconstrained. During the experimental protocol, the specimen was kept moist using saline.

Next, 2 optical motion capture marker triads were mounted to the specimen, 1 to the distal fibula and 1 to the distal tibia (Figure 2A). Six 1280 × 1024, 240-Hz motion capture cameras (Flex 13; Optitrack) were positioned in a

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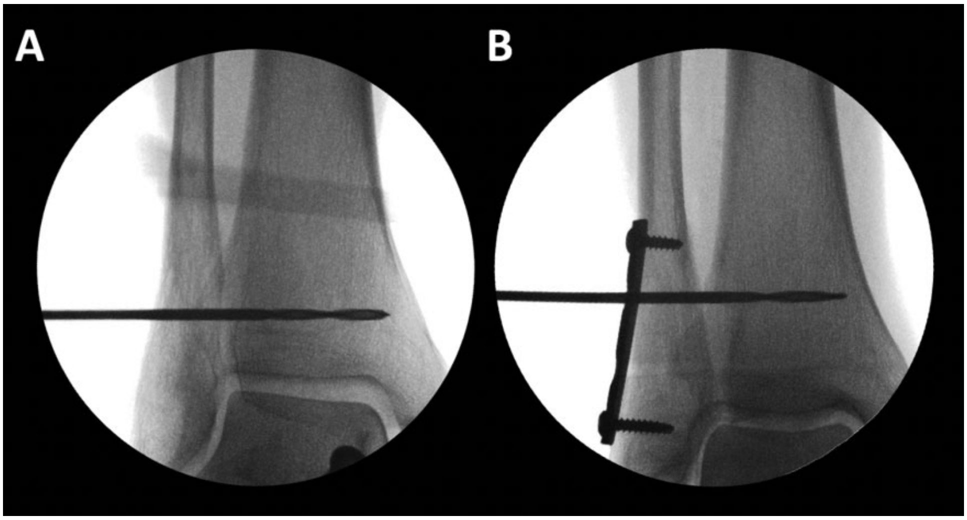

Figure 1. Anterior-posterior view radiographs of an ankle specimen demonstrating the placement of (A) the distal predrilled hole and (B) the fibular plate and the proximal predrilled hole. Both predrilled holes are angulated 30° anteriorly.

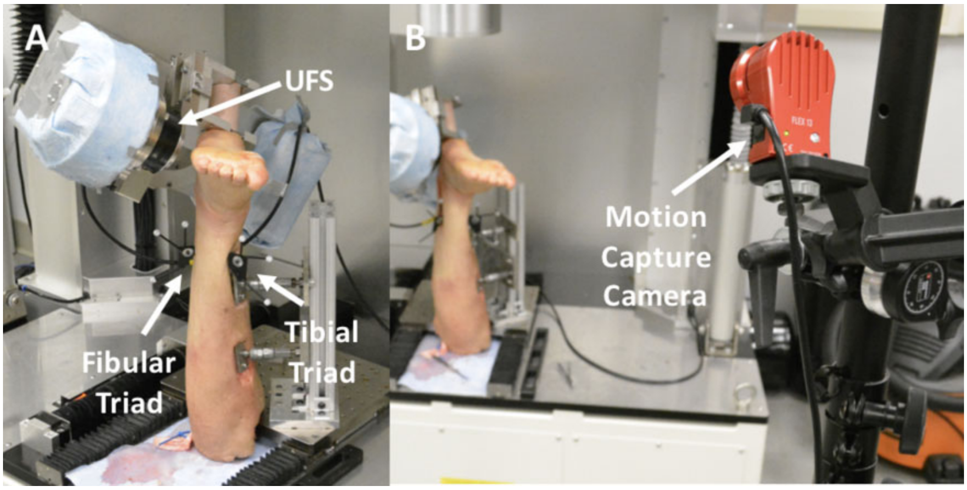

Figure 2. (A) Experimental setup with full-length fibular specimen rigidly mounted to the robotic testing system through the calcaneus and a universal force-moment sensor (UFS). Optical motion capture markers are noted on the fibula and tibia. (B) The experimental setup with the robotic testing system surrounded by 6 motion capture cameras, such as the one shown, arranged in a semicircular configuration.

