Metal-on-Metal Hip Wear Measurement of Retrievals, Methodology and Validation

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Statement of Purpose: The wear depth and volume of material loss of retrieved metal-on-metal (MoM) hip components is important to understand the wear and failure mechanisms of this class of hip replacement device. The presented method is able to measure aspherical heads and wear located on the rim of cups, where a significant volume of material loss may be located. This algorithm does not assume a spherical shape, but rather uses the assumption of axial symmetry to identify the linear wear depths. It is measurement method-agnostic and can be used with coordinates collected from any precise method, thus increasing its utility to researchers and industry.

Methods: For validation, a Contura G2 (Zeiss, Oberkochen, GER) coordinate measurement machine (CMM) with 2.5 µm resolution was utilized. Approximately 30,000 coordinates were collected per component for analysis using a custom MATLAB (Mathworks, Natick, MA) algorithm.

The spherical, articulating surface was subdivided into 120 curvilinear, rectangular regions, with a linear least squares (LLSQ) sphere fit applied to each region. A comparison of the fit radii inside each region was made to identify which regions contained gross, uneven deviations of the surface. Potentially unworn regions were isolated by identifying the regions where 90% of the measured radii did not exceed 2.5 µm of the arithmetic mode of the fit radii. Evenly worn regions were further isolated from the potentially unworn regions group by removing regions which contained a mean radius exceeding 5 µm of the mean of the radii of the potentially unworn regions group. A final LLSQ sphere was fit using the coordinates contained in the potentially unworn regions group, the center of which was used to identify the original, unworn surface.

The original surface was identified by comparing all of the radii at a specific latitude. The upper 5th percentile of radii (upper for heads, lower for cups) was used to identify an approximate location of the unworn surface. Any points with radii exceeding 10 µm from this reference radius was rejected. The median radius of the remaining radii was used to identify the original, unworn surface at each latitude.

For cups, identifying the center of the original, unworn surface is not sufficient to calculate wear on the rim due to the toroidal geometry of the rim. The cup axis must be correctly identified. This was performed by identifying the location of the minimum wear depth on the rim, which must be negative if the cup was measured off-axis. All coordinates are rotated in the plane containing the measured axis and minimum wear depth, about the identified center of the spherical surface, such that the minimum wear depth becomes zero.

The linear wear depth at a measured coordinate was determined by calculating the perpendicular distance between each measured coordinate and the unworn reference surface. Volumetric material loss was calculated by multiplying the spherical surface area of each region by the arithmetic mean of the linear wear depths for all coordinates located within the region, and summing up the wear volumes of all regions.

A gravimetric comparison was performed for validation of this method. Material was machined from never-implanted components, weighed, and converted to volume based on the density of the material. A wide range of physiologically-relevant masses were used, up to 95 mm^3 equivalent volume. These gravimetric volumes were compared with the CMM-measured and MATLAB-calculated volumes.

Results: Using linear regression, the slope of the gravimetric comparison, a measure of accuracy of the measurement and analysis method, was 0.987 and 0.971 for heads and cups, respectively. This linear fit resulted in $R^2 = 0.998$ for both heads and cups independently.

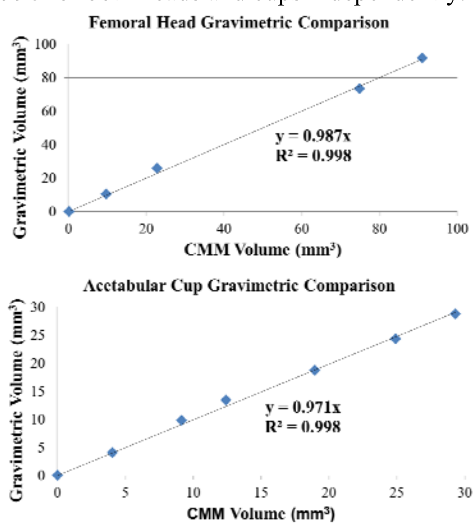

Figure 1. The gravimetric validation for heads (top) and cups (bottom) exhibited high precision and accuracy.

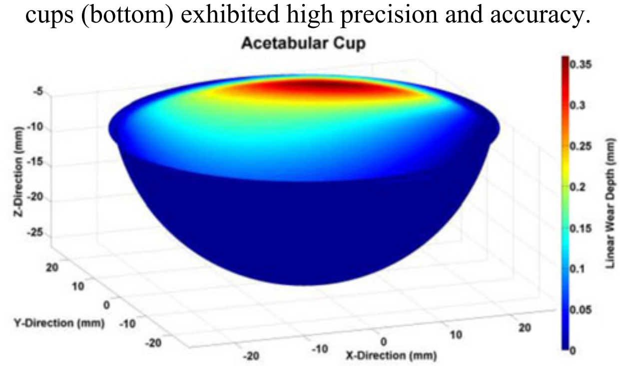

Figure 2. A 3D model detailing the linear wear depths across the surface of a cup illustrates a non-polar maximum linear wear depth.

Conclusions: A measurement method-agnostic, numerical method for calculating the linear wear depths and wear volumes for retrieved heads and cups, including the rim of the cup, is possible without *a priori* knowledge of the dimensions of the components.