The Application of a CMM-based Technique for the Assessment of the Volume Change on Retrieved Cups

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Disclosures:

Introduction: Wear at the bearing surface and consequent generation of wear debris is identified as one main cause of the failure and revision of hip prostheses [1]. The accurate estimation of volume change in polyethylene cup due to creep and wear is an important step for identifying the cause of failure and improving the longevity of metal-on-polyethylene (MoP) hip prosthesis. Several techniques have been described for assessing the volume change in MoP hip prostheses, among which the gravimetric methods are commonly used to determine the weight loss and hence volumetric wear of the components. However, in case of retrieved components, the gravimetric methods are not feasible due to the unknown pre-wear data. The coordinate measuring machine (CMM) technique was then used in this case recently, which required the determination of the unworn area in the components [2,3]. This is challenge for mildly worn components where the unworn area and worn area are difficult to be identified. The aims of this study were to develop and apply a methodology for calculating volume change on retrieved polyethylene cups with different degrees of wear in which no pre-wear surface data was available by using a combination of CMM data and a Matlab (The Mathworks, Inc.) code.

Methods: Data collection. Two retrieved polyethylene cups, one had severe wear (severely worn cup) and another had mild wear (mildly worn cup), were scanned using a coordinate measuring machine (CMM, Legex 322, Mitutoyo, UK) with resolution of 0.8 µm. Each acetabular cup was scanned by taking 2304 points in the form of 36 traces with an interval of 10°. Each trace consisted of 64 points with a pitch of 0.5 mm starting at the pole and finishing at the rim of the cup.

Original surface prediction. The coordinate data collected from the CMM was read in to a Matlab program to predict volume change. To determine the original surface of the cup, all the coordinate data was imported in a two-dimensional coordinate system, the points that formed the traces which coincided with each other were selected for the first surface fitting, from which a new spherical surface was predicted. The deviation of the selected points was calculated. If the maximum deviation of the points was larger than 10 µm, a threshold value was set based on the maximum deviation of the points. Any point of which the calculated deviation was greater than the threshold value was discarded. The remaining points were used in the fitting of the second sphere. The process was repeated until the maximum deviation of the points was smaller than 10 µm, and the sphere predicted at this stage was assumed as the original surface of the cup.

Volume change prediction. Once the original surface of the cup was determined, the deviation of each original point was calculated, the maximum penetration depth and the wear direction were determined. The wear direction was defined as the angle between the rim plane of the cup and vector from centre of the cup to the maximum deviation point. To calculate the volumetric change, adjacent points were connected to form gridsquares. A mean penetration depth for each gridsquare was calculated by taking the mean of the depths at the four corners. The area of each gridsquare was then calculated and multiplied by the corresponding mean wear depth to give a volume change. These individual volumes were then summed for the entire component to give an overall volume change.

Results: The shape, orientation and depth of the wear scar on the two retrieved cups are shown in Figure 1.
The predicted maximum penetration depth, wear angle and volume change for the two retrieved cups are summarized in Table 1.

<table>
<thead>
<tr>
<th>Components</th>
<th>Maximum penetration depths (mm)</th>
<th>Wear angle (degree)</th>
<th>Volume change (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severely worn cup</td>
<td>1.85</td>
<td>32.5</td>
<td>432.7</td>
</tr>
<tr>
<td>Mildly worn cup</td>
<td>0.23</td>
<td>3.9</td>
<td>93.5</td>
</tr>
</tbody>
</table>

The severely worn cup had a liner penetration of approximately 1.85 mm while the mildly worn cup had a liner penetration of about 0.23 mm. The maximum penetration for the severely worn cup was offset at an angle of approximately 32.5° from the rim plane while for mildly worn cup, the maximum penetration was predicted at the rim of the cup. The volumetric changes for the two retrieved cups were predicted to be 432.7 mm³ and 93.5 mm³ respectively.

**Discussion:** A CMM-based technique that can calculate the wear volume and geometry changes of components with no pre-wear data, CAD model and original design drawing was presented and applied on two retrieved polyethylene cups in the present study. The validation of the methodology was conducted in a previous study using polyethylene tibial knee inserts with physical volume removal [4]. This study showed that the CMM-based technique can be used effectively and reliably for determining the volume change in retrieved polyethylene cups and characterizing the wear patch by showing the shape, location, orientation and depth of retrieved components for hip prostheses with different degrees of wear in which no pre-wear data, CAD model and original design drawing were available. The limitations of this method include that it determines a combination of wear volume and creep volume, and does not determine wear volume on its own.

**Significance:** This CMM-based technique presented in this study allows accurate assessment of volume change in components of hip prostheses which were either retrieved from failed prostheses or obtained from pre-clinical in vitro testing. It can be used to develop a greater understanding of the tribology and true clinical performance of the hip joint replacement.

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