Short communication

Highly cross-linked polyethylene acetabular liners retrieved four to five years after revision surgery: A report of two cases

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ABSTRACT

There is currently considerable interest in the use of highly cross-linked polyethylene (XLPE) acetabular liners for total hip arthroplasty (THA). In literature, only a single retrieval analysis of one type of XLPE liner implanted for greater than four years exists. The purpose of the present report is to quantify surface deviations in two XLPE liners implanted during revision THA and retrieved between four to five years after implantation. The two XLPE acetabular liners (Reflection, Smith and Nephew Inc., Memphis, TN) were retrieved from patients undergoing their second revision surgery, at 4.90 and 4.07 years. The retrieved liners and a new, non-implanted, unworn liner of the same size were scanned using micro-computed tomography (micro-CT). Articular surface deviation maps were created by comparing the retrievals to the unworn liner, based on the liner geometry obtained from micro-CT. The linear penetration rates were found to be 0.018 and 0.008 mm/year. Localized scratches and pits with deviations greater than 0.205 mm were also found on the articular surfaces of both liners. The XLPE liners retrieved from the two cases demonstrated low linear penetration rates. Regions with greater focal deviations were also apparent, likely due to third-body wear. The results are consistent with previously published clinical follow-ups of other XLPE liners.

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1. Introduction

There is currently considerable interest in the use of highly cross-linked polyethylene (XLPE) acetabular liners for total hip arthroplasty (THA; Beksc et al., 2009; McCalden et al., 2009; McCalden et al., 2009). The advantage of XLPE is an apparent reduction of wear rate versus conventional polyethylene (Beksc et al., 2009). A number of clinical follow-up studies on XLPE liners exceeding five years have recently been published (Beksc et al., 2009; McCalden et al., 2009; Bitsch et al., 2008; Engh et al., 2006; Dorr et al., 2005). To our knowledge, only a single retrieval analysis of one type of XLPE liner implanted for greater than four years exists in literature (Knahr et al., 2007). That study reports on two XLPE liners implanted during primary
THA. The purpose of the present report is to quantify surface deviations in two XLPE liners implanted during revision THA and retrieved between four to five years after implantation.

2. Patients and methods

2.1. Case 1

The patient was a 63 year-old man with ankylosing spondylitis who was 1.76 m tall and weighed 77 kg (body mass index of 24.9). He underwent second-stage revision THA in October 2002, due to a previously infected THA. At that time, the treating surgeon implanted an Echelon (Smith and Nephew, Memphis, TN) porous bowed stem (size 18R, 260 mm length, +15 mm), a 32 mm, +0 cobalt–chromium femoral head, a Reflection porous acetabular cup (64 mm outer diameter, liner size H, standard size), and a Reflection acetabular liner (20 degree overhang, 32 mm inner diameter, 62–64 mm outer diameter, size H). The Reflection XLPE liner is manufactured from ram-extruded GUR 1050 polyethylene, and cold cross-linked using 10 Mrad of gamma irradiation with subsequent melting (Willie et al., 2006). The polyethylene is sterilized using ethylene oxide. The patient underwent a polyethylene liner and head exchange for recurrent infection in April of 2003; at that time, he had replacement of his liner with the same design (20 degree overhang, 32 mm inner diameter, 62–64 mm outer diameter, size H). Unfortunately, he developed a recurrent deep periprosthetic infection from a methicillin sensitive Staphylococcus aureus (Fig. 1A–B). He underwent removal of his implants in March of 2008, at which time the liner was retrieved. There was no obvious biofilm on the surface of the retrieved liner. It had been in situ for 4.90 years.

2.2. Case 2

The patient was a 74-year-old man who was 1.81 m tall and weighed 98.5 kg (body mass index of 30.1). He had a primary cemented THA performed in October of 2002 for osteoarthritis. He went on to aseptic loosening of his cemented femoral stem, and was revised to a size 16 cemented Echelon (Smith and Nephew, Memphis, TN) 175 mm length, standard collar in June of 2004 by a second surgeon. He unfortunately went on to aseptic subsidence of his femoral stem and his cement mantle (Fig. 1C–D), and underwent re-revision THA to a cementless revision arthroplasty in July of 2008. At the time of his most recent revision, the original acetabular cup was maintained but all other components were revised; these included a
cemented revision stem, a cobalt–chromium Taper Femoral Head (32 mm diameter, 12/14 taper, –8 neck), and a Reflection acetabular liner (20 degree overhang, 32 mm inner diameter, 62–64 mm outer diameter, size H). The retrieved liner had been in situ for 4.07 years. Currently, at an almost two-year follow-up, he has shown no signs of re-infection or further complication, and appears to have achieved radiographic ingrowth of his femoral stem.

