Long-Term (5-Million Cycles) Wear Properties of a Novel Biomaterial against Cartilage

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INTRODUCTION: Due to their everyday use, the tribological properties of orthopedic implants used in total joint replacement are well-characterized. Conversely, these wear properties are relatively uncharacterized when used in hemiarthroplasty, articulating with cartilage tissues. Traditional materials have demonstrated adverse effects when articulating with native cartilage, especially when the material presents a high coefficient of friction[1]. A novel biomaterial has been developed to articulate with cartilage. The material, called BioPoly®, is a hydrophilic polymer which is a combination of two common orthopedic materials: ultra-high molecular weight polyethylene (UHMWPE) and hyaluronic acid. This material has been used to repair focal chondral and osteochondral defects in the knee in partial resurfacing implants since 2012. Interim results report significantly improved clinical outcomes in patients at 2-year follow-up[2] with long-term results forthcoming. In order to characterize the tribological properties of the BioPoly material against cartilage, the present study was designed to measure the coefficient of friction (CoF) and wear rate of BioPoly and Cobalt Chrome Molybdenum alloy (CoCrMo), a common hemiarthroplasty material, during articulation with cartilage. Particular attention was paid to characterizing wear over a longer period than currently available in literature, 5 million cycles.

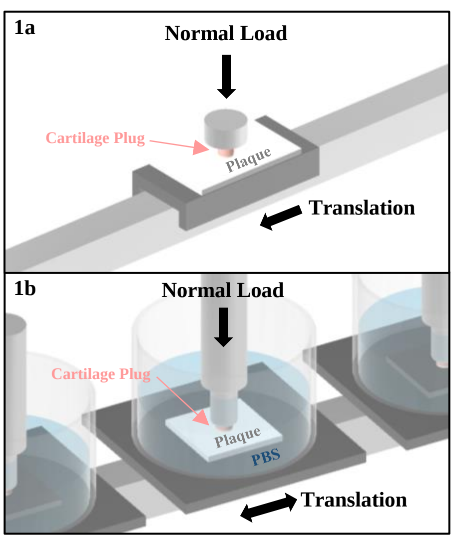
METHODS: CoCrMo was used as the control for this study given its wide-range use in hemiarthroplasty devices. Cartilage samples (10mm osteochondral plugs) were harvested from bovine femur specimens. To determine CoF, a loading apparatus designed to apply a normal force and sliding translation as is shown in Figure 1a. A normal pressure (0.44 MPa) was applied to the osteochondral plugs in articulation against plaques made from BioPoly or highly polished CoCrMo. Reagent grade water was used to lubricate the articulating surfaces. The plaque specimens were translated, measuring the translational force via a calibrated load cell five (n=5) times for each material. To characterize cartilage wear, the loading apparatus was configured as in Figure 1b. Osteochondral plugs were paired with three (n=3) plaques of each material. A normal pressure (0.7 MPa) was applied to the plugs as the plaques were cyclically translated in a linear 7.3mm path at 2 Hz. The test setup was temperature-controlled at 37°C in PBS solution. Osteochondral plugs were replaced at regular intervals. Cartilage thickness was recorded before and after each replacement. Lastly, in 500k cycle increments up to 5.0 million cycles, material plaques were cleaned, dried, and weighed. For each test result, a one-sided student's t-test was performed with significance set at $\alpha=0.05$.

RESULTS: BioPoly CoF (0.007 ± 0.003) against cartilage was significantly less than ($p < 0.05$) CoCrMo CoF (0.047 ± 0.002) (Figure 2a). Gravimetric wear and wear rate were significantly lower ($p < 0.05$) for BioPoly material than for CoCrMo (Figure 2b). This significance was not seen for volumetric wear and wear rate. The change (reduction) in cartilage thickness of the osteochondral plugs (Figure 3a) was also significantly lower ($p < 0.05$) for the BioPoly group versus the CoCrMo group. Images captured of osteochondral plugs (Figure 3b) show that the cartilage spread beyond the plug circumference over time; however, his effect was seen to a higher extent in plugs articulating with CoCrMo, supported by the measured change in thickness.

