INTRODUCTION
Meniscectomy leads to osteoarthritis (OA) in both human and animal knee joints. Spatial changes in biochemical composition and biomechanical properties over the entire surface of articular cartilage following meniscectomy have been previously reported [1, 2].

Abnormal mechanical conditions on the articular cartilage surface have been hypothesized to initiate and develop cartilage degeneration following meniscectomy [3, 4]. However, no studies have calculated detailed strains over entire articular cartilage surfaces in a meniscectomized joint when a realistic cyclic loading is applied.

The objective of this study was to measure the variation of nominal strains over entire 3D articular cartilage surface after meniscectomy under a physiologic magnitude and frequency of cyclic compressive loading, and to investigate whether there is a relationship between mechanical strains in the articular cartilage surface and previously described [1] localized biomechanical and biochemical property changes following meniscectomy in sheep models.

METHODS
Sample Preparation: Three young sheep (2 years old, 50kg) hind limbs were frozen at a 45 degree knee flexion angle. The entire knee joint was then cored from medial to lateral to contain the entire tibio-femoral joint, the menisci, and the collateral and cruciate ligaments.

Cyclic Compression: A joint specimen was cyclically loaded inside a specially designed pneumatic loading device [5]. The magnitude (2 times body weight) and the frequency (1 Hz) of load were calibrated to match real sheep gait data [6].

MR Imaging: 4.7T MRI scanner was used to scan the articular cartilage deformation [5, 6]. A sample was cyclically loaded for 30 min prior to imaging to allow the articular cartilage reach the steady-state deformation [6]. The sample was scanned with intact meniscus under cyclic load. After 1 day of full thickness recovery time, medial meniscus was removed from the sample, cyclic load was again applied until the articular cartilage deformation reached steady-state, and the medially meniscectomized sample was then scanned under cyclic load.

Strain Measurements: Each 3D cartilage model was created from MR data [5], and divided into 4 zones on the meniscectomized side and 3 zones on the meniscus intact side (Figure 1). Each zone consists of 2 or 3 sub-sections. These zones correspond to zones that have previously been used to study alterations in articular cartilage biochemical composition and material properties in a sheep meniscectomy model [1]. The steady-state nominal strains during cyclic loading from day 2 were subtracted from those of day 1 (Figure 1). S-GAG content (S-GAG/dry tissue; μg/mg) and shear modulus (G*; MPa) changes in each area six months following meniscectomy were obtained from a previous in-vivo sheep study [1].

RESULTS
As expected, the control side of articular cartilage showed very small nominal strain changes over the entire cartilage surface although the outer part of the control side was overloaded. The middle portion of meniscectomized cartilage was highly overloaded and the outer portion of the cartilage was significantly underloaded after meniscectomy (Figure 2).

DISCUSSION
Regions of articular cartilage in the middle and outer regions of the meniscectomized condyle experienced significant changes in nominal strain. Both overloaded and underloaded articular cartilage appears to develop a reduction of shear modulus, a sign of cartilage degeneration and softening. Interestingly, S-GAG content only decreased at the middle of meniscectomized cartilage (overloaded), but increased at the outer part of the cartilage (underloaded). These results could explain different articular cartilage degeneration mechanisms due to the endochondral ossification on the underloaded cartilage and cartilage fibrillation on the overloaded cartilage following meniscectomy.

In conclusion, the strong relationships between post-meniscectomy changes in nominal strain and osteoarthritic cartilage degeneration as measured by changes in S-GAG content and shear modulus were established. These results provide further insight into the mechanical etiology of osteoarthritis.

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