INTRODUCTION: Biomaterials placed against articular cartilage are commonly used in orthopaedic surgery. However, because the artificial surface articulates against native cartilage, there is a great concern for wear of the tissue ultimately leading to revision surgery [1-3]. Despite the advantages of hemiarthroplasty over total joint replacement, many studies recommend a total joint replacement even when the cartilage appears normal, due to the high potential for wear and need for later revision [3,4]. A key factor in determining the longevity of this type of reconstruction is the tribological properties of the material [5,6]. Comparison of few published data on materials tribology against cartilage is difficult because of the wide range of experimental techniques and biomaterials used in these studies. Hence, basic understanding of the underlying wear mechanisms of native cartilage articulating against different biomaterials is of paramount importance. Since high-friction contact interfaces generally result in high wear rates, a well-lubricated system is characterized by the formation of an intimate contact interaction. The purpose of this study was to measure friction coefficients and wear rates of four commonly used orthopaedic materials: 1) cobalt chrome (CoCr), 2) alumina ceramic (Al₂O₃), 3) polyethylene (PE), and 4) stainless steel (SS) against articular cartilage. The null hypotheses were that 1) there is no difference in cartilage wear rates when different materials articulate against normal cartilage, and 2) there is no difference in friction coefficients of the surfaces of the different materials.

METHODS: Articular cartilage plugs (diameter=5 mm, thickness=4 mm) were removed from the anterior medial region of femoral condyles of juvenile bovine stifles joints within 12 hr of slaughter. Explants were placed in serum-free, chemically-defined Dulbecco’s modified Eagle medium (D-MEM/F-12, Invitrogen), supplemented with 0.1% bovine serum albumin, 100 units/ml penicillin, 100µg/ml streptomycin, and 50µg/ml ascorbate-2-phosphate prior to testing. Implant materials were prepared as disks for testing with the surfaces finished similar to those currently used in orthopedic applications. Cartilage Surface Friction. To determine long-term wear effects of the materials on cartilage, the friction coefficient of articular cartilage (n=7) was measured on a pin-on-disk (POD) tribometer in reciprocating sliding mode. Explants were equilibrated under load against respective materials for 2 min [7] and shear load was applied for 60 min under 1.8 N load (0.1 MPa) at 0.5 mm/s sliding speed in 10 mL of phosphate buffered saline (PBS). Disks were sonicated in PBS prior to each measurement. Cartilage Wear Rate. Following friction testing, cartilage plugs were rinsed 2 times with 500 µL PBS and the PBS bath collected. The disks were then rinsed 3x with 500 µL PBS and collected with the rest of the bath. The PBS was concentrated to ~100 µL and frozen for protein quantitation. Protein content in the wear debris was measured using the micro BCA assay (Pierce). Wear rates were calculated as mass lost from the cartilage surface, per contact area and sliding time (µg/mm²/s).

Material Surface Friction. The nanoscale friction characteristics of the materials were studied with an atomic force microscope (AFM) (Asylum MFP-3D-CF) in air. Each disk was scanned in 5 different locations using triangular Si₃N₄ tips (R=10 nm, k=0.02 N/m) over a 60x60 µm² area with matrix size=128x128 pixels and rate=1 Hz. A constant normal force of 7.07 nN, determined by the thermal calibration method [8], was applied. The half width of the friction loop and lateral calibration based on the direct force balance method [9] with a silicon grating (TGF11, Mikromash) was used to calculate the friction force. Statistics. A two-way ANOVA and Fisher’s PLSD post-hoc tests with a significance level of p<0.05 were used to determine differences between friction coefficients of cartilage at 1 and 60 min. A one-way ANOVA and Fisher’s PLSD tests with p<0.05 were used to determine differences between the cartilage surface protein wear rates. A nested one-way ANOVA and Fisher’s PLSD tests with p<0.05 tests were used to determine differences between the biomaterials surface friction.

RESULTS: Cartilage Friction. For all biomaterials, the cartilage friction coefficient increased nonlinearly with sliding distance (Fig 1A).

DISCUSSION: In the clinical application, it is important that the friction between the material and cartilage remain low and cause minimal wear. Results indicate that CoCr, the most commonly used material against cartilage, has the least desirable tribological properties of the four materials tested. It caused both the highest friction coefficient of cartilage and had the highest nanoscale surface friction. PE performed better than the other materials when sliding against cartilage, causing the lowest wear and friction of cartilage throughout the 60 min of sliding. These results are consistent with previous studies [1,2,4,10]. However, in measurements of the surface tribological properties, PE also had one of the highest surface friction coefficients, similar to that of CoCr. These discrepancies may be attributed to differences in opposed material surfaces (i.e., cartilage vs. Si₃N₄) and scale-dependent friction (and wear) mechanisms encountered in the POD and AFM experiments. Other factors, such as surface roughness and formation of sacrificial boundary films of proteins may have also contributed to the observed disparities in tribological behavior. For example, surface roughness controls the thickness of the fluid film at the biomaterial/cartilage interface, affecting the lubrication mode and, in turn, the resulting tribological behavior. Further investigations to the specific proteins worn from the surface would provide insight into the wear mechanisms of the materials. Superficial zone protein is an important boundary lubricant that is likely to be a constituent in the wear debris. Quantification of SZP may explain the differences seen between the materials in friction coefficient but not in total protein wear. The present study indicates that polyethylene would cause the least wear of articular cartilage, while CoCr alloy would produce the highest wear rate.