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 predispose to OA. But current knowledge concerning the relationships between altered surface anatomy and contact stress is very limited. With the advent of patient-specific finite element (FE) modelling 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 there following fractures, but rarely develops in the absence of traumatic injury. In this study, we report a modality for 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 (male, age 89 years at death), the other from a post-operative intra-articular fracture patient (male, age 53 years at injury). The fracture involved an antero-medial fragment, fixed with screws, but reduced 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 techniques previously described (Grosland and Brown, 2002). In brief, the subchondral surfaces of the distal tibia and the proximal talus were segmented, rigid surfaces connoting the bones were defined, and 1.5 mm layers of articular cartilage (E=12MPa, v=0.42) were meshed to cover these surfaces. The apposing surfaces of these cartilage regions were defined as deformable contact pairs with a frictionless interface. The large displacement FE simulations were carried out using ABAQUS (v6.4).

To accommodate minor misalignments in the bones associated with a relaxed posture during CT scan acquisition, weak linear and torsional springs were defined to resist talar motion during provisional loading (axial compressive force to 600N). The tibia was then rotated about a flexion/extension axis located in the talus.

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To accommodate minor misalignments in the bones associated with a relaxed posture during CT scan acquisition, weak linear and torsional springs were defined to resist talar motion during provisional loading (axial compressive force to 600N). The tibia was then rotated about a flexion/extension axis located in the talus so as to produce a neutral ankle posture, while still subject to the 600N load. The torsional springs were 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) were applied to the tibia to simulate the stance phase of gait (Figure 1). It is important to note that since the talus was rotationally unconstrained except about the flexion/extension axis, ankle rotation was not constrained to a single axis.

RESULTS:
In order to characterize the contact stress exposure to which the cartilage was subjected, computed contact stress values were summed at each surface node across thirteen discrete instances in the stance phase of gait. This exposure measure was then compared between the intact and fractured models.

DISCUSSION:
These patient-specific FE models of ankle loading during the stance phase of gait provide insight into the contact stress histories which articular cartilage experiences 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.

The contact stress exposures, appropriately scaled across a period of service, might logically be compared to previously published values for chronic stress tolerance in human articular cartilage (10 MPa–years of contact stress > 2 MPa; Hadley et al., 1990). Using this approach, predictions of the likelihood of post-traumatic OA occurring in a given ankle can be made. For example, in the present intact ankle, it would be predicted to take 70 years to reach this tolerance level, assuming 2 million cycles of gait a year. In the fracture case (step-off roughly 1 mm), 58 years would be required to accumulate the same level of exposure. Prospective clinical evaluations of outcomes must necessarily be used to establish the validity of such predictions, and we are currently performing just such studies.

REFERENCES:

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