Quantification of Third Body Debris in Retrieved Polyethylene Orthopedic Components Using Micro CT

MBP 3970Z 6-Wek Project

Patrick Lai, Matthew Teeter Ph.D.c

4/13/2012

For: Dr. MacDonald
**Introduction**

Total hip and knee arthroplasties (THA) and (TKA) are common methods of therapy for failed joints. Over sixty thousand hospitalizations in Canada over the past year were due to TKA and THAs. The average age of implantation currently is about 65 years of age. However, patients as young as 40 years of age are starting to receive arthroplasty treatment (Bohm, Dunbar et al. 2009). As a result, the patient usually outlives the implant, and thus making a costly revision arthroplasty necessary.

The overriding objective is to increase the lifetime of the implant such that revision arthroplasties are unnecessary. At this time, the main reason for implant failure is due to osteolysis, polyethylene wear and infection. Two of these issues, osteolysis and polyethylene wear are correlated with third-body debris embedded within the liner (Hayashi 2009).

The objective of this investigation is to attempt to provide meaningful data on the third party debris embedded within a retrieved polyethylene component. This will be completed via three aims:

a) To explore the data that can be retrieved on polyethylene components with an X-ray micro computed tomography scan (Micro CT)

b) To validate the data from the imaging with observations

c) To explore and remove artifacts in the imaging and methods to increase the accuracy of the image

**Theory**

TKA and THAs are designed to sustain motion that mimic the biomechanics of the original joint.
The implant is constructed in components that mimic the original. In the Hip implant, the femoral stem, head and acetabular cup were all constructed of metal. This is to provide structural strength to the implant. In a TKA, the schematics are similar; the structural femoral and tibial components are made of metal. In the implants used in the study, all of the structural components consisted of Cobalt-Chrome. This trend is typical of many implants in recent years.

The polyethylene liners are meant to serve as replacement for the cartilage components of the biological joint. These components in both THA and TKA serve as the bearing surface to reduce friction and facilitate joint movement. Unlike cartilage, polyethylene cannot be dynamically replaced. Therefore, even under normal wear conditions, the polyethylene will become scratched and worn with time.
When joints are extended over their normal range of motion, impingement occurs. This is defined as when repetitive stresses are applied to the implant component such that it leads to loosening (Murray 1992).

In addition to loosening the implant, impingement also aggravates the metal component, causing small metal parts to break off from the main body. This metal debris can then be carried onto the bearing surface where the natural motion of the implant can then grind the debris inside of the polyethylene component.

Figure 3 – Sketch of process of impingement (Murray 1992)
This debris not only affects the bearing surface of the implant, not causes inflammation of the tissue surrounding the implant. The inflammation causes the reabsorption of bone holding the joint in place. When osteolysis occurs, the implant loosens and eventually fails.

At the moment of writing, there is no current method of investigating the metal debris embedded in a polyethylene component. This pilot study will attempt to do so using X-Ray micro Computed Tomography (micro CT).

Micro CT is a method of capturing 3 dimensional information of a specimen. Exposures are taken in a circular method around the specimen to get information from all sides.

Each exposure is taken in the X-ray spectrum. The imaging created by each exposure is a function of X-ray attenuation versus position. X-ray attenuation is defined as the fractional amount of light absorbed. This property is related to the density of the material being imaged,
and its thickness. After the images are taken at each angle, a computer program then compiles the images into a 3D model (Jurewicz, Jones et al. 2003). Due to the nature of translating 2D images to 3d space, there are possibilities for artifacts being created that may not exist in the specimen. Corrective measures can be taken to avoid these artifacts (Armstrong, Teeter et al. 2011).

**Methods**

11 specimens were chosen from a database of over two thousand retrieved polyethylene liners of failed TKA and TKA. These specimens were screened at this step to have visible metal debris embedded in the liner.

These specimens were then scanned using a micro CT scanner. There images taken at 360 angles, and each angle was averaged over 10 shots. The aim of the large amount of shots is to increase accuracy in the reconstruction. The aim of averaging over 10 mages at the same angle is to increase the SNR at each angle. The scans took approximately an hour and a half each. No special procedures were taken to attempt to reduce artifacts as stated in the theory section. This was done to preserve the generality of the method to those scanners who may not have this type of calibration available.

The images were then loaded onto software called ‘Microview’. This program allowed for the visualization and manipulation of the 3D images. For the analysis, a Maximum Intensity Projection (MIP) was taken in the Z direction for the knees and the Y/Z axis for the hips. Though not computationally meaningful, the goal of the MIP was to aid the human eye in picturing the spatial information in the image.
Next, a histogram of the reconstruction was created using the visualization program. The modal gray values present on the histogram were assigned to known values of x-ray attenuation of certain materials. From these gray levels, the image was then segmented at those levels and volumes the volumes of materials were calculated from the segmented images. For visualization, the segmented reconstructions were made into 3D surfaces that can be manipulated using ‘Paraview’ software.

**Results**

The results are summarized in three tables:

<table>
<thead>
<tr>
<th>Table 1 (page 8)</th>
<th>Results of THAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2 (page 8)</td>
<td>Results of TKAs</td>
</tr>
<tr>
<td>Table 3 (page 10)</td>
<td>Rejected results and reasons</td>
</tr>
</tbody>
</table>

The images produced good examples of MIPs. The implants showed clear debris that was distributed well over the entire surface of the polyethylene.

![Figure 5- MIP in X/Z direction of specimen #H571](image-url)
The clear bright areas were indicative of metal debris that were embedded within the polyethylene.

In two of the five hip implants, cement was still attached to the implant at time of scanning. This cement was segmented into its own surface using the same technique.

