INVESTIGATING CHRONIC STRESS EXPOSURE FOLLOWING INTRA-ARTICULAR FRACTURE USING A FINITE ELEMENT MODEL OF THE ANKLE

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INTRODUCTION

Post-traumatic osteoarthritis (OA) is a disturbingly frequent outcome following intra-articular fracture. It has long been felt that altered articular surface anatomy is the primary culprit, subjecting cartilage to chronically aberrant contact stress distributions which eventually lead to OA. But current knowledge concerning the relationships between altered surface anatomy and contact stress is sorely inadequate. With the advent of patient-specific finite element (FE) modeling techniques comes the ability to address this issue more definitively.

The ankle is an ideal joint in which to study the pathogenesis of post-traumatic OA, since OA often develops in it following fractures, but rarely develops in the absence of traumatic injury. In this study, we present preliminary work towards characterizing chronic stress exposure following intra-articular fracture using FE models of intact and fractured ankles from patients.

METHODS

Two different ankles were studied, one from an intact cadaver, the other from a 4-month post-operative intra-articular fracture patient. The fracture involved an antero-medial fragment, reduced with a single screw, but healed in a somewhat depressed position. In both cases, CT studies were obtained following a standard clinical protocol, and 3-d finite element models were created (Figure 1) using voxel-based

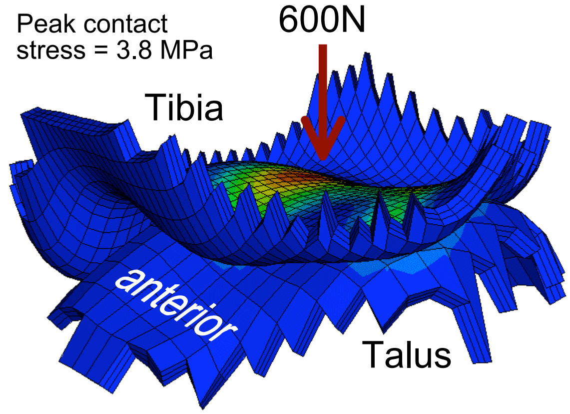

Figure 1: Schematic of ankle FE model with provisional 600N compressive seating load. The tibia is rotated about a flex/ext axis in the talus.

techniques previously described (Grosland and Brown, 2002). In brief, the subchondral surfaces of the distal tibia and the proximal talus are segmented, rigid surfaces connoting the bones are defined, and 1.5 mm layers of articular cartilage (E=12MPa, ν=0.42) are meshed to cover these surfaces. The apposing surfaces of these cartilage regions are defined as deformable contact pairs with a frictionless interface. The simulations were carried out using ABAQUS (v6.4) FE code.

To accommodate minor misalignments in the bones associated with a relaxed posture during CT scan acquisition, weak linear and torsional springs are defined to resist talar motion during provisional loading (straight compressive force to 600N – Figure 1). The tibia is then rotated about a flex/extension axis located within the talus so as to produce a neutral ankle posture, while still subject to the 600N load. The torsional springs are removed, and a sequence of thirteen loading conditions (10 to 2800N loads, rotations from 5° plantar- to 9° dorsi-flexion) taken from Stauffer et al. (1977) are applied to the tibia to simulate the stance phase of gait.

In order to characterize the contact stress exposure to which the cartilage is subjected, computed contact stress values were summed at each surface node across the stance phase of the gait cycle.

RESULTS AND DISCUSSION

Intuitively credible solutions were obtained with both models (Figure 2). Contact stress distributions in the post-op fracture case tended to line up along the residual fracture step-off. At sites away from the fracture, contact stresses were decreased compared to those in the intact ankle. The peak cumulative local stress for the fracture case was 25% higher than in the intact ankle, and located several mm from the incongruity lip.

The contact stress exposures, appropriately scaled across a period of service, might logically be compared to previously published values for chronic stress tolerance in articular cartilage (Hadley et al. (1990)).

SUMMARY

These patient-specific FE models of ankle loading during the stance phase of gait provide insight into the contact stress histories which articular cartilage experience over many cycles each day. The long-theorized chronic stress exposure following intra-articular fractures healed with residual incongruity may now be studied in the living ankle. This opens new avenues to study the link between chronic stress exposure and the onset of post-traumatic OA.

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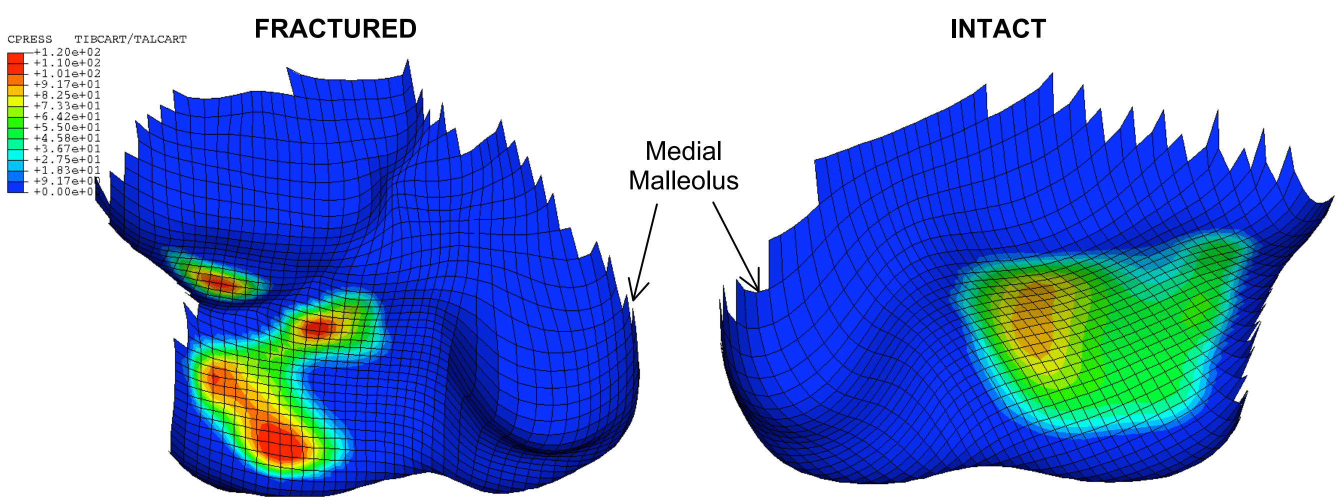

Figure 2: In these anterior views of the inferior aspect of the tibial articular surface, plots of contact stress exposure (effectively time integrals of instantaneous contact stress summed over the stance phase of gait) demonstrate contact stress aberration following a healed intra-articular fracture.