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Predicting UHMWPE Wear: Evidence for Rapid Decline in Wear Rates Following a Change in Sliding Direction

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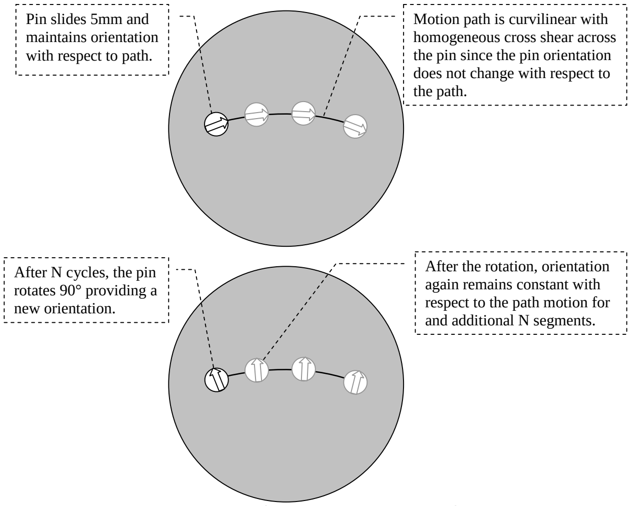
INTRODUCTION

Extending the service life of total joint replacements by improving the wear resistance of UHMWPE remains a priority that is driven by the demands of a more active patient [1]. Extensive experimental testing has shown that wear rates depend on the details of the wear path: Unidirectional paths produce minimal wear while those with direction change produce high wear [2-4]. This implies that a linear wear path that undergoes a sudden change in direction will generate a high wear rate immediately following that direction change and then will transition to a near zero wear rate with continued sliding. To the authors' knowledge, this variation in wear rate with sliding distance after a change in sliding direction has not been explored experimentally. The goal of this study was to investigate the incremental wear as the sliding distance is increased between step-changes in sliding direction. 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.

METHODS

Wear was evaluated for similar geometric paths having three different sliding distances per cycle (5mm, 10mm, 100mm) using an OrthoPOD Wear Testing Machine (AMTI, Watertown, MA). Pins (n=3) reciprocated in 5mm segments 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 1). The pins then stopped translating and rotated 90° about their own axis under a reduced vertical load of 10N (~0.1MPa). The loading was restored to 330N and sliding recommenced. A complete cycle included 2 sliding periods and 2 rotations of ±90°. In the case of the 100mm path, pins reciprocated 20 times in 5mm increments, rotated 90°, slid 100mm again, and then rotated back to 0°. In every case, this essentially resulted in 'square' sliding paths, all having a identical cross-shear values (as calculated by existing definitions [2]). Testing was performed at 37±1°C in 90% bovine serum (HyClone, Logan UT) that has been supplemented with 0.2% sodium azide and 20mM EDTA to retard bacterial growth and calcium precipitation. Eighteen moderately crosslinked UHMWPE pins were used in this test for wear and soak specimens. All pins were machined from the same GUR 1020 ram extruded bar that had been gamma irradiated to 50±5 kGy, remelted to extinguish free radicals, and annealed. The pins (17.8mm long, 9.5mm diameter) articulated against mirror polished wrought Co28Cr6Mo counterfaces (12.7mm thick, 38.1mm diameter).


Pin slides 5mm and maintains orientation with respect to path.

Motion path is curvilinear with homogeneous cross shear across the pin since the pin orientation does not change with respect to the path.

After N cycles, the pin rotates 90° providing a new orientation.

After the rotation, orientation again remains constant with respect to the path motion for and additional N segments.

Fig 1. Description of pin motion. See text for details.

Wear was quantified via gravimetric methods every 2.5 days (instead of a specified cycle count) to control any confounding effects from the denaturing serum. Pins were cleaned and weighed on a digital balance (XP250, 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.

RESULTS

The cumulative wear of all groups increased steadily with increasing cycle count (Fig 2). There was no significant difference in the wear rate per cycle ($p>0.05$). Also there was no significant difference ($p>0.05$) when cumulative wear was normalized by the number of turns (Fig 3).

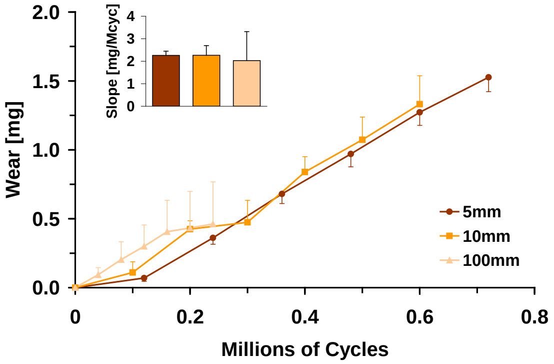


Fig 2. Cumulative wear vs cycle count. Inset displays slopes [mg/Mcyc].

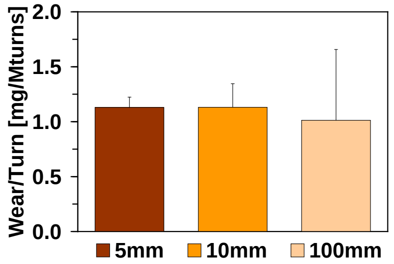


Fig 3. Wear data normalized by number of turns.

DISCUSSION

Our wear results depend only on the number of turns and are independent of sliding distance after direction change (Fig 3). The fact that the wear per turn does not increase with increasing sliding distance supports our notion that instantaneous wear rates decrease to near zero after some distance of sliding following a direction change. Furthermore the data suggests this distance is less than 5 mm. It is important to note that current wear algorithms [2-4] do not account for this variation in wear rate with sliding distance after direction change and would incorrectly scale wear results with the overall length of the sliding path. Specifically, they would predict a 20 fold increase in the wear per cycle of the 100mm path compared to the 5 mm path, which is in stark contrast to the uniform wear rate that was observed here. This improved understanding of polyethylene wear will be valuable as computational tools are being used to predict wear of total joint replacement [5]. Further work is required to determine the equation describing the instantaneous wear rate as a function of sliding distance after direction change.

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