semicircle around the robotic testing system to detect the optical motion capture markers attached to the tibia and fibula (Figure 2B). The repeatability of this experimental setup is 0.3 mm for translation and 1.5° for rotation. The tibial tuberosity, Gerdy tubercle, tibiotalar joint center, and lateral malleolus were digitized to create coordinate systems for the tibia and fibula. The axes of the tibia were defined as follows: medial-lateral axis as the vector from the tibiotalar joint center to the lateral malleolus, proximal-distal axis as the vector from the tibiotalar joint center to the tibial tuberosity, and anterior-posterior axis as the vector resulting from the cross product of the proximal-distal axis and the vector from the tibiotalar joint center to the Gerdy tubercle. The coordinate system of the tibia, as defined at 0° of flexion with no applied loads, was translated from the tibiotalar joint center to the location of the lateral malleolus to create the coordinate system of the fibula.

The passive path of plantarflexion-dorsiflexion of the tibiotalar joint of the intact ankle was established from 10° of dorsiflexion to 30° of plantarflexion. The positions that satisfied the condition of zero forces and moments across the joint were determined as the path of passive plantarflexion-dorsiflexion. The reference position for the intact ankle state was defined at 0° of flexion with zero external applied forces or moments from the robotic testing system. A constant 200 N of axial compression was applied to the intact ankle, while 5 N·m of external rotation and

5 N·m of inversion moments were also independently applied at 0° of flexion, 15° and 30° of plantarflexion, and 10° of dorsiflexion; the resulting tibiofibular motion was recorded by use of the optical tracking system. A 200-N axial compression was used to simulate a weightbearing load within the limits of the robotic testing system. This weightbearing load would represent the load that occurs in the early postoperative period (<1 week) in certain proposed accelerated rehabilitation progams.[11] External rotation and inversion moments were used to simulate the mechanism of syndesmotic and lateral ankle ligament injuries, respectively.[2,23] The AITFL, PITFL, and IOM (to 10 cm above the tibial plafond) were then sharply transected with a No. 11-blade scalpel, the loading conditions were repeated at each joint position, and the resulting tibiofibular motion was recorded via the optical tracking system.[10,12] Extreme care was taken not to disrupt the calcaneofibular ligament and anterior talofibular ligament during transection.

Next, tibiofibular kinematic parameters were recorded under each loading condition at each ankle position for 5 different techniques: (1) single 3.5-mm tricortical screw fixation, (2) double 3.5-mm tricortical screw fixation, (3) hybrid fixation (single screw and single suture button), (4) single suture button fixation, and (5) divergent suture button fixation. With regard to the procedure for fixation, the syndesmosis was reduced at 0° of flexion through manual manipulation and stabilization using a thumb until the location and orientation of the distal predrilled hole were confirmed using a guide wire, then a 3.5-mm tricortical screw was placed from lateral to medial to achieve syndesmotic fixation. The same method was used to confirm the reduction of the syndesmosis before placement of each fixation method. Next, another 3.5-mm tricortical screw was placed in the proximal predrilled hole. The distal 3.5-mm tricortical screw was then removed, and a suture button (Invisiknot; Smith & Nephew) was placed in its position to create the hybrid fixation construction. The proximal 3.5-mm tricortical screw was then removed in order to test the single suture button construct. Finally, a suture button was placed in the proximal predrilled hole to maintain the syndesmotic reduction before the distal suture button was removed. Next, a new 3.5-mm hole was drilled using 0° of angulation in the anterior-posterior plane in the same distal position that the previous suture button was removed. The suture button was then passed through the newly drilled distal hole with 0° of anterior-posterior angulation to create the divergent suture button fixation construct.

Outcome measures included medial-lateral translation, anterior-posterior translation, and internal-external rotation of the fibula relative to the tibia in response to each applied moment and flexion angle in the following joint states: (1) intact ankle; (2) AITFL, PITFL, and IOM transected (complete injury); (3) single 3.5-mm tricortical screw fixation; (4) double 3.5-mm tricortical screw fixation; (5) hybrid fixation (single screw and single suture button); (6) single suture button fixation; and (7) divergent suture button fixation. Repeated-measures analysis of variance with a Bonferroni correction was performed to compare the differences in tibiofibular motion between the complete injury state and different repair technique states and the intact ankle at each flexion angle. Significance was set at a P value of $< .05$.

