CASE REPORT

Delamination of a highly cross-linked polyethylene liner associated with titanium deposits on the cobalt-chromium modular femoral head following dislocation


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Retrieval studies of total hip replacements with highly cross-linked ultra-high-molecular-weight polyethylene liners have shown much less surface damage than with conventional ultra-high-molecular-weight polyethylene liners. A recent revision hip replacement for recurrent dislocation undertaken after only five months revealed a highly cross-linked polyethylene liner with a large area of visible delamination. In order to determine the cause of this unusual surface damage, we analysed the bearing surfaces of the cobalt-chromium femoral head and the acetabular liner with scanning electron microscopy, energy dispersive x-ray spectroscopy and optical profilometry. We concluded that the cobalt-chromium modular femoral head had scraped against the titanium acetabular shell during the course of the dislocations and had not only roughened the surface of the femoral head but also transferred deposits of titanium onto it. The largest deposits were 1.6 μm to 4.3 μm proud of the surrounding surface and could lead to increased stresses in the acetabular liner and therefore cause accelerated wear and damage.

This case illustrates that dislocations can leave titanium deposits on cobalt-chromium femoral heads and that highly cross-linked ultra-high-molecular-weight polyethylene remains susceptible to surface damage.

Highly cross-linked and thermally stabilised ultra-high-molecular-weight polyethylene (HXLPE) has been introduced as an alternative to conventional gamma-irradiated ultra-high-molecular-weight polyethylene (UHMWPE) as the bearing material of choice for acetabular component liners since 1998. Many studies have shown that the former wears much less than conventional UHMWPE under both smooth and roughened conditions. Retrieval studies of HXLPE liners have shown comparatively little surface damage, although surface cracking and minor degrees of delamination have been reported on some retrievals. Delamination is a fatigue process characterised by removal of sheet-like pieces of material and is associated with the propagation of cracks beneath the surface. Areas of delamination decrease the conformity further and can lead to accelerated failure. Delamination of HXLPE is more common when used for tibial inserts in total knee replacement and can occur with routine use in vivo, severe damage may result from dislocation because of contact between the femoral head and metal acetabular shell. Recently, a HXLPE liner and cobalt-chromium (CoCr) modular femoral head were retrieved after dislocating five times and the early surface damage was analysed. The implant had been in situ for five months but the damage to the liner included an area of delamination substantially larger than any surface damage previously reported for HXLPE used in hip replacement. It was hypothesised that damage to the liner was due to the transfer of titanium deposits and roughening of the femoral head from contact with the rim of the acetabular shell during the dislocations. The retrieved implant was analysed using optical microscopy, scanning electron microscopy (SEM) and energy dispersive x-ray spectrometry (EDX) to characterise the damage and the transfer of material. Additionally, the topography of the femoral head was examined with an optical profilometer.
Case report

A 52-year-old woman with a body mass index of 31 kg/m², who had undergone resurfacing hip arthroplasty in October 2004, developed aseptic loosening and underwent a revision total hip replacement in January 2008. The revision component was an Alloclassic stem (Zimmer, Warsaw, Indiana) with a 36 mm Co-28Cr-6Mo femoral head and Longevity HXLPE liner (10 Mrad of electron beam radiation, re-melted above 135°C) with a 58 mm Trabecular metal acetabular shell (Zimmer, Warsaw, Indiana) (tantalum porous coating on Ti-6Al-4V backing). One month after surgery she suffered a posterior dislocation and there were four more dislocations in the following three months. All of the dislocations were managed by closed reduction within two to three hours of the occurrence. In June 2008, five months after implantation, a revision was undertaken. The components were found to be well positioned and it was concluded that the dislocations were a result of deficiency of the soft tissue. The femoral head and acetabular liner were replaced and a constrained acetabular liner was used. Microscopic examination of periarticular soft-tissue biopsies showed no signs of acute inflammation and cultures were negative.

The liner and femoral head were examined using optical microscopy (Sony XCD-SX910, Tokyo, Japan) and SEM (Hitachi TM-1000, Schaumburg, Illinois). In order to determine if material had been transferred, both components were also analysed using SEM (XL-30 ESEM-FEG, FEI Company, Hillsboro, Oregon) in combination with EDX (EDS Detector, EDAX, Mahwah, New Jersey).

