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Computational wear simulation of patellofemoral articular cartilage during *in vitro* testing

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ABSTRACT

Though changes in normal joint motions and loads (e.g., following anterior cruciate ligament injury) contribute to the development of knee osteoarthritis, the precise mechanism by which these changes induce osteoarthritis remains unknown. As a first step toward identifying this mechanism, this study evaluates computational wear simulations of a patellofemoral joint specimen wear tested on a knee simulator machine. A multibody dynamic model of the specimen mounted in the simulator machine was constructed in commercial computer-aided engineering software. A custom elastic foundation contact model was used to calculate contact pressures and wear on the femoral and patellar articular surfaces using geometry created from laser scan and MR data. Two different wear simulation approaches were investigated—one that wore the surface geometries gradually over a sequence of 10 one-cycle dynamic simulations (termed the "progressive" approach), and one that wore the surface geometries abruptly using results from a single one-cycle dynamic simulation (termed the "non-progressive" approach). The progressive approach with laser scan geometry reproduced the experimentally measured wear depths and areas for both the femur and patella. The less costly non-progressive approach predicted deeper wear depths, especially on the patella, but had little influence on predicted wear areas. Use of MR data for creating the articular and subchondral bone geometry altered wear depth and area predictions by at most 13%. These results suggest that MR-derived geometry may be sufficient for simulating articular cartilage wear *in vivo* and that a progressive simulation approach may be needed for the patella and tibia since both remain in continuous contact with the femur.

1. Introduction

According to recent data from the US Centers for Disease Control and Prevention, arthritis costs the US economy close to $128 billion annually and remains the leading cause of disability (CDC, 2007). The most common form, osteoarthritis (OA), disables about 10% of the population above age 60, with the knee being the joint most commonly affected (Buckwalter et al., 2004).

Despite the growing burden of knee OA to society, researchers have made little progress at developing treatments that modify the course of the disease. One reason is the difficulty of performing experimental knee OA studies in human subjects. Consequently, much of the experimental OA research has involved animal or *in vitro* studies (Setton et al., 1999; Herzog et al., 2004; Griffin and Guilak, 2005). Coupled with clinical observations, such studies have led to viable hypotheses for how biomechanical factors affect the initiation and progression of the disease. One hypothesis proposed by several researchers is that altered joint kinematics (e.g., due to anterior cruciate ligament injury) cause previously unloaded regions of the joint to become overloaded, creating damage that eventually spreads to neighboring regions as well (Wu et al., 2000; Carter et al., 2004; Andriacchi and Mundermann, 2006).

Since contact stresses and strains across the knee's articular cartilage surfaces cannot be measured accurately *in vivo* (Winby et al., 2009), a computational approach could be valuable for evaluating such hypotheses and ultimately predicting the outcome of proposed treatment scenarios. Numerous finite element (Li et al., 1999; Donahue et al., 2002; Pena et al., 2006; Papaioannou et al., 2008; Yao et al., 2008b; Yang et al., 2010) and elastic foundation (Blankevoort et al., 1991; Cohen et al., 2003; Bei and Fregly, 2004;

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