

# A 3D POROELASTIC FINITE ELEMENT STUDY OF A STEP-OFF ARTICULAR INCONGRUITY

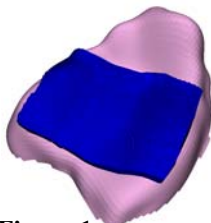
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**INTRODUCTION** Post-traumatic osteoarthritis is thought to be exacerbated by alteration of the local mechanical environment accompanying incongruous repair of a fractured articular surface, particularly if also accompanied by joint instability. A recent cadaver study of tibial pilon fractures demonstrated increases in cartilage contact stress and stress gradients in the presence of a step-off articular incongruity [1]. Especially high gradients were recorded in cases in which the talus subluxated from beneath the tibia, rapidly loading the displaced fragment of the tibia. The present study investigated the response of cartilage to this loading using a 3D, poroelastic finite element model of the tibia. Contact stress histories from the cadaver study were applied to the model to investigate the transient responses of the solid and fluid phases throughout the full cartilage thickness.

**METHODS** A 1.5mm cartilage layer consisting of 241,000 linear brick elements was extruded from CT scans of subchondral bone using TrueGrid as shown in Figure 1. Only the central portion of the subchondral bone needed to



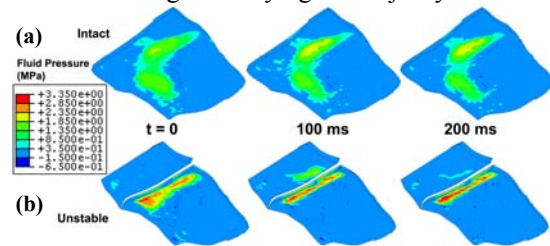
**Figure 1.** Subchondral bone (red) and extruded cartilage layer

be meshed since the contact stresses are recorded only in that region. The cartilage was considered fixed at the cartilage-bone interface. Transient contact stress histories from the cadaver study were applied to the articular surface as time-varying surface pressures. A step-off incongruity was created by translating the anterior 30% of the cartilage layer 2mm proximally.

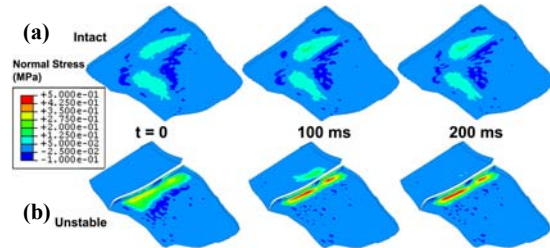
A transversely-isotropic, poroelastic cartilage material model was used in this study. A local material orientation was used in which the '1' and '3' directions were parallel to the articular surface and the '2' direction was normal to the surface. The permeability used was  $1.14 \times 10^{-15} \text{ m}^4/(\text{N}\cdot\text{s})$  [2]. The tangential ( $E_1=E_3$ ) and normal ( $E_2$ ) moduli of elasticity were 33 MPa and 0.55 MPa, respectively [3,4]. The Poisson's ratio characterizing the transverse response to a transverse load was 0.146 [5] and the Poisson's ratio characterizing the transverse response to a normal load was 0.074 [2]. Literature values for the shear modulus in the '1-2' plane in the superficial layer range up to 4 MPa [6], however a shear modulus of 10 MPa was used for this analysis since the dominant shear stress occurs in the deep layers of this model and deep layer cartilage is around 2 to 3 times stiffer than the superficial layer [4].

**RESULTS** Fluid pressure results for normal, intact cartilage and for fractured cartilage with a 2mm step-off incongruity are shown in Figure 2. Fluid pressures in the

presence of an instability were nearly double those of the intact model. The rapid loading of the displaced fragment results in fluid pressure transients of 35 MPa/s, compared to 17 MPa/s in the intact model. The normal component of solid phase stresses for the intact and unstable models is shown in Figure 3. The unstable model experienced higher solid phase stresses and stress transients than the intact model. However, the normal stresses for the intact and unstable models are approximately one order of magnitude lower than the fluid pressures, indicating that the fluid phase of the cartilage is carrying the majority of the load.



**Figure 2.** Fluid pressures for (a) intact and (b) unstable models.



**Figure 2.** Normal solid phase stresses for (a) intact and (b) unstable models.

The models presented here provide a means by which to quantify, spatially and temporally, differences in the mechanical loading environment caused by the talus subluxating from beneath the tibia during an unstable motion in the presence of an articular incongruity. Such transient loadings are strongly predisposed to osteoarthritis, for reasons not currently well-understood.

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