The topography of the CoCr femoral head was quantified using a Wyko NT3300 profiling system (Veeco, Plainview, New York) which comprises a white-light interferometer that can measure surface heights with a resolution of 10 nm to 30 nm and measure in the surface plane with micron-scale resolution. The topography data were analysed using the accompanying Vision32 post-processing software (Veeco). For each site of measurement, small areas of missing data were interpolated, and the tilt and curvature were removed based on the adjacent un-scraped area. The accuracy of the interferometer measurements was confirmed using a stylus profilometer (Dektak IID, Sloan Technology Co., Santa Barbara, California).

Analysis of the acetabular liner. Extensive damage was present on the bearing surface of the liner (Fig. 1a). The greatest damage was a 4 mm × 6 mm area of delamination on the anterosuperior region (Fig. 1b). Pitting, scratching and abrasion were prominent over approximately 30%, 50% and 90% of the bearing surface, respectively. A piece of CoCr debris of approximately 10 μm in thickness and 40 μm in diameter was found embedded in the liner.

Analysis of the femoral head. The femoral head exhibited readily visible markings over an area of 10 mm × 25 mm on the articulating portion (Fig. 2). The marks were 200 μm to 500 μm wide and 2 mm to 10 mm long, and were probably due to the femoral head scraping against the acetabular shell during the dislocations and reductions.

EDX analysis of the scraped areas revealed many sites with deposits of titanium on the CoCr surface (Fig. 3). SEM images indicated that the typical deposits were oblong and between 15 μm and 50 μm long. There were also small deposits which ranged in length from 3 μm to 7 μm and the largest deposits were 100 μm to 300 μm in length.

Topographical analysis of the scrapes corroborated the presence of raised deposits and roughening (Fig. 2), but also revealed that some portions of the scrapes had a mean surface level lower than that of the adjacent undamaged surface. The scraped surfaces were 0.5 μm to 0.75 μm below the un-scraped surface and the highest
transfer peaks were 1.6 μm to 4.3 μm above the local scraped surface.

In order to quantify the change in topography, three measurement sites (Fig. 2) were divided into scraped and un-scraped regions. Four parameters of roughness from each region were calculated (Fig. 4): mean roughness ($R_m$), total roughness ($R_z$), peak height ($R_p$), and skewness ($R_{sk}$). All parameters in the scratches, except the skew, were greater than in the neighbouring un-scraped areas (Fig. 5).

In addition to the change in roughness, the size of the deposits was also studied. Deposits were isolated by defining continuous areas with a greater height than a threshold height above the un-scraped surface. Threshold heights were chosen for each measurement site as the minimum height that would isolate the main peaks. Four parameters of size were calculated for each deposit: peak height, area, volume, and aspect ratio (peak height divided by half-width). These measured the size of the deposit above the adjacent un-scraped surface. The sizes of the five deposits with the greatest volume from each of the three measurement sites are shown in Figure 6. The volume of the deposits is directly related to peak height and area, and so correlated with both ($r^2 = 0.83$ and $0.75$, respectively). However, the other parameters did not correlate strongly-

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**Fig. 2**

Optical, scanning electron microscopy and profilometry analysis of the damage to the cobalt-chromium modular femoral head. Several marks are easily visible; macroscopically they appear to be scratches. I to III). However, topography maps of scraped regions on the femoral head show increased roughness from scratching into the surface as well as from deposits on top of the surface. The heights on the legends are measured from the un-scraped areas at each location. Note: the height-axis for image III is magnified compared with the horizontal axes.
with each other (correlation coefficients between the other parameters range from 0.005 to 0.39). As an example, the peak from measurement site II with the greatest area also had a large volume, but the lowest aspect ratio and a moderate height.

Discussion
Our findings indicate that as the acetabular shell made contact with the femoral head during the dislocations and reductions, it scraped across the bearing surface, leaving behind roughened areas and deposits of titanium. These damaged areas of the femoral head then articulated against the liner and in all probability caused the extensive surface damage and delamination seen on the liner.