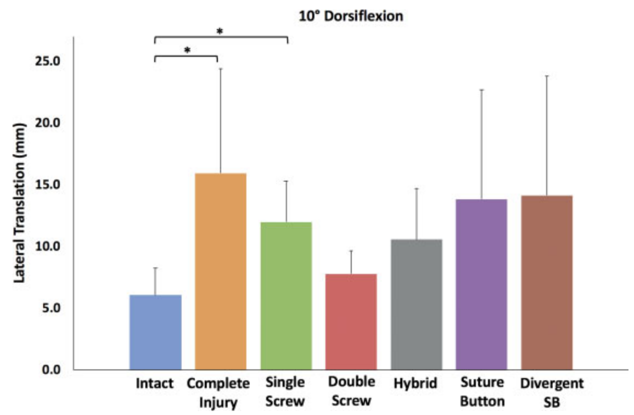

Figure 3. Lateral translation of the fibula relative to the tibia (mean ± SD; 9 specimens) in response to 200-N axial compression and 5-N·m external rotation torque at 10° of dorsiflexion for the intact ankle, the complete injury ankle, single-screw fixation, double-screw fixation, hybrid fixation, single suture button (SB) fixation, and divergent SB fixation. *$P < .05$.

RESULTS

No significant differences were seen between any of the fixation techniques and the intact ankle at any ankle position when only axial compression of 200 N was applied. In response to 200 N of axial compression and a 5-N·m external rotation torque, single-screw fixation significantly increased the lateral translation of the fibula by 5.9 mm compared with that of the intact ankle at 10° of dorsiflexion ($P < .05$). Single suture button and divergent suture button fixation on average resulted in a larger increase in lateral translation by 7.7 and 8 mm, respectively, at 10° of dorsiflexion, but this difference was not statistically significant given the high standard deviation for these measurements (3.5 and 4.8, respectively) (Figure 3).

Posterior translation of the fibula was significantly increased with axial compression after suture button fixation at 0° of flexion and 10° of dorsiflexion and after divergent suture button fixation at 0° of flexion compared with that of the intact ankle ($P < .05$). After single suture button fixation, posterior translation increased by 2.9 and 3.2 mm at 0° of flexion and 10° of dorsiflexion, respectively, compared with that of the intact ankle ($P > .05$) (Figure 4). Double-screw fixation significantly decreased the external rotation of the fibula compared with that of the intact ankle in response to the same loading condition by 0.8° at 15° of plantarflexion ($P < .05$).

In response to 200 N of axial compression and a 5-N·m inversion torque, none of the fixation techniques resulted in a significant increase in motion in any of the planes of

