Regional Measurements of Surface Deviation Volume in Worn Polyethylene Joint Replacement Components
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Introduction
A number of in vitro laboratory tools have been developed to quantify the gravimetric or volumetric changes (due to wear) in polyethylene components that have been retrieved from patients or undergone wear simulator testing. Recently, micro-computed tomography (micro-CT) has been used to measure the overall volume of polyethylene tibial inserts, acetabular liners, and spinal discs [1-3], and to measure the volume loss due to wear in retrieved polyethylene acetabular liners [4]. Techniques have also been developed to measure and map the three-dimensional surface deviations due to wear in tibial inserts and acetabular liners [1-2]. A similar technique to measure the local volume change within specific operator-selected regions of interest (to ensure only true wear is quantified) would be useful, for comparing the location (e.g. medial versus lateral side of a tibial insert) and type of deviation (e.g. burnishing versus pits).

This study was designed to describe the development of a technique to measure the regional volumes of surface deviations due to wear in polyethylene tibial inserts, and to measure the intra-observer repeatability and inter-observer reproducibility of the technique.

Methods
A group of 12 polyethylene tibial inserts (AMK, DePuy Inc., Warsaw, IN) of the same design and size that were available to our laboratory were included in this study. Six of the inserts had undergone wear testing to 5.5 million cycles in a prior wear simulator trial. The remaining six inserts had experienced no wear and were used to construct an unworn reference geometry.

Each insert was scanned with a micro-CT scanner (eXplore Vision 120; GE Healthcare, London, ON) in a previously described fashion [1-2]. All scans were obtained using an isotropic resolution of 50 µm. The reconstructed scan images were analyzed with dedicated micro-CT software (MicroView v2.2, GE Healthcare, London, ON). A previously described custom software application was used to co-register the worn geometries to the unworn geometry and quantify the deviations between the surfaces [2]. A second software application was developed to compute the volume deviation between the geometries, based on operator-defined regions of interest.

One expert observer and two trainee observers performed the volume-outlining task. The region of surface deviation on both the medial and lateral sides of the articular surface for each of the six worn insert were identified visually and manually outlined. The deviation volume, number of points used in the outlining, and point spacing index (0-1, where 1 represents completely uniform spacing) was recorded. Measurements were repeated three times for all of the worn inserts. The intra-observer variability (i.e. the coefficient of variation between repeated measurements of the same deviation volume by an observer) was calculated along with inter-observer variability (i.e. the coefficient of variation between the deviations of the same surface deviation volume by the three observers) was also calculated. Statistical analysis of the deviation volumes, number of points, and point spacing index was performed using one-way repeated measures ANOVAs with Tukey post-hoc multiple comparison tests. Pearson correlations between the deviation volumes and number of points, and between the deviation volumes and point spacing index, were also performed.

Results
The overall surface deviation volume across all observers was 37.0 ± 7.1 mm³ medially and 98.1 ± 7.8 mm³ laterally (Figure 1). The volumes calculated by one of the trained observers were found to be significantly lower (p < 0.0001) than the expert observer and the second trained observer for both the medial and lateral sides. The overall intra-observer variability was 5.7% medially and 1.8% laterally. The intra-observer variability for one of the trained observers was consistently greater than both the expert observer (9.1% vs. 4.3% medially and 2.7% vs. 1.4% laterally) and the second trained observer (9.1% vs. 4.3% medially and 2.7% vs. 1.2% laterally). The overall inter-observer variability was 20.9% medially and 4.9% laterally. The same trained observer, who reported consistently lower volumes than the other two observers, again raised the variability. Excluding that observer, the intra-observer variability between the remaining two observers was 4.1% medially and 1.7% laterally.

The number of points used by each observer to outline the surface deviation volume differed greatly between observers. However, no correlation was found between the surface deviation volume and number of points medially (r = 0.08, p > 0.05) or laterally (r = -0.08; p > 0.05). The point spacing index was more consistent between observers. Again, no correlation was found between the surface deviation volume and point spacing index medially (r = -0.23, p > 0.05) or laterally (r = 0.16; p > 0.05).

Discussion
The medial surface deviation volume measurement showed greater variability than the lateral measurement. In examining the surface deviation maps, the lateral deviations appear to be both larger and more distinct (i.e. have a stronger edge) than the medial deviations, perhaps resulting in easier point placement laterally. It was determined that the trained observer who reported significantly lower deviation volumes was placing the points closer to the center of the deviations than the other observers, avoiding the diffuse region in favor of regions with a stronger edge. Placement of the points appears to contribute the greatest variability to the deviation volume measurement, and is therefore the greatest source of potential error when using this application. An “

The intra-observer and inter-observer variability reported here compares well to other wear volume measurement techniques, which have been primarily applied to components from total hip replacement. Bowden et al. [3] used micro-CT to measure the wear volume in retrieved acetabular liners. They reported intra-observer and inter-observer variability of approximately 10%, with the variability increasing to 50% for one liner with a low volume of wear. Chuter et al. [4] compared coordinate measuring, fluid displacement, and a radiographic technique for measuring wear in acetabular liners. Coordinate measuring was found to be the most repeatable at 2.5% (range 0.25% to 9.8%), followed by fluid displacement at 4.8% (range 1.6% to 6.9%), and finally the radiographic technique at 15.7%.

In summary, we have developed a technique to measure the regional volume of surface deviations due to wear in polyethylene tibial inserts. This technique enhances the utility of micro-CT for wear measurement, adding to existing capabilities of surface deviation mapping and measurements of whole-component volume [1-2]. The intra-observer repeatability and inter-observer reproducibility of the method was found to be similar to other wear volume measurement techniques such as fluid displacement and radiographic methods. The technique described in this study can be used in wear simulator, pin on disk, and retrieval studies of polyethylene components used in joint replacement, including total knee and total hip replacement.

References
1. Teeter et al., J Arthroplasty. 2010;In press.

Figure 1. Mean surface deviation volumes (in mm³) of the medial (A) and lateral (B) sides as measured by each observer. Bars are SD.