INTRODUCTION
Scratches produced by third-body debris in total joint replacements substantially accelerate wear. In metal-on-polyethylene designs, scratches on retrieved metal components often show a locally prevailing direction of scratching. Because wear of polyethylene is an adhesive-abrasive process, the direction of scratching relative to counterface motion would seemingly influence wear.

A reciprocating motion physical wear test protocol was employed to identify the direction-dependence of polyethylene wear as a function of relative scratch orientation. Concurrently, a local finite element (FE) model of scratch traverse was developed to identify surrogate stress/strain measures showing similar direction-dependence. Such surrogate parameters could be useful as predictors of direction-dependent wear, in analytical research models for which physical material erosion and debris production are not possible.

METHODS
Wear test protocol
Arrays of parallel scratches were produced at 150 μm intervals on polished stainless steel plates. To form the scratches, a row of eleven diamond styli of tip radii 50 μm was dragged across the plate under load and then incrementally offset, until the plate was uniformly scratched. This method created scratches with typical lip heights, lip widths and furrow widths of 1.3, 22 and 23 μm, respectively (Figure 1).

The scratched counterface plate was driven reciprocally against a 25.4 mm diameter polyethylene pin, loaded by 1269 N (nominal stress 2.5 MPa). Parametric tests, in which the plate was moved across the polyethylene pin, at angles of 0, 2.5, 5, 15, 30, 45, 60, and 90º relative to the scratch orientation, were conducted for both conventional UHMWPE and highly-crosslinked UHMWPE (HXPE). The contact surface was immersed in bovine serum, and wear was assessed gravimetrically. Tests were run until wear rates approximated steady state.

Finite element model
A 3D FE model was utilized to study the localized contact interaction. Angle-specific nonlinear computational models, typically about 45,000 elements, were used to model contact between the polyethylene and a representative scratch profile developed from interferometry readings of the scratched metal platen. The model included both geometric (contact) and constitutive [1] nonlinearities.

A loaded scratch was displaced across the polyethylene surface at constant velocity (Figure 2), replicating the parametric traverse directions of the physical experiment. Stress/strain data were output at serial instants during the event of scratch approach, overpass, and recession. A post-processing algorithm was developed to “integrate” the mechanical disturbance history experienced at a given site on the polyethylene surface, due to scratch passage.

RESULTS AND DISCUSSION
Experimentally, a scratch oriented at 15º with respect to the sliding direction was found to produce the greatest wear for conventional UHMWPE. The direction of greatest sensitivity for HXPE was 5º (Figures 3,4). The angle-specific wear rates were normalized for comparison with the results of the finite element analysis.

Three full-field stress/strain tensorial components in the FE model behaved consistently with observed direction-dependent wear of HXPE. These were normal strains ε23, shear strains γ23, and shear stresses σ23, for a scratch loaded normal to the 2-plane and sliding normal to the 1-plane. For conventional UHMWPE, normal strains ε33 showed dependence similar to observed wear (Figures 3,4). For purposes of wear modeling at the macroscopic level, these parameters arguably could be used as surrogates for orientation-dependent wear in UHMWPE.

REFERENCE

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Figure 1. Laser scanning micrography image of custom scratch profile created on 316L stainless steel. Surface roughness Ra=1-1.5 μm.

Figure 2. Instantaneous stress induced in polyethylene by a counterface scratch lip sliding at an angle of 45º.

Figure 3. Surrogate predictors of wear as a function of scratch orientation in highly-crosslinked UHMWPE.

Figure 4. Tensile strain ε33 as a predictor of wear dependence in conventional UHMWPE.