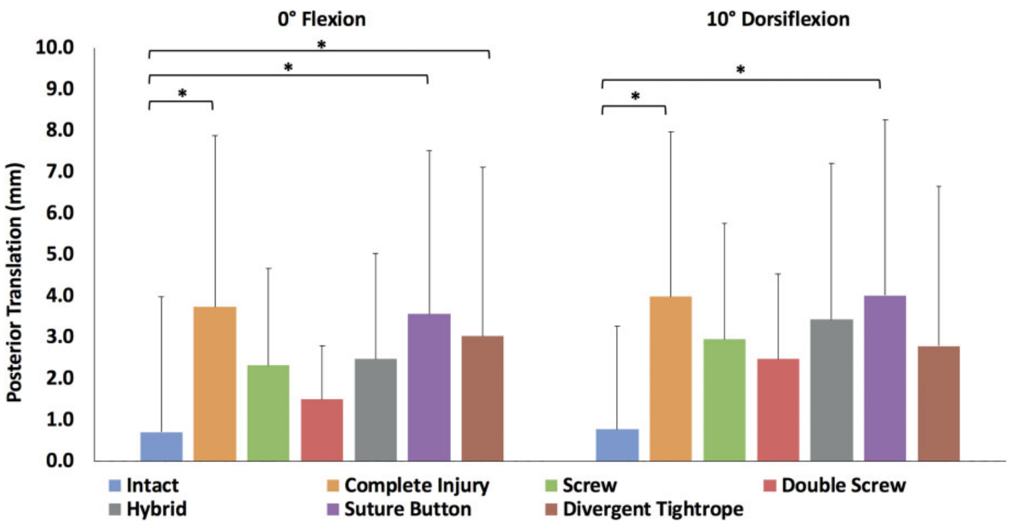

Figure 4. Posterior translation of the fibula relative to the tibia (mean ± SD; 9 specimens) in response to 200-N axial compression and 5-N·m external rotation torque at 0° of flexion and 10° of dorsiflexion for the intact ankle, the complete injury ankle, single-screw fixation, double-screw fixation, hybrid fixation, single suture button fixation, and divergent suture button fixation. *$P < .05$.

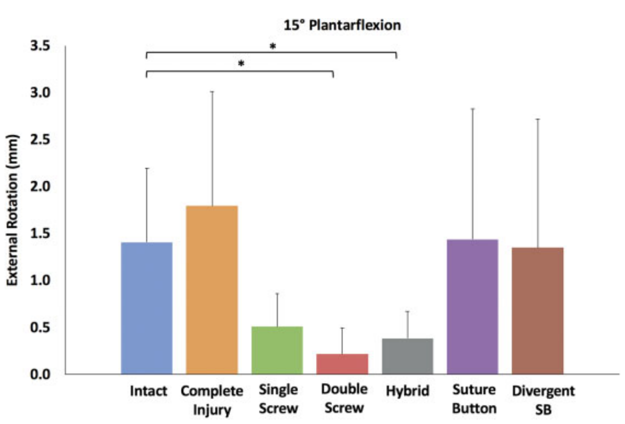

Figure 5. External rotation of the fibula relative to the tibia (mean ± SD; 9 specimens) in response to 200-N axial compression and 5-N·m inversion moment at 0° of flexion and 10° of dorsiflexion for the intact ankle, the complete injury ankle, single-screw fixation, double-screw fixation, hybrid fixation, single suture button (SB) fixation, and divergent SB fixation. *$P < .05$.

motion. However, certain fixation methods resulted in significantly decreased motion with respect to medial-lateral translation and internal-external rotation in this loading condition. Single-screw fixation significantly decreased lateral translation of the fibula at 30° and 15° of plantarflexion by 3.3 mm and 2.8 mm, respectively, compared with that of the intact ankle ($P < .05$). Hybrid and double-screw fixation both decreased lateral translation of the fibula by 3 mm compared with that of the intact state at 15° of plantarflexion, but only the hybrid fixation was significantly lower ($P < .05$). Additionally, in response to the axial compression and inversion torque, double-screw and hybrid fixation significantly decreased external rotation of the fibula at 15° of plantarflexion by 1.2° and 1.0°, respectively ($P < .05$) (Figure 5).

DISCUSSION

The main findings of this study were that single-screw and suture button constructs were unable to restore native tibiofibular kinematics after syndesmotic injury, whereas double-screw and hybrid fixation resulted in overconstraint of the distal tibiofibular joint. Increased motion of the distal tibiofibular joint after syndesmotic fixation using single-screw and suture button constructs occurred in response to axial compression and external rotation of the ankle, whereas single-screw, double-screw, and hybrid fixation led to significantly decreased motion in response to axial compression and inversion of the ankle compared with that of the intact ankle. Additionally, none of the fixation techniques resulted in tibiofibular motion that was significantly different from that of the intact ankle when only an axial load was applied.

