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Three-Dimensional Analysis of Fibular Motion After Fixation of Syndesmotic Injuries With a Screw or Suture-Button Construct

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Abstract

Background: Suture-button constructs are an alternative to screw fixation for syndesmotic injuries, and proponents advocate that suture-button constructs may allow physiological motion of the syndesmosis. Recent biomechanical data suggest that fibular instability with syndesmotic injuries is greatest in the sagittal plane, but the design of a suture-button construct, being a rope and 2 retention washers, is most effective along the axis of the rope (in the coronal plane). Some studies report that suture-button constructs are able to constrain fibular motion in the coronal plane, but the ability of a tightrope to constrain sagittal fibular motion is unknown. The purpose of this study was to assess fibular motion in response to an external rotation stress test in a syndesmotic injury model after fixation with a screw or suture-button constructs.
Methods: Eleven fresh-frozen cadaver whole legs with intact tibia-fibula articulations were secured to a custom fixture. Fibular motion (coronal, sagittal, and rotational planes) in response to a 6.5-Nm external rotation moment applied to the foot was recorded with fluoroscopy and a high-resolution motion capture system. Measures were taken for the following syndesmotic conditions: intact, complete lateral injury, complete lateral and deltoid injury, repair with a tetracortical 4.0-mm screw, and repair with a suture button construct (Tightrope; Arthrex, Naples, FL) aimed from the lateral fibula to the anterior medial malleolus.
Results: The suture-button construct allowed significantly more sagittal plane motion than the syndesmotic screw. Measurements acquired with mortise imaging did not detect differences between the intact, lateral injury, and 2 repair conditions. External rotation of the fibula was significantly increased in both injury conditions and was not restored to intact levels with the screw or the suture-button construct.
Conclusion: A single suture-button placed from the lateral fibula to the anterior medial malleolus was unable to replicate the motion observed in the intact specimen when subjected to an external rotation stress test and allowed significantly more posterior motion of the fibula than when fixed with a screw in simulated highly unstable injuries.
Clinical Relevance: Fixation of a syndesmotic injury with a single suture-button construct did not restore physiological fibular motion, which may have implications for postoperative care and clinical outcomes.

Keywords: syndesmosis, ankle, suture-button construct, injury, screw

Although it is well established that syndesmotic injuries should be treated, the optimal treatment strategy remains controversial.[26,28,32] Traditionally, syndesmotic injuries are reduced and stabilization is achieved with a screw construct,[27] where the objective is to provide rigid stabilization, thereby allowing the syndesmotic complex to heal in an anatomical position. In some cases, the screw(s) are removed at a later date to reduce malreductions that may be present, to prevent screw breakage, and to allow the theoretical resumption of physiological motion.[13,20] Abnormal syndesmotic motion may partially explain poorer patient outcomes seen in patients with syndesmotic malreduction[16] and improved patient outcomes following syndesmotic screw breakage or removal.[11]

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Suture-button devices (eg, Tightrope; Arthrex, Naples, FL) may allow more physiological motion of the syndesmois.[15] Syndesmotic motion and reduction have traditionally been assessed in the coronal plane on a mortise radiograph by measuring tibiofibular overlap or medial clear space widening.[4,21,30] Measurement of these radiographic indices intraoperatively with the application of a stress test is typically used to determine if syndesmotic fixation is required following ankle fracture fixation and to determine if the syndesmotic repair is adequate.[2,3,9,12] Suture-button fixation has been shown to be able to sufficiently constrain coronal plane fibular motion[17-19,24]; however, syndesmotic motion in other planes may result in measurement artifact. Some early studies suggest that fibular motion in response to stress testing may be greater in the sagittal plane than the coronal plane.[3,31] Despite this, motion in the sagittal plane has largely been neglected with studies assessing suture-button constructs.

Accordingly, the objective of this study was to assess multiplanar fibular motion in response to an external stress test in a syndesmotic injury model after fixation with a screw or suture-button construct. The primary hypothesis was that a suture-button construct would provide similar syndesmotic stability in the coronal plane but not sagittal plane compared with the syndesmotic screw.

Figure 1. Experimental setup. The tibia is secured to the testing frame with 2 threaded rods. A canvas strap is attached to the forefoot for external rotation stresses, and the marker clusters for motion capture are rigidly secured to the bone with screws. The foot is held in neutral dorsiflexion position with elastic bands.

