Polyethylene Wear Rates Of Postmortem TKR Contrasted Against THR Manufactured From Identical Material

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Introduction: The annual wear rate and osteolysis threshold of the polyethylene (PE) acetabular liner in total hip replacements (THR) is well established. Less so is known about the total knee replacement (TKR) in vivo wear rate and its contribution to osteolysis. Few reliable volumetric wear data of TKR liners have been reported. Most studies have relied on linear estimates based on radiographic measurements, where the complex geometry of TKR tibial plateaus accompanied by lack of precision using standard x-ray technology interfere with the accuracy of the individual wear readings. Thus, retrieval studies are warranted. In particular wear data from well-functioning TKR implants are needed as a baseline. Here, we compare the wear rates of postmortem retrieved knee and hip implants made from identical PE. Both joints undergo different tribological stresses in that crossing motion angles are typically larger in THR compared with TKR [1]. Furthermore, THRs exhibit a larger contact area during articulation, which is known to increase adhesive PE wear [2]. On the contrary, TKRs undergo rolling/sliding contact and are therefore prone to surface fatigue. Based on the severity of this wear mechanism, it is our hypothesis that the wear rate is higher in TKRs.

In order to test the hypothesis we analyzed and quantified wear of two groups of postmortem retrievals (TKRs and THRs), made by the same manufacturer and from the same material using a CMM.

Methods: The volumetric wear rate of 15 THRs and 16 TKRs implanted was assessed. All components were part of an IRB approved postmortem implant retrieval program at Rush University Medical Center, Chicago, IL. Only implants from patients with good clinical outcome as defined by Harris Hip Score (HHS) or Hospital for Special Surgery Score (HSS) of >79 for THR and TKR, respectively and an in situ time of >5 years were included in the study. There were 14 (10/4 m/f) THR and 13 (4/9 m/f) TKR patients. Patient age at implantation was 63.9±9.4 yrs. for the hips and 75.95±8.9 yrs. for the knees. The average time in situ for hips and knees was 9.3±2.4 years, respectively. All components were well fixed at the time of retrieval. The latest radiographs of all patients were consulted to rule out any malalignment. THR patients had an average HHS of 94±5. TKR patients had an average HSS of 91±7. All implants were made by the same manufacturer (Zimmer Inc., Warsaw, IN). The acetabular and tibial liners were all made from the same PE resin (GUR 4150, Ticona), ram-extruded, machined and gamma sterilized in air with (nominally) 25kGy. The THRs were from two different designs, Harris-Galante (HG) and the succeeding HGII. Differences between these two designs were limited to the locking mechanisms for the liner and features of the acetabular shell. All liners articulated against CoCrMo femoral heads (28 or 32mm). The knee components were from the MGII design and articulated against femoral condyles made from either CoCrMo or Ti-alloy. All TKR components were cemented. It is known that PE liners from that generation were prone to oxidation due to gamma irradiation in air. Thus, the shelf time of the components may have an impact on wear. All components were made by the same manufacturer (Zimmer Inc., Warsaw, IN). The acetabular liner wear was measured tactile by a touch probe with 2mm ball diameter in 24 line scans (set 15 deg apart) from rim through dome. At least 8,000 data points were obtained; the accuracy in the x- and y-directions of this set up constitutes 2 μm and 3 μm in the z-direction. For the tibial liners a previously developed method using autonomous mathematical reconstruction was utilized [3]. The liner surface was scanned with 400k points using a laser in place of a touch probe with an accuracy of 2 μm. The volumetric wear rate was determined based on metrology data in that the original surface was reconstructed from unworn sections. The difference between reconstructed and worn surface was determined for each data point and plotted as linear penetration.

Results: Examples of the resulting penetration plots are shown for an acetabular and a tibial liner in Fig. 1.
Figure 1 penetration plot of a) an acetabular and b) a tibial liner
For the acetabular liners there was no significant difference in wear rate between HG and HGII liners (p=0.62) or cemented and uncemented components (p= 0.12). Thus, all liners are handled as one group. In Fig. 2 the relationship between wear and time in-situ is displayed. Using a linear regression model, the overall volumetric wear rate of all acetabular liners was 46± 15.2 mm³/yr (R²=0.40, p=0.01). Unlike in the hip, the PE liners of the knee joint exhibited multiple wear features including scratches, polishing, pitting and oriented striations. Some of the components were also severely delaminated or showed early signs of delamination in the form of subsurface cracks (as evidenced using back lighting). The average wear rate was 32.1±21.2 mm³/yr (R²=0.68, p<0.001). As shown in Fig 2, there were tibial liners with high wear. Each of these liners exhibited severe delamination and thus had undergone a fatigue related wear mechanism as opposed to the other liners. When excluding cases with severe delamination the wear rate dropped to 22.7±9.3 mm³/yr (R²=0.49, p=0.035).
Discussion: This study compared for the first time in vivo wear rates of postmortem retrieved THRs and TKRs and found approx. twice as much wear for acetabular hip cups compared to tibial knee liners. The material was tightly controlled, such that both, cup and tibial liner were made from the same PE with the same processing history and sterilization technique by the same manufacturer. Our initial hypothesis that the wear rate of TKRs would be higher due to surface fatigue had to be rejected. The higher crossing angles of the motion trajectories during hip articulation [1] and the larger contact area during force transfer [2] appear to have a larger impact than the sliding/rolling contact movement. The THR wear rate of this study is in the range of the average value of 50 mm3/yr established in literature for conventional PE. Patient age (p<0.001) and gender (p<0.05) differed significantly, with the THR group being younger and having less males. Both factors may have an influence on patient activity and thus impact wear rate. The more important factor, time in-situ, was comparable between both groups. Although the study bears the characteristic limitations of any retrieval study, including that the materials of this investigation are no longer in clinical use, the resulting TKR/THR wear rate ratios (0.70 and 0.57, with and without fatigued implants, respectively) will prove useful for current materials. Considering that PE oxidation has been considerably suppressed with modern manufacturing and sterilization techniques, it may be more accurate to use the wear rate ratio without delaminated components, i.e. 0.57. Lower incidence of osteolysis in TKRs is mainly linked to closed particle pathways to the bone interface for cemented TKRs. However, in uncemented TKRs particles can migrate. The results of this study indicate a significant lower particle burden for uncemented TKRs compared to THRs.

Significance: Polyethylene wear is a limiting factor for the longevity of total joint replacements and has not yet been accurately established for TKR tibial liners in vivo. Knowledge of such data will allow for the design of better wear simulators, provide more accurate input data for wear simulation, and develop biologically meaningful cell/tissue response models.

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