The mechanism for injury of the syndesmosis typically involves combined axial force and external rotation torque with the ankle dorsiflexed. Thus, this is the condition in which tibiofibular motion is expected to increase the most after surgical fixation.[13,14] This is consistent with the findings of our study, which showed that lateral and posterior translation significantly increased in response to axial compression and external rotation torque with the ankle in dorsiflexion after single-screw and suture button fixation, respectively. Although the increase in lateral translation after single and divergent suture button fixation was not statistically significant because of high variability of the measurements, the increases exceeded 8 mm more than that of the intact ankle and 2 mm more than that of the single-screw fixation and thus may be clinically significant. The high variability of measurements with suture button fixation may be due to an inability to accurately assess tension when tightening the construct, and this may result in some patients having less syndesmotic stability than that of others in the clinical setting. The lateral displacement of the fibula with axial compression and external rotation seen in this study with single-screw and both suture button fixation constructs may result in ankle instability in the early postoperative period given that there is > 5 mm of diastasis. Additionally, the significantly increased posterior translation of the fibula after suture button fixation is consistent with previous studies and further emphasizes the need for assessment of posterior translation of the fibula when suture button fixation is used, especially if the patient is to participate in an accelerated rehabilitation protocol.[2,9]

Although applying an external rotation torque with axial compression produced increased tibiofibular motion after fixation compared with that of the intact state, lateral translation and external rotation of the fibula were significantly overconstrained after specific fixation techniques in response to an inversion torque and axial compression. The fixation techniques that constrained tibiofibular motion—single-screw, double-screw, and hybrid fixation—all did so in positions of ankle plantarflexion. Imaging studies have shown that single-screw as well as single suture button and divergent suture button fixation all cause a significant volumetric reduction or overcompression of the syndesmosis, suggesting that overconstraint may occur regardless of the fixation technique used.[19,20] A previous biomechanical study demonstrated that syndesmotic injuries can cause inversion instability, and the investigators recommended using additional taping when patients initially return to sports in order to prevent inversion forces.[23] Thus, it might be clinically acceptable to slightly overconstrain tibiofibular motion in response to an inversion torque in plantarflexion in order to protect the anterior talofibular ligament, which is typically injured by this mechanism.[3,4] Although the long-term consequences of overconstraint are still unknown, it may be inconsequential in these constructs given that in the clinical setting, the screws are prone to break after the syndesmosis has healed and thus may fully restore preinjury syndesmosis motion.

Based on the findings of this study, hybrid fixation was the only fixation technique that was able to restore tibiofibular kinematics in all planes and ankle positions without overconstraint in response to axial compression and external rotation torque. However, in addition to providing recommendations on which fixation technique to use for early weightbearing, these data can be used to provide insight into how the postoperative rehabilitation protocol can be modified depending on the fixation technique used. For example, single-screw and suture button fixation constructs do not restore tibiofibular kinematics in response to axial compression and external rotation torque but do in response to axial compression alone. When these fixation techniques are used, early weightbearing is still possible, but it may be beneficial to use some form of immobilization, such as a controlled ankle movement boot, for a longer period of time to avoid external rotation torque on the ankle.

The novel experimental setup with the use of a robotic testing system coupled with a motion tracking system allowed for tracking of tibiofibular motion in a highly accurate and repeatable manner. However, there are some limitations to this study. The specimens used in this study had a mean age that is higher than that of the population of patients who typically sustain purely ligamentous syndesmotic injuries. Additionally, the order in which the fixation constructs were tested was not randomized in this study. Thus, it is theoretically possible that repeated loading of the ankle during testing may have caused more tibiofibular laxity, which may have influenced the measurements of the later tested constructs (single or divergent suture button constructs). Because this is a cadaveric study, the healing response during rehabilitation could not be studied. Thus, the results of this study must be framed in the context of time zero after fixation, and they assume that weightbearing may be started early enough (<1 week) that there is minimal healing response, as is done in certain accelerated rehabilitation programs. This study does not take into account the effect of cyclic loading, which may provide insight into the durability of the constructs, but previous biomechanical studies have shown that there may not be significant differences between fixation methods with increasing cyclic loading.[17] The findings from this study will serve as a foundation to support in vivo kinematic testing to further evaluate which fixation technique is best for early weightbearing after syndesmotic injury.

CONCLUSION

Based on the data in this study, hybrid fixation with 1 suture button and 1 tricortical screw may most appropriately restore tibiofibular kinematics for early weightbearing. However, overconstraint of motion during inversion, which has unknown clinical significance, may occur. Surgeons may consider this data when deciding on the best algorithm for syndesmosis repair and postoperative rehabilitation in patients.

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