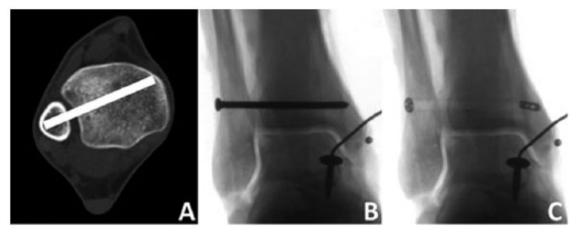

Figure 2. Axial computed tomography representation of the screw and suture-button construct trajectory (A), as well as representative mortise images of the screw (B) and suture-button construct (C).

Materials and Methods

Cadaveric models have been used to investigate syndesmotic injuries,[24] and this study used 11 fresh-frozen lower limb cadaveric specimens with intact proximal tibia-fibula articulations of a mean age of 71 years (50-84 years). As part of the selection criteria, specimens with previous foot and ankle trauma or any medical conditions that may compromise bone anatomy or quality (eg, paraplegic, diabetic neuropathy, long-term anticonvulsant usage) were excluded. All specimens were then subjected to a brief clinical and radiographic screening examination and were found to be free of any gross lower extremity pathological condition. Screening examinations included a visual inspection of lower extremity alignment and evidence of any previous trauma (eg, scars), as well as a range-of-motion test for the ankle and coupled transverse tarsal motion. The radiographic assessment included anteroposterior (AP), mortise, and lateral radiographs of the ankle. Prior to testing, specimens were stored in a −20°C freezer and thawed at room temperature. Skin and fat were excised from the knee to the midfoot, and care was taken to preserve all ankle ligaments, joint capsule, and muscle/tendons crossing the ankle. Following dissection, each specimen was secured to a custom-made fixture with 2 threaded rods/nuts inserted through the tibial diaphysis (one at the proximal/middle one-third junction of the tibial shaft and one at middle/distal one-third junction), and the fixture was then clamped to a table for testing (Figure 1). Fibular motion was unconstrained by the apparatus throughout.

Syndesmotic lateral injury was created by sectioning the anteroinferior tibiofibular ligament (AITFL), the posteroinferior tibiofibular ligament (PITFL), and the distal 10 cm of the interosseous membrane/ligament.[24] Syndesmotic full injury was created by adding complete superficial and deep deltoid complex transection to the lateral injury condition. The injury was then reduced under direct syndesmotic visualization and stabilized using a tetracortical 4.0-mm screw (Synthes, West Chester, PA). To ensure an anatomical reduction was obtained in each specimen, a 2.8-mm pilot drill hole was placed prior to syndesmotic disruption with the foot in neutral dorsiflexion. In the coronal plane, the drill hole was placed under fluoroscopic control parallel to and along the proximal aspect of the physeal scar. In the axial plane, the drill was aimed along the anterior aspect of the transmalleolar axis as this represented the standard trajectory for syndesmotic screws placed through laterally/posterolaterally based fibular plates (Figure 2). After the specimen was tested with the screw in place, the screw was removed and a suture-button construct was placed (Knotless Tightrope; Arthrex) through the same drill hole and was securely tightened as per the manufacturer's operative technique guide.

Fibular and tibial motion were tracked while an external rotation stress was applied to the foot. The external rotation moment was 6.5 Nm and was created by applying a laterally directed force to the forefoot using a canvas strap (Figure 1). The distance from the center of the strap on the forefoot to the lateral malleolus was measured to determine the amount of force required to generate the external rotation moment. A 6.5-Nm moment was chosen because it approximated the moments recorded by a force actuator when 2 fellowship-trained foot and ankle surgeons who were blinded to force measures were asked to perform a strong external rotation stress test on a pilot specimen. To ensure reproducible moments for each specimen, a load cell was placed in series with the canvas strap, and the tension in the strap was displayed in real time to the experimenter. Fibular and tibial motion were tracked under the aforementioned conditions: intact syndesmosis, syndesmotic lateral injury, syndesmotic full injury, reduction with a syndesmotic screw, and reduction using a suture-button device (Knotless Tightrope; Arthrex).

