MECHANICAL RESPONSE OF BONE SURROUNDING OSTEOCHONDRAL GRAFT: A FINITE ELEMENT STUDY

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INTRODUCTION: Osteochondral graft implantation is well established as a treatment option for repair of cartilage defects. Prior work[1] has shown that graft placement, amount of press-fit and other dimensional parameters can influence the local stress state and may therefore influence the clinical outcome. The potential relationship between local stress and the clinical outcome is further supported by animal studies[2] which show that a geometric mismatch at the articular surface between the graft and surrounding host tissue may influence local healing and bone remodeling. Prior computational work[1] emphasized stresses and strains in articular cartilage around osteochondral grafts. However; it appears that subchondral bone also plays a significant role in joint disease[3] and the performance of osteochondral grafts. This study examines the effect of various parameters on stress and strain in both cartilage and subchondral bone.

MATERIALS AND METHODS: Axisymmetric finite element models (Abaqus Standard, Rev. 6.6-1) represent a portion of a medial condyle in a distal femur, and an opposing tibial segment, as shown in Figure 1.

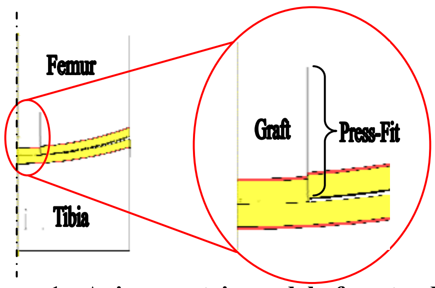

Figure 1 - Axisymmetric model of protruding graft case. Cancellous bone is shown in white, subchondral plate in red and cartilage in yellow.

For preliminary work, cancellous subchondral bone and the subchondral bone plate were modeled as linearly elastic materials. For the cartilage, a linear hyperelastic simplification was used (Marlow model) for preliminary static analysis which does not consider the time dependent viscoelastic response. Material elastic modulus values[1,4] were: cancellous bone (2300 MPa), subchondral plate (18,000 MPa) and cartilage (1MPa). Three cases were studied: (a) Perfect alignment of graft and femur (no geometric mismatch) (b) Graft countersunk below surface of femur by 0.25mm and (c) Graft protrudes .25mm above femur surface. Radial interference (press-fit) between graft and host tissue was 0.05mm. Models were constructed to allow variations in graft diameter, length and other dimensions to determine sensitivity. Frictional sliding contact is defined at the interfaces between graft and femur and between tibia and femur. Analysis includes both press-fit and pressure applied to the tibia to represent peak ambulatory load.

RESULTS: Figure 2 shows Von Mises equivalent stress results in the model for the perfectly aligned (a), countersunk (b) and protruding (c) grafts.

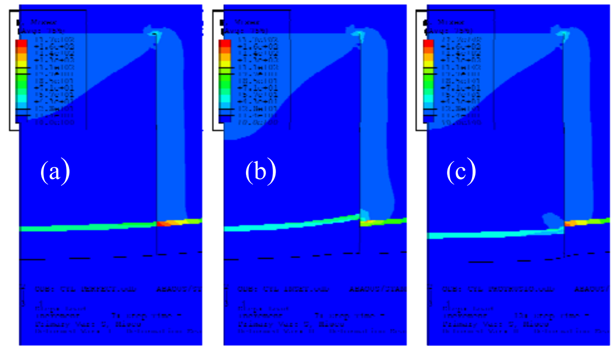

Figure 2 – Von Mises equivalent stress (MPa) in model for (a) perfectly aligned, (b) countersunk and (c) protruding graft cases.

The highest stress occurs in the subchondral plate for all three cases. Geometric mismatch for cases (b) and (c) causes some local stress elevation in cancellous bone.

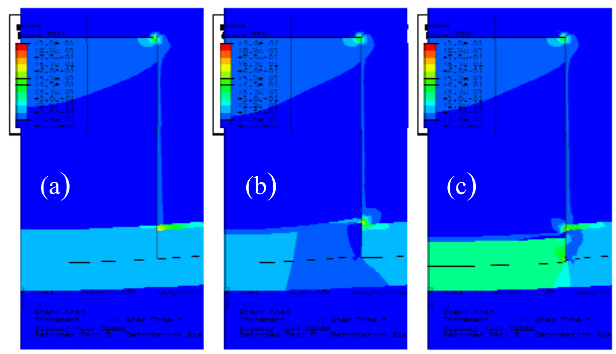

Figure 3 - Strain energy density (SENER) in model for cases (a), (b) and (c).

Strain energy density plots (Fig. 3) highlight the cartilage strains which vary considerably among the three cases.

DISCUSSION: The subchondral plate, though thin, is an order of magnitude stiffer than the cancellous bone and causes a stress concentration that is very sensitive to geometric mismatch. The observed stress and strain results primarily from press-fit, and is impacted little by tibio-femoral loading. Geometric mismatch produces significant changes in cartilage strain and affects cancellous bone near the subchondral plate. It does not seem to affect strains and stresses at the superior corner of the graft, a place where post-implant bone cysts are sometimes observed. This may be a limitation of the small amount of countersink and protrusion (0.25mm).

REFERENCES: [1] J.Z. Wu et al., Medical Engineering & Physics, 24, 2002, 85-97 [2] L. Bálint et al., Clinical Orthopaedics and Related Research, 430, 2005, 208-218 [3] C.E. Kawcak et al., In Depth; Current Concepts in Equine Osteoarthritis, AAEP Proceedings, 47, 2001, 157-163 [4] B. Li and R.M. Aspden, Annals of the Rheumatic Diseases, 56, 1997, 247-254