Fluid Dynamics Play a Role In Distributing Ankle Stresses in Anatomic and Injured States

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Introduction/Purpose: In 1976, Ramsey and Hamilton published a landmark cadaveric study demonstrating a dramatic 42% decrease in tibiotalar contact area with only 1 mm of lateral talar shift. An increase in principal stress of at least 72% is predicted based on these findings though the delayed development of arthritis in minimally misaligned ankles does not appear to be commensurate with the results found in dry cadaveric models. We hypothesize that synovial fluid is a previously unrecognized factor that contributes significantly to stress distribution in the tibiotalar joint in anatomic and injured states.

Methods: As it is not possible to directly measure contact stresses with and without fluid in a cadaveric model, finite element analysis (FEA) was employed for this study. FEA is a modeling technique used to calculate stresses in complex geometric structures by dividing them into small, simple components called elements. Four test groups were investigated utilizing a finite element model (FEM): baseline ankle alignment, 1 mm laterally translated talus and fibula, and the previous two bone orientations with fluid added. The FEM selected for this study was the Global Human Body Models Consortium (GHBMC) M50 version 4.2, a validated model of an average sized male. The ankle was loaded at the proximal tibia with a distributed load equal to the GHBMC body weight and first principal stress (which is also the maximum principal stress) was computed.

Results: All simulations were stable and completed with no errors. In the baseline anatomic configuration, the addition of fluid between the tibia, fibula and talus reduced the maximum principal stress measured in the distal tibia at maximum load from 31.3 N/mm2 to 11.5 N/mm2. Following 1 mm lateral translation of the talus and fibula there was a modest 30% increase in the maximum stress in fluid cases. Qualitatively, translation created less high stress locations on the tibial plafond when fluid was incorporated in the model (Figure 1).
Conclusion: The findings in this study demonstrate a potential role for synovial fluid in distributing stresses within the ankle that has not been considered in historical dry cadaveric studies. The increase in maximum stress predicted by simulation of an ankle with fluid is less than half that projected by cadaveric data, indicating a protective effect of fluid in the injured state. The trends demonstrated by these simulations suggest that bony alignment and fluid in the ankle joint change loading patterns on the distal tibia and should be accounted for in future experiments.

Figure 1: Inferior view of the tibia and fibula demonstrating principal stresses under four test configurations: A) baseline ankle alignment, no fluid; B) 1mm laterally translated talus and fibula, no fluid; C) baseline ankle alignment, fluid; and D) 1mm laterally translated talus and fibula, fluid.