For all tests, fibular motion was quantified using fluoroscopy as well as a 4-camera motion capture system with a resolution of 0.5 mm and 0.5 degrees (Eagle 4; Motion Analysis Corporation, Santa Rosa, CA) that tracked the positions of reflective markers rigidly secured to the fibula and tibia. Pilot testing demonstrated that the motion measured by the motion capture system was similar to the radiographic measures, and hence, only radiographic measures for planar motion are presented herein because they are more clinically relevant to the intraoperative setting. Fibular rotation about its long axis was calculated with the motion capture system and is reported in reference to the unloaded and uninjured specimen.

To assess motion with fluoroscopy, the fluroscope was positioned so that a true lateral and mortise image of the specimen was obtained, with the ankle in the center of the fluoroscope image projection. Placing the ankle in the center of the image receiver minimized fluroscopic distortion. A true mortise image was defined as having symmetrical medial, lateral, and superior talar joint spaces. A true lateral image was defined by having perfectly congruent tibial and talar articular surfaces, with no double densities of the tibial or talar articular surfaces. The fluroscope base was locked and the beam positions to obtain these images were recorded; these positions were used for the remainder of the testing (the specimen was securely clamped to the testing table, which eliminated image projection as a variable in obtaining radiographic measurements). To enable measurement with fluoroscopic imaging, a radio-opaque calibration sphere was implanted in the medial malleolus, which approximated but did not obscure the level of the joint line on the lateral radiograph. Mortise and lateral plane images were acquired for each condition when 6.5 Nm of load was applied to the specimen. Incisural width and medial clear space were measured in the mortise image, and the sagittal fibular position was measured on the lateral radiograph using imaging software and the reference calibration sphere to establish measurements (OsiriX, Geneva, Switzerland; Figure 3). All measures after the stress testing were normalized to the uninjured and unloaded specimen measure (ie, tested measure-control measure). All measures were recorded by 1 fellowship-trained surgeon observer; pilot testing for intraobserver reliability revealed that radiographic measures were all within 0.5 mm for 5 chronologically spaced samplings.

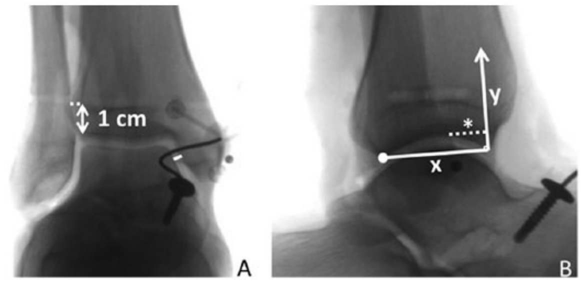

Figure 3. Fluoroscopic imaging demonstrating radiographic measures. (A) The mortise image is used to define the medial gutter (solid line) and the incisural width (dashed line). The incisural width is measured 1 cm proximal to the lateral tibial articular surface, as defined by the cortical density of the lateral distal tibia incisura and the medial cortical density of the fibula. (B) The sagittal fibular position is measured in reference to the lateral cortical density of the tibial articular surface. A line connects the posterior and anterior aspects of the articular surface of the distal tibia, and a perpendicular tangent is extended proximally. Proximal to the tibial articular surface line, a parallel line is drawn from the intersection of the anterior cortical density of the fibula to the tibial perpendicular tangent. This line (*) represents the sagittal fibular position. The drill hole for the screw trajectory is visible on both images.

Statistics

Repeated-measures analyses of variance were performed to test for differences in syndesmotic motion between the intact, injured, and reduced conditions. Post hoc comparisons of means for medial clear space, incisural width, sagittal motion of the distal fibula, and external rotation of the fibula were performed using Tukey's tests. Although the primary hypothesis was that a suture-button construct would provide similar syndesmotic stability in the mortise plane but not sagittal plane compared with the syndesmotic screw, a more conservative statistical approach by analyzing the variance of all test conditions in the same statistical model was used. Statistical significance was set at $\alpha = 0.05$.