2.3. Micro-CT scanning and 3D surface analysis

The liners were scanned with micro-computed tomography (micro-CT) and underwent 3D surface analysis using a previously described approach (Teeter et al., 2010; Vicars et al., 2009; Bowden et al., 2005). A new, never-implanted liner of the same type as the retrieved liner (Reflection, Smith and Nephew, Memphis, TN; 20 degree overhang, size H, 32 mm inner diameter, 62–64 mm outer diameter) was also scanned to serve as an unworn reference for the surface analysis. Each liner was individually scanned and reconstructed using a laboratory micro-CT scanner (eXplore Vision 120, GE Healthcare, London, Ontario). All scans were obtained using an isotropic resolution of 50 µm over 1200 views, with 10 frames averaged per view at an exposure time of 16 ms. The X-ray tube voltage was 90 kV with a current of 40 mA. The scans were reconstructed at the full 50 µm resolution. The reconstructed scans of the liners were then analyzed with 3D micro-CT analysis software (MicroView v2.2, GE Healthcare, London, Ontario). Isosurface rendering was performed using a threshold of −664 Hounsfield units with the highest possible surface quality and no decimation. The resulting 3D volume of each liner was saved in stereolithography file format. Gravimetric measurements were also obtained for the three liners, and their masses were converted to volumes based on the known polyethylene density (931 km³). The gravimetric volumes were compared to the CT volumes to ensure the accuracy of the micro-CT technique.

The surface file for each of the liners was then imported into Geomagic Studio (Geomagic Inc., Research Triangle Park, N.C.) and converted to the wrap file format. The surface volume was edited down to contain only the articular surface in order to exclude artificial surface deviations (such as chisel marks) in the non-articular surfaces, caused by damage during the retrieval process. The edited articular surfaces of the new liner and retrieved liner were then imported into Geomagic Qualify (Geomagic Inc., Research Triangle Park, N.C.), where the new liner was set as the reference object and the retrieved liner set as the test object. The two liners were co-aligned using an automated, iterative best-fit alignment algorithm.

Once co-aligned, a 3D comparison was performed to report any deviation between the surfaces of the two liners. This analysis was used to identify any focal deviations (such as scratching and pitting), in addition to more diffuse patterns of deviation that correspond to femoral head penetration. The maximum negative 3D deviation within the diffuse region closest to the center of the articular surface was used to estimate linear penetration. Deviations due to scratches and pits were not used for the calculation of linear penetration. The linear penetration rate for the first liner was calculated by dividing the maximum linear penetration by the implantation time. The second liner was then imported into the software as the test object and the process was repeated.

3. Results

Under visual inspection, the liner in the first case exhibited numerous scratches on the articular surface. The liner in the second case had only a few scratches on the articular surface, but also had six small pits on the surface. Both liners were yellowed on their backside surface (facing the acetabular shell), and the liner from the first case also had yellowing of the articular surface. The scratching and pitting of the articular surfaces can be seen in the 3D rendered volumes of the liners obtained using micro-CT (Fig. 2). The mean difference between the gravimetric and CT volumes was 0.42%, with the CT volumes consistently lower than the gravimetric volumes.

The surface damage observed macroscopically and with micro-CT was also apparent during the surface analysis (Fig. 3). A gradient of increasing deviation appeared for both liners from the outer edge to the inner center of the articular surface. The scratches on the articular surface of the liner from the first case had a 3D deviation of approximately −0.207 to −0.113 mm compared to the unworn reference liner (Fig. 4A). Similarly, the pitting on the articular surface of the liner from the second case had a 3D deviation of approximately −0.279 to −0.141 mm (Fig. 4B).

The diffuse region corresponding to head penetration was within the −0.090 to −0.053 mm contour interval in the first case, for which the maximum deviation was −0.087 mm (Fig. 4A). The linear penetration rate was therefore calculated as 0.018 mm/year. The diffuse region in the second case was within the −0.053 to −0.017 mm contour interval, for which the maximum deviation was −0.032 mm (Fig. 4B). The linear penetration rate was calculated as 0.008 mm/year.

4. Discussion

The linear penetration rates for the two retrieved XLPE acetabular liners (Reflection, Smith and Nephew Inc.,
Fig. 3 – Maps of 3D deviation (in mm) between the articular surfaces of the retrieved liners and a new, unworn liner. A–B is the retrieved liner from case 1 and C–D is the retrieved liner from case 2. The surfaces are oriented as in Fig. 2.