![Figure 6 - MIP of H836, with cement](image)

The cement in the image here shows as brighter than the polyethylene but less than that of the metal (outlined in green). In this particular scan, there has been streaking that occurred near the metal components (highlighted in red).

This is an example of a MIP of a knee specimen:
The knee polyethylene also showed good segmentation of the metal and polyethylene material.

Below are the volumes of the hips for each material:

<table>
<thead>
<tr>
<th>Specimen IRAL Number</th>
<th>Threshold 250 (mm³) (Polyethylene)</th>
<th>Threshold 2000 (mm³) (Cement)</th>
<th>Threshold 10000 (mm³) (Metal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H489</td>
<td>384320.969</td>
<td>N/A</td>
<td>0.355</td>
</tr>
<tr>
<td>H439</td>
<td>28928.735</td>
<td>N/A</td>
<td>0.153</td>
</tr>
<tr>
<td>H571</td>
<td>11740.59</td>
<td>N/A</td>
<td>4.788</td>
</tr>
<tr>
<td>H836</td>
<td>38800.547</td>
<td>9102.142</td>
<td>243.731</td>
</tr>
<tr>
<td>H872</td>
<td>31738.167</td>
<td>8242.695</td>
<td>749.511</td>
</tr>
</tbody>
</table>

Table 1 - Volumes of various materials for Hip implants

<table>
<thead>
<tr>
<th>Specimen IRAL Number</th>
<th>Threshold 250 (mm³)</th>
<th>Threshold 10000 (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K225</td>
<td>13288.446</td>
<td>0.196</td>
</tr>
<tr>
<td>K293</td>
<td>13652.791</td>
<td>1.655</td>
</tr>
<tr>
<td>K394</td>
<td>15866.734</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Volumes of various materials for Knee implants</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>-----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>K682</td>
<td>10731.801</td>
<td>0.537</td>
</tr>
<tr>
<td>K720</td>
<td>21051.426</td>
<td>0.405</td>
</tr>
<tr>
<td>K722</td>
<td>20734.746</td>
<td>101.496</td>
</tr>
</tbody>
</table>

Anomalies were notice immediately for several the scans from the MIP image. H439 had bright pixel around the edges of the image. H836 had large bright areas on the MIP. This is reflected in the abnormally large volumes of metal for its size.

![Figure 8- MIP of H836 with large artifacts](image)

In addition, two of the knee implants also displayed discrepancies in the MIPs and the volume calculated. K394 displayed zero volume of metal, where the MIP clearly shows it to be non-zero.
Figure 9 - MIP of K394 with metal volumes highlighted

Figure 10 - MIP of K722 with ring artifact
In the images of K722, a ring surrounding the polyethylene is present in the MIP. This ring creates a bright area that is detected in the volume calculated.

In total the four specimens with visible artifacts had their volumes invalidated.

<table>
<thead>
<tr>
<th>Rejected Specimen</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>H439</td>
<td>Bright pixels on edge of reconstruction</td>
</tr>
<tr>
<td>H836</td>
<td>Large bright spots on the MIPs surrounding the metal areas</td>
</tr>
<tr>
<td>K394</td>
<td>Showed zero metal volume, though MIP clearly showed metal</td>
</tr>
<tr>
<td>K722</td>
<td>Large outer ring artifact.</td>
</tr>
</tbody>
</table>

Table 3 – Rejected specimens and reason for rejection

The specimens that did not show immediate anomalies had their volumes visually inspected. These values match that of normal volumes for TKA and THAs.

**Discussion**

Of the eleven polyethylene liners scanned, seven showed no signs of anomalies when scanned and had their volumes calculated. Only four specimens had anomalies in the images. Many of those artifacts were outside of the volume of interest and could be cropped out using the ‘Microview’ software.

Through further investigation, it was found that the bright areas and ring artifacts in H836 and K722 were caused by beam hardening. These specimens had large areas of very dense metal that
starkly contrasted with the majority of the light polyethylene. The lower energy photons are absorbed preferentially as they pass through the dense material. In the reconstruction process, the loss of the lower energy photons is read as a uniformly dense material. This creates a bright streak in that angle which is the wrongly portrayed in the reconstruction (Barrett and Keat 2004).

If this explanation is valid, it would imply that the image of the polyethylene and metal volumes have been corrupted with artifacts. Even if outer artifacts are cropped out, the streaks will still exist inside the volume. As a result, the volumes of the four images with artifacts were deemed invalid. For later scans, a technique to reduce the appearance of these artifacts is to calibrate the scanner to use higher energy beams beforehand. This would reduce the probability of streaks in the scan. However, it would be disadvantageous to do under normal situations as it would reduce the contrast available in the reconstruction. The recommendation is the visually inspect the specimen beforehand. Any large volumes of metal discovered at this stage will receive a calibrated scan, rather than a normal scan.

Overall, the scans were generally reliable in creating spatial information of where possible and calculating a volume for each component of the scan. Of those that were rejected, there were clear signs from the imaging that they were to be rejected. There are also known methods and techniques that will reduce these artifacts in the future.

**Conclusion**

In conclusion, the aim of quantifying third-body debris within a retrieved polyethylene liner was accomplished. Meaningful results were gathered from seven of eleven specimens scanned. This was confirmed with a visual inspection of the specimen. Of the four specimens that produced artifacts, they were very clear and pronounced. In addition, there are known methods to work
around the problem. Overall, it is shown that it is possible to create a segmentation method of Polyethylene liners using X-ray Micro CT. Further studies can be conducted to increase the generality of the method.

Works Cited