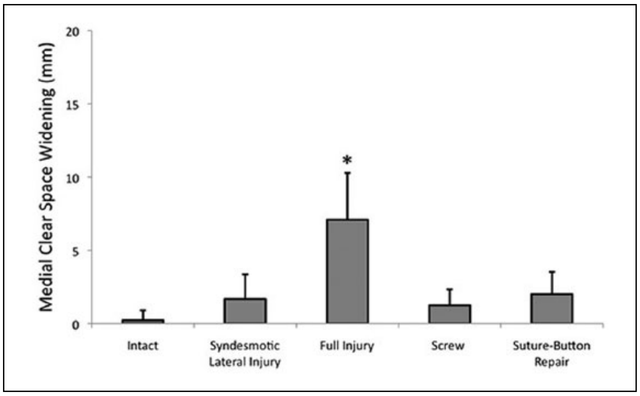

Figure 4. Medial clear space widening during an external rotation stress test. The full-injury condition demonstrated increase clear space compared with the other conditions (*$P < .001$).

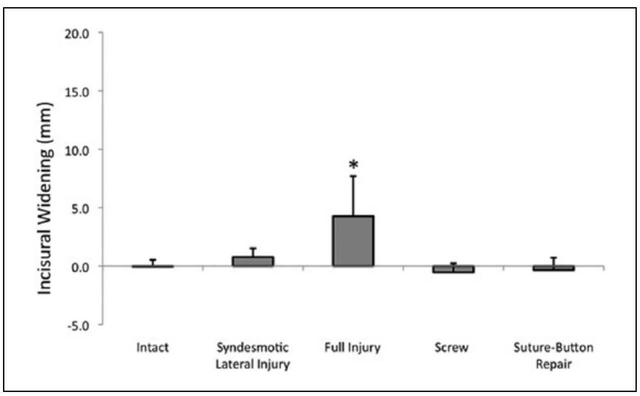

Figure 5. Incisural widening on the mortise fluoroscopic image. The full-injury condition demonstrated elevated motion compared with all other conditions (*$P < .001$).

Results

There were no significant differences in medial clear space widening, incisural widening, and fibular rotation between the suture-button construct and the screw (Figures 4-6). However, there was significantly more posterior motion ($P < .001$) in the suture-button construct compared with the screw (4.8 ± 1.7 mm vs 0.1 ± 2.1 mm, respectively; Figures 7 and 8).

There were no significant differences in medial clear space widening and incisural widening between the repair conditions and the intact condition (Figures 4 and 5). However, there was significantly more posterior fibular translation in the suture-button construct compared with the intact condition (4.8 ± 1.7 mm vs 1.0 ± 2.3 mm, respectively; Figures 7 and 8). There was significantly more fibular external rotation in both the suture-button construct (7.4 ± 5.0 degrees) and the screw (5.0 ± 3.2 degrees) relative to the intact condition (1.7 ± 1.6 degrees; Figure 6).

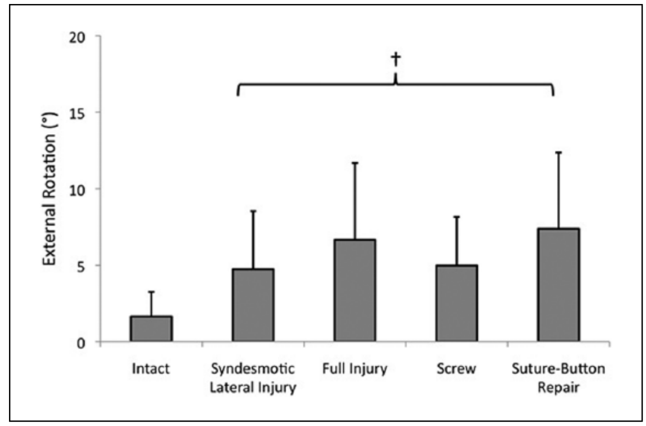

Figure 6. External rotation of fibula with external rotation stress testing. All injury and repair conditions demonstrated increased external rotation compared with the intact condition (†$P < .05$).