Memphis, TN) found in this report are within the range of radiographically-measured head penetration rates for this type of liner. The rates reported here are 0.018 and 0.008 mm/year, versus a mean of 0.025 mm/year (95% confidence interval, 0.004–0.047 mm/year) reported by Whittaker et al. (in press) for the Reflection XLPE. In addition, the linear penetration rates were within the mid-range of rates reported for other XLPE acetabular liners after a five-year follow-up. Radiographically-measured head penetration rates for other XLPE acetabular liners have been reported as 0.002 ± 0.084 and 0.003 ± 0.027 for Zimmer Longevity (Beksac et al., 2009; McCalden et al., 2009), 0.029 ± 0.02 for Zimmer Durasul (Dorr et al., 2005), and 0.032 ± 0.047 and 0.010 ± 0.070 for DePuy Marathon (Bitsch et al., 2008; Engh et al., 2006). The linear penetration rates from the only other retrieval study of XLPE liners (0.013 and 0.015 mm/year; Knahr et al., 2007) are also close to the rates found in this report (0.018 and 0.008 mm/year). For that previous study, linear penetration rate was measured using coordinate mapping in two Zimmer Durasul liners retrieved after four and five years.

The advantage of the micro-CT based surface analysis technique used for this report is that it facilitates quantification of focal regions of surface deviations, such as the scratching and pitting seen on the articular surfaces of the two liners studied here. These regions could be due to third-body wear, but would not normally be interpreted as loss of material using other wear estimation methods such as measurement of changes in head penetration depth or deviation from spheri- cal shape (Knahr et al., 2007). The scratching and pitting seen on the liners in this report were two to eight times as deep as the estimated femoral head penetration.

Infection occurs in 1%–2% of THA surgeries, with the risk increasing to 2%–6% during revision THA surgery (Moyad et al., 2008). The linear penetration rate of the first case, which was a revision due to recurrent infection, was 0.010 mm/year greater than in the second case, which was a revision due aseptic loosening. The length of implantation in the first case was only 10 months greater than the second case. However, we can find no evidence that recurrent infections influence polyethylene wear in the literature. Shah et al. (2009) recently reported that constrained acetabular liners that failed due to infection had similar damage compared to other groups.

The yellowed surfaces of the liners retrieved in these two cases have also been previously observed in other retrieved XLPE liners. Knahr et al. (2007) found a yellow pigmentation on the liner backside surface. No oxidation of the polyethylene was observed under Fourier transform infrared spectroscopy, so they attributed the pigmentation to diffusion of absorbed body-fluid particles. Rieker et al. (2003) noted that yellowing was relatively common in early retrievals of XLPE liners, and attributed the coloring to diffusion of lipids into the polyethylene.

The primary limitation this study was that true wear was not differentiated from plastic deformation. Previous studies
have reported that much of the apparent wear seen in XLPE liners after retrieval or tested in a wear simulator can be restored after melt-recovery experiments (Knahr et al., 2007; Muratoğlu et al., 2004). This suggests that plastic deformation likely contributed to the surface deviations observed in this study. However, the surface deviations measured here with micro-CT are comparable to previously reported linear penetrations measured radiographically, which also do not take plastic deformation into account.

Some limitations are associated with the micro-CT based surface analysis technique. Although micro-CT has been demonstrated to be accurate and highly repeatable for quantification of volumetric wear in retrieved polyethylene acetabular liners, scanner error up to 0.6% has been reported (Bowden et al., 2005). Vicars et al. (2009) reported a volume measurement resolution of ±3 mm³ for micro-CT of the polyethylene cores from total disc replacements, and recommended that gravimetric analysis should be used alongside micro-CT to ensure accuracy. We observed an excellent agreement between micro-CT and gravimetric volumes in this study, to a mean difference of 0.42%. The retrieved liners in this report were geometrically compared to a new, unworn liner of the same size, rather than their original, unworn geometry. This method of comparing the geometries of retrieved components to a never-implanted original, unworn geometry. This method of comparing the geometries of retrieved components to a never-implanted original, unworn geometry has been described for knees (Blunt et al., 2008) as well as for hips (Teeter et al., 2010). As there is some variability between liner geometry even before implantation, this introduces a degree of uncertainty to the surface analysis, as would any design changes by the manufacturer. The liner surface has been previously estimated to vary by approximately 20 μm (Teeter et al., 2010). However, only the spherical articular surfaces of the liners were compared, thus reducing the effects of any geometric changes, and a similar pattern of surface deviation was seen in both retrieved liners. The linear penetration rate found in this report is in the same range as the values reported for similar liners, suggesting the methods used here provide a good approximation of the true annual penetration rate.

In conclusion, we have demonstrated minimal surface deviation in two XLPE acetabular liners retrieved four to five years after implantation for revision THA using a micro-CT based surface analysis method. The linear penetration in the two cases reported here are similar to those reported for other XLPE liners at the same time period.

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**References**