The deposits of titanium would be expected to increase damage to the HXLPE more than an increase in the surface roughness associated with normal in vivo function, since the deposits were much higher than the surrounding material. McNie et al. found that asperities with higher aspect ratios increase the magnitude of plastic strain in conventional UHMWPE. Also, asperities with a larger cross-sectional area, which correlate with their volume ($r^2 = 0.97$) increase the amount of conventional UHMWPE wear debris more than asperities with smaller cross-sectional areas.

It should be noted that using a single parameter of roughness to compare surfaces can be misleading. Mean measurements, such as $R_\alpha$, describe the average feature size and are relatively easy to use, but misrepresent non-uniform topographies and do not describe the distribution of the roughness. Extremity measurements, such as $R_\alpha$ or $R_\delta$, only describe the most extreme points and may not distinguish between peaks and valleys. Skewness, $R_{sk}$ (a relative parameter), correlates with wear better than $R_a$ by describing the distribution of peaks and valleys on the surface, but does not describe the magnitude of the features. While all parameters can be sensitive to the location and size of measurement sites, three-dimensional (3D) profilometry is better than two-dimensional profilometry for capturing information about deposits. A combination of parameters of roughness measured at several sites using 3D techniques is probably the most appropriate method to characterise and compare the bearing surfaces of joint replacements. In this retrieval, although measurement site I had the greatest mean roughness, the skewness reveals that this roughness arose mainly from valleys and that site III, which had the lowest mean roughness, has the highest peaks. This study is a step towards reporting multiple parameters of roughness in retrieval analysis.

The sizes of the deposits and measurements of roughness in this retrieval are comparable to previous reports in the literature. Ito et al. measured mean peak-to-valley heights ($R_p$) of 3.72 μm (SD 0.64) and roughness ($R_a$) of 0.54 μm.
Bowsher et al.\textsuperscript{16} reported titanium transfer deposits of up to 1 μm in height and 25 μm in width on dislocated metal-on-metal hip implants and roughness (R\textsubscript{s}) of up to 0.304 μm. On dislocated ceramic heads, titanium deposits of 3 μm in height have been reported by Kim, Ritchie and Hardaker\textsuperscript{24} and 5 μm by Luchetti et al.\textsuperscript{25}

From this case report, clinical implications can be drawn regarding the wear and fatigue of HXLPE and damage sustained by a metal head resulting from dislocation. The marked damage present and short period in vivo suggest that most of the wear is likely to be due to delamination. Often, surface damage is only evident because the wear has not been extensive enough to remove the damaged material at the surface and leave a smoothly worn surface.\textsuperscript{26,27} It is possible that the volume of wear was increasing due to the raised peaks of the titanium deposits. McNie et al.\textsuperscript{19} Fisher et al.\textsuperscript{28} and Dowson, Taheri and Wallbridge\textsuperscript{29} have demonstrated that the accumulation of material at the edges of scratches greatly increased the wear of conventional UHMWPE during uni-directional pin-on-disc wear tests.

Although HXLPE has an improved resistance to adhesive and abrasive wear, it has sacrificed resistance to fatigue-crack propagation in the bulk material and is more susceptible to fracture in the presence of flaws than conventional UHMWPE.\textsuperscript{30,31} Asperities, such as the deposits of
titanium with large volumes or high aspect ratios, can increase the plastic strain of the subsurface material. This increases fatigue wear that can lead to delamination and pitting, which may explain the increased damage observed in this case.

Metallic transfer is often reported in studies of dislocated ceramic heads, but most studies on dislocated metallic heads only describe the damage as visible stripes or surface roughening. Titanium transfer to metallic heads has been reported in one other case and in one in vitro study. This difference in reporting may be related to the similar appearance between scratching on a metal head and metal deposits on a metal head. This retrieval report shows the severity of damage to a HXLPE liner that can occur in association with metal transfer deposits on a CoCr femoral head.

Metallic deposits on ceramic heads have been shown to increase the damage and wear to HXLPE liners. Caution and close monitoring has been recommended following dislocation of ceramic femoral heads, and this case illustrates that similar monitoring is appropriate for metallic femoral heads.

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References