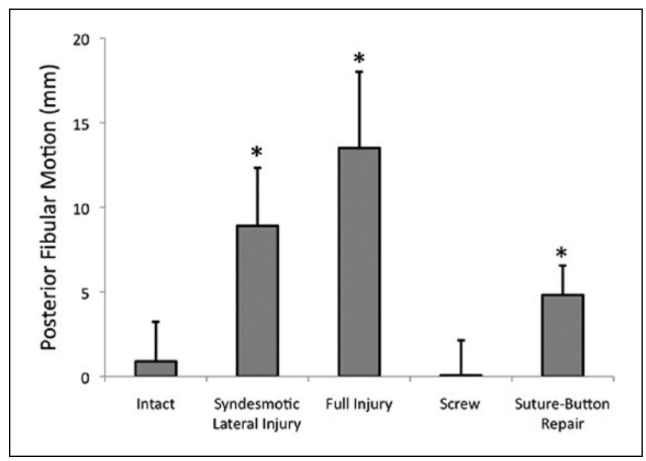

Figure 7. Posterior fibular motion as measured on the lateral fluoroscopic image. Motion did not differ between intact and screw repair conditions, but all other conditions were different from one another (*$P < .001$ compared with all other conditions).

There was significantly less medial clear space widening and incisural widening in both the suture-button construct and the screw relative to the full-injury condition but not the syndesmotic lateral injury condition (Figures 4 and 5). Posterior fibular translation was significantly reduced in both repair conditions (screw = 0.1 ± 2.1 mm; suture-button construct = 4.8 ± 1.7 mm) relative to the syndesmotic lateral injury (8.9 ± 3.4 mm) and full-injury conditions (13.5 ± 4.5 mm; Figure 6).

Discussion

Suture-button constructs are an evolving technique of syndesmotic fixation.[2,17,20,22,23] They are potentially beneficial in that they may obviate the need for syndesmotic hardware removal. In addition, suture-button constructs may

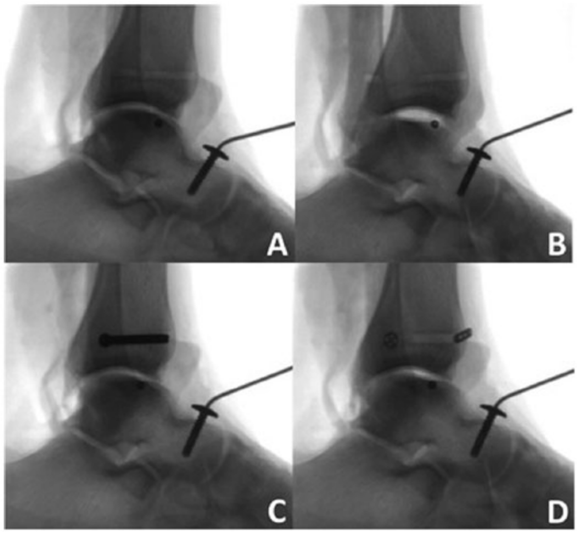

Figure 8. Representative lateral images of the ankle with the application of an external rotation stress test in the intact (A), full-injury (B), screw (C), and tightrope (D) conditions.

allow motion of the syndesmosis while simultaneously minimizing the risk of late syndesmotic diastasis on mortise radiography.[9,17,19,20,22,24] This idea has led some investigators to allow earlier range of motion in their syndesmotic injury patients, which may improve short-term outcomes such as time to return to work.[2,20,22,24] However, there are no long-term clinical outcome studies. Furthermore, the precise multiplanar nature of fibular motion in various degrees of syndesmotic injury and repair remains unclear. Moreover, the ability of suture-button constructs to allow physiologic motion but prevent syndesmotic diastasis and subluxation of the talus under the tibia remains unknown.

The current study showed that syndesmotic fixation with a screw or a suture-button construct was able to constrain coronal plane fibular motion, but the suture-button fixation allowed greater posterior motion in response to an external rotation stress test compared with the screw. The current results also demonstrated that a single suture-button construct aimed from the lateral malleolus to the anterior aspect of the medial malleolus was unable to constrain posterior fibular motion to the same degree that native ligaments are able to and that sagittal plane fibular motion was also greater than lateral plane motion in very unstable injuries. Klitzman et al[10] also reported that fibular motion is significantly increased in the sagittal plane, relative to the intact situation, when secured with a suture-button device. This is likely because suture-button constructs work by providing a tensile restraint to displacement; suture-button constructs are likely most effective when placed parallel to the primary direction of motion that constraint is desired. Accordingly, the trajectory of the tightrope in the current study was aimed to the anterior aspect of the transmalleolar axis while still exiting the medial malleolus, as is done in clinical practice. Theoretically, this trajectory would provide more restraint to posterior motion than a suture-button construct placed along the posterior aspect of the transmalleolar axis.