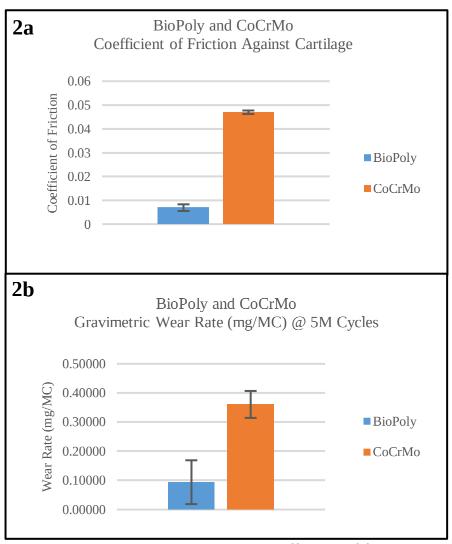
DISCUSSION: BioPoly material outperformed CoCrMo in both coefficient of friction, gravimetric wear, and wear of the opposing cartilage surface. However, this study only evaluated simplified articulating surfaces, i.e. flat on flat. Further research would be necessary to characterize actual wear of each material in orthopedic implants; although, a method of characterizing *in-vivo* cartilage wear is not obvious. In order for the osteochondral plugs to survive for a reasonable amount of cycles, the applied stress in this study was lower than the maximum stress found in some joints. However, the resulting stress was still physiologically relevant at 0.7MPa. Further testing could be performed at higher stresses but for fewer cycles than 5 million.

SIGNIFICANCE/CLINICAL RELEVANCE: This study characterized the long-term wear of orthopedic materials against cartilage in order to better predict how permanent hemiarthroplasty implants may behave against cartilage *in vivo*. This study implies that BioPoly, a novel biomaterial, is more compatible with cartilage than CoCrMo, the most common material for that purpose, with potential to extend the lifetime of hemiarthroplasty implants and delay revision to partial or total joint replacement.

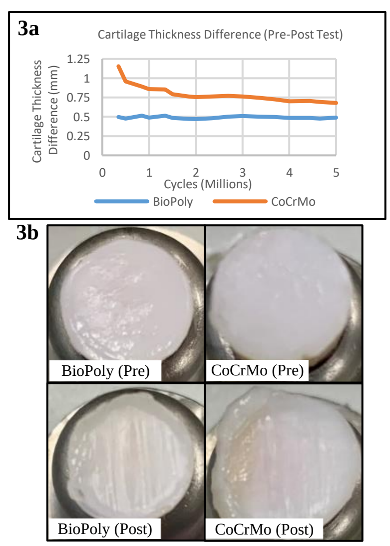
REFERENCES:
[1] Oungoulian, et al.: Wear and Damage of Articular Cartilage with Friction Against Orthopaedic Implant Materials. *J Biomech*, 2015; 48(10)
[2] Nathwani, et al.: Partial Resurfacing of the Knee with the BioPoly Implant. *JBJS Open Access* 2017; 2(2)



Figures 1(a-b): Test apparatus for **a)** Coefficient of Friction and **b)** Wear Characterization of BioPoly and CoCrMo orthopedic materials. Both utilize a plaque translating underneath a loaded osteochondral plug. The wear test was performed in a PBS solution.



Figures 2(a-b): BioPoly and CoCrMo coefficients of friction **(a)** and gravimetric wear rates at 5M cycles **(b)** after articulation against cartilage. BioPoly demonstrated a lower CoF and gravimetric wear rate than CoCrMo with significance at $p < 0.05$ when articulated against cartilage.



Figures 3(a-b): Difference in cartilage thickness **(a)** and spreading of cartilage **(b)** examined pre and post articulation against BioPoly and CoCrMo materials. Osteochondral plugs articulated against BioPoly material saw less damage.