INTRODUCTION
Articular cartilage performs remarkably as a bearing material and provides low friction and wear over a lifetime. Though several theories have been proposed, no clear consensus has emerged as to the mechanism of cartilage lubrication. Some investigators, including ourselves [1-4], have proposed that cartilage can achieve very low frictional coefficients because its interstitial water can pressurize considerably under contact loading, supporting most of the applied load. This study provides a direct experimental verification of this hypothesis [1,2] by investigating whether a correlation exists between the time-varying frictional coefficient and interstitial fluid load support, in the configuration of sliding of cartilage against glass under a constant applied load.

METHODS
Specimen Preparation: Eight cartilage plugs (8mm diam.) were harvested from the femur and patella of three bovine knee joints obtained from a local abattoir (ages 11 to 16 months). The samples were stored at -20°C in physiological buffered saltine solution (PBS) until testing. On the day of testing, samples were sledge micromotomed to remove about 1mm of tissue from the deep zone, leaving the articular surface intact (avg thickness of samples: 0.77±0.03mm). In order to obtain a uniform cylindrical cross section, 6mm plugs were further cored out from the samples.

Test Apparatus: Reciprocal sliding motion was provided by a computer controlled translation stage (Model PM500-IL, Newport Corporation, CA). Normal loads were applied via a 1mm glass slide using a dead weight of 0.5N, with a prescribed load of ~4.5N, with simultaneous intermittent sliding over logarithmic time increments (range of translation ±2mm; sliding velocity 1mm/s). The test was terminated when the interstitial fluid pressure nearly reduced to zero. The normal force, frictional force, displacement and average interstitial fluid pressure were monitored throughout the test. Data acquisition and control was performed using a personal computer equipped with a data acquisition card. The experiment was performed at room temperature and the entire specimen and loading glass surface were immersed in 0.15M PBS solution mixed with protease inhibitors (Complete protease inhibitor cocktail tablets, Lucas Novasensor, CA). Displacements were measured with a linear variable differential transformer (HR100, Shaevitz Sensors, VA).

Experimental Protocol: The test protocol consisted of sliding cartilage against glass under the configuration of unconfined compression creep, with a prescribed load of ~4.5N, with simultaneous intermittent sliding over logarithmic time increments (range of translation ±2mm; sliding velocity 1mm/s). The test was terminated when the interstitial fluid pressure nearly reduced to zero. The normal force, frictional force, displacement and average interstitial fluid pressure were monitored throughout the test. Data acquisition and control was performed using a personal computer equipped with a data acquisition card. The experiment was performed at room temperature and the entire specimen and loading glass surface were immersed in 0.15M PBS solution mixed with protease inhibitors (Complete protease inhibitor cocktail tablets, Roche Applied Science, IN), throughout the test.

Recent experimental studies have demonstrated that fluid load support at the deep zone of cartilage may be lower than at the articular surface due to the depth-wise inhomogeneity of material properties [6]. To account for this disparity, a second set of experiments was performed on the same samples to extract the ratio surface intact (avg thickness of samples: 0.77±0.03mm). In order to obtain a uniform cylindrical cross section, 6mm plugs were further cored out from the samples.

DISCUSSION
Previous studies have shown that articular cartilage can have low frictional coefficients immediately upon loading; however, if the applied load is maintained under static conditions for long (non-physiologic) durations, the friction coefficient becomes quite elevated and unfavorable for efficient lubrication [2-4]. The results obtained here are in good agreement with these previous studies. As predicted by our theoretical model, a very strong inverse correlation was observed between the fluid load support and the frictional coefficient (Fig.2). The fluid load support reduced the initial value of the friction coefficient by a factor ranging from 4 to 250 relative to its equilibrium value. These findings support the hypothesis that hydrostatic pressurization is a fundamental mechanism governing the frictional response of articular cartilage. To our knowledge, this is the first study where the fluid pressure and the frictional coefficient have been simultaneously measured and correlated. According to this hypothesis, the frictional coefficient remains low and achieves physiologically favorable values as long as the fluid load support remains high (Fig. 1). This finding is in agreement with our previous studies where we report that fluid load support remains elevated over a wide range of physiological loading frequencies and subsides only under non-physiologic sustained static loading [5-7]. These results suggest that any degenerative process, such as may occur in osteoarthritis, which compromises interstitial fluid pressurization will likely have adverse effects on the frictional response of cartilage.

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REFERENCES

Figure 1: Variation of fluid load support and effective friction coefficient over time for a typical sample.

Figure 2 The effective frictional coefficient as a function of the fluid load support, using data from Fig.1.

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