Suture-button orientation influences the ability of the construct to constrain fibular motion.[22,23] Teramoto et al[23] examined the influence of tightrope orientation on fibular motion in a syndesmotic injury model. Motion ("diastasis") was defined as the distance between the anterolateral edge of the tibia to the reciprocal anterior aspect of the lateral malleolus, and diastasis therefore combined coronal and sagittal motion based on the obliquity of the transmalleolar axis. When a single or double suture-button construct was placed approximating the transmalleolar axis, it was unable to constrain fibular diastasis to the same degree as the intact situation in response to a 5.0-Nm external rotation torque.[23] However, when the suture-button construct was placed from the posterior fibular cortex to the medial aspect of the tubercle of Chaput (ie, close to parallel with the direction of fibular translation), it constrained fibular motion similar to the intact situation. However, the authors did note that although this trajectory is effective mechanically, it might not be clinically realistic due to the proximity to the peroneal tendons and the superficial peroneal nerve.

Biomechanical literature supports that coronal plane fibular motion as measured by tibiofibular diastasis may[14,19,24] or may not[5,6,10,23] be adequately controlled with suture-button syndesmotic fixation. The current study suggested that the suture-button construct and screw were equally effective in holding the reduction of the syndesmosis on the mortise image when subjected to an external rotation stress test. However, there were no significant differences in fibular motion between the complete lateral injury and the intact condition, which suggests that mortise imaging is insensitive to detecting lateral fibular translation because the motion is occurring in planes not detectable on the mortise image. Only after complete deltoid transection did the coronal plane fibula motion become significantly apparent on the mortise radiograph. This is in keeping with research suggesting that with syndesmotic injuries, the fibula is more unstable in the sagittal plane than the coronal plane.[10] Although it is clear that syndesmotic malreductions and instability do more poorly,[16,29] it is unclear how the direction of malreduction or fibular instability influences patient outcomes.

The current study demonstrated that fibular rotation was significantly increased in all conditions, including screw fixation, in response to an external rotation stress test, relative to the intact situation. Given that the screw point of fixation of the fibula was in the middle of the anteroposterior plane, which is closer to the fibular center of rotation about its long axis, small amounts of screw toggle would allow fibular rotation to occur. The screw position is much different from the native fibular footprints of the AITFL and PITFL, which would be better suited mechanically for constraining rotation. The clinical significance of such rotation is unknown. Furthermore, the clinical relevance of fibular motion direction and magnitude in syndesmotic injuries remains unknown, as no clinical series has been published correlating fibular motion with clinical outcomes. Motion may allow ligaments or tendons to heal in an elongated position, or it may allow the healing of a more organized structure with improved mechanical properties.[1,25]

The current study is limited in that syndesmotic injuries were modeled as complete or intact situations; syndesmotic injuries are complex and do not always occur as an all-or-none phenomenon.[7,8] However, our goal for this study was to demonstrate fixation in conditions of maximum instability. Our loading model was also limited in that it was designed to replicate the clinical use of an external rotation stress test, as is commonly used pre- or intraoperatively. Therefore, the loading protocol did not include repeated cycles, axial loading contributions, or muscle loads as would be seen in the postoperative period. However, given the current data demonstrating instability observed during a stress test, it is reasonable to assume that repeated cycles would not improve stability and reduce measured translation/rotation. The study is also limited in that syndesmotic repair was limited to a single screw or a single suture-button construct. Additional screws or suture-button devices may constrain fibular motion differently than the single devices used in this study and should be considered in future work. Last, the clinical significance of the biomechanical studies presented herein are unknown. Additional prospective randomized trials are needed to evaluate the clinical outcomes of patients with screw or suture-button constructs.

Conclusion

It can be concluded that a single suture-button placed from the lateral fibula to the anterior medial malleolus was unable to restrict supraphysiologic motion of the fibula in the injured specimen when subjected to an external rotation stress test and in the condition of a very unstable injury. Furthermore, if rigid stability of the syndesmosis is desired for a very unstable injury, a single suture-button construct may be less effective, particularly in the sagittal plane, compared with a screw construct.

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Declaration of Conflicting Interests

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