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Predicting UHMWPE Wear: Decreasing Wear Rate Following a Change in Sliding Direction

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INTRODUCTION

The patient demographic for total joint replacement is becoming younger and more active leading to increased performance expectations [1]. To develop new products that meet these demands, computer simulations that predict wear are emerging as potential design tools [2]. The algorithms for these simulations typically assume a linear relationship between wear and sliding distance [3-5] and therefore do not account for the possibility of a variable wear rate along a path (Fig 1). In a previous study we demonstrated that the wear of crosslinked polyethylene did not depend on the sliding distance, rather on the number of crossing events (ie changes in direction) [6], implying that large portions of sliding did not contribute to the total wear. We were unable, however, to identify the transition from high wearing multidirectional sliding to the low wearing unidirectional sliding (Fig 1). The purpose of this study was to further investigate this transition by examining a broader range of sliding distances. We hypothesized that small increases in sliding distance after a direction change would produce additional wear while no additional wear would be produced at longer sliding distances sufficient to reestablish 'unidirectional' sliding.

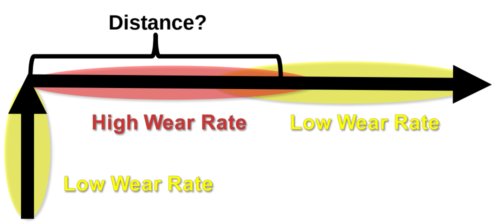

Fig 1. A linear wear path that undergoes a sudden change in direction will generate a high wear rate initially and then will transition to a near zero wear rate with continued sliding. The sliding distance required to achieve the reduced wear rate is unknown.

METHODS.

Thirty UHMWPE pins were assigned to five sliding distances (1mm, 2mm, 5mm, 10mm, 100mm) having dedicated wear (n=3) and soak specimens (n=3). Using similar methods to the previous study [6], pins reciprocated in short segments (1mm, 2mm, 5mm) on a broad arc (R=52.4mm) under a vertical load of 330N (~4.7MPa) until they achieved the target sliding distance per cycle (Fig 2). The pins then stopped translating and rotated 90° under a reduced load of 30N (~0.1MPa). The loading was restored to 330N and sliding recommenced. The pins reciprocated 1, 2, or 20 times to achieve the desired sliding distance prior to rotating back to 0° under reduced load. A complete cycle included two sliding periods and two rotations to 90° and 0°. In every case, this essentially resulted in 'square' sliding paths, all having identical cross-shear values as calculated by existing definitions [3-5].

Sliding Between Turns	*Recipro-cations*	*Single Leg Distance*	*Total Turns*	*Total Cycles*	*Total Distance*
1mm	1	1mm	1.62M	0.81M	1.6km
2mm	1	2mm	1.56M	0.78M	3.1km
5mm	1	5mm	1.44M	0.72M	7.2km
10mm	2	5mm	1.60M	0.80M	16.0km
100mm	20	5mm	0.48M	0.24M	48.0km

Table 1. Experimental conditions.

Testing was performed at 37±1°C in 90% bovine serum (HyClone, Logan UT) that was supplemented with 0.2% sodium azide and 20mM EDTA to retard bacterial growth and calcium precipitation. All pins were machined from the same GUR 1020 ram extruded bar that had been gamma irradiated to 50±5 kGy, remelted, and annealed. The pins (17.8mm long, 9.5mm diameter) articulated against mirror polished wrought Co28Cr6Mo counterfaces (12.7mm thick, 38.1mm diameter). Wear was quantified via gravimetric methods every 2.5 days to control any confounding effects from the denaturing serum. Pins were cleaned and weighed on a digital balance (AX250, Mettler-Toledo) and wear values were determined by summing the measured weight loss of each experimental specimen with the average weight gain of three soak specimens. A least squares fit of the cumulative wear yielded a wear rate (mg/Mcyc) for each specimen. A one-way analysis of variance was used with Tukey's post-hoc analysis (Minitab R14.13, State College, PA) to detect differences between groups with type I error limited at 0.05.

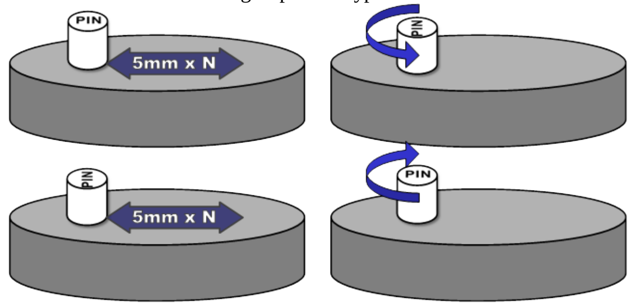

Fig 2. (a) Pins reciprocated in short segments (1, 2, or 5mm) under a 330N vertical load until they achieved the target sliding distance (eg 5mm x 20 to achieve 100mm). (b) The pins stopped translating and rotated 90° under a reduced vertical load of 30N. (c) The loading was restored to 330N and sliding recommenced. (d) The pins rotated to 0° under reduced load.

RESULTS

The cumulative wear of all groups increased with increasing cycle count (Fig 3). Wear rates appeared different among the groups (Fig 3 inset), but were not statistically significant due to a large variance in the 100mm group. Results from 5, 10, and 100mm are repeated from a previous study [6].

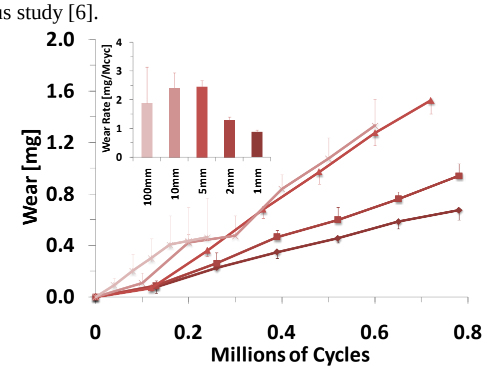

Fig 3. Cumulative wear and wear rate (inset). Error bars represent one standard deviation.

DISCUSSION

The results support our hypothesis that the wear rate diminishes with continued sliding after a change of direction (Fig 1). Initially, the wear increases with increasing sliding distances. After 5mm, however, additional sliding produces no additional wear. This signifies that a low wear condition associated with unidirectional motion [3-5] has been reestablished. Current wear algorithms [3-5] do not incorporate a diminishing wear rate and consequently predict a 100 fold difference in the wear rates for the groups tested in this study, which is stark contrast to our empirical results. This improved understanding of wear may help formulate new wear algorithms for developing better joint replacements.

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