■ CASE REPORT

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

E. W. Patten,
S. A. Atwood,
D. W. Van Citters,
B. A. Jewett,
L. A. Pruitt,
M. D. Ries

*From the University
of California, San
Francisco, California,
United States*

■ E. W. Patten, MS, BS, PhD
Student
■ S. A. Atwood, PhD Student
■ L. A. Pruitt, PhD, MS, BS,
Professor
Department of Mechanical
Engineering, 5134 Etcheverry
Hall
MC 1740, Medical Polymers
Group, University of California,
Berkeley, Berkeley, California
94720-1740, USA.

■ D. W. Van Citters, PhD, MS,
AB, Professor
Thayer School of Engineering,
Dartmouth College, 8000
Cummings Hall, Hanover, New
Hampshire, 03755, USA.

■ B. A. Jewett, MD,
Orthopaedic Surgeon
Slocum Centre for
Orthopaedics and Sports
Medicine, 55 Coburg Road,
Eugene, Oregon 97401, USA.

■ M. D. Ries, MD, MS, BS,
Orthopaedic Surgeon
Department of Orthopaedic
Surgeon
Box 0728, 500 Parnassus
Avenue, MU 320W, University
of California, San Francisco,
San Francisco, California
94143-0728, USA.

Correspondence should be sent
to Dr M. D. Ries; e-mail:
riesm@orthosurg.ucsf.edu

©2010 British Editorial Society
of Bone and Joint Surgery
doi:10.1302/0301-620X.92B9.
24290 \$2.00

J Bone Joint Surg [Br]
2010;92-B:1306-11.
Received 16 December 2009;
Accepted 19 April 2010

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 1998.¹ Many studies have shown that the former wears much less than conventional UHMWPE²⁻⁴ under both smooth^{5,6} and roughened conditions.^{7,8} Retrieval studies of HXLPE liners have shown comparatively little damage,⁹⁻¹¹ although surface cracking and minor degrees of delamination have been reported on some retrievals.¹²

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.¹³ Delamination of HXLPE is more common when used for tibial inserts in total knee replacement where contact stresses are higher than in the hip, and the Hertzian contact results in high subsurface stress.¹⁴ This delamination has

historically been secondary to radiation-induced oxidation.

Although roughening of CoCr femoral heads can occur with routine use *in vivo*,¹⁵ severe damage may result from dislocation because of contact between the femoral head and metal acetabular shell.¹⁶⁻¹⁸ 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.

Fig. 1a

Fig. 1b

Delamination of the highly cross-linked ultra-high-molecular-weight liner after only five months *in vivo*. Figure 1a – photograph showing the pitting, scratching, and abrasion on the bearing surface, visible in the portion of the figure with reflected light Figure 1b – composite SEM image showing the large area of delamination.

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 un-damaged surface. The scraped surfaces were 0.5 µm to 0.75 µm below the un-scraped surface and the highest

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.

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_a), total roughness (R_t), 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-

Fig. 3

Scanning electron microscope image and energy dispersive x-ray spectroscopy analysis of a large titanium deposit ($120\ \mu\text{m} \times 300\ \mu\text{m}$) on the femoral head.

Fig. 4

Diagrammatic illustrations describing the parameters of roughness used to describe the topography of the surface of the femoral head. A mean roughness (R_a) is the mean deviation from the mean surface level. Total roughness (R_t) is the height difference between the highest peak and lowest valley within one sample. Peak height (R_p), is the highest point within one sample. Skew (R_{sk}) is a measure of how many peaks there are compared with valleys. See Hall et al²⁰ for more detailed descriptions.

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 al¹⁹ 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.¹⁹

It should be noted that using a single parameter of roughness to compare surfaces can be misleading. Mean measure-

ments, such as R_a , 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_p or R_t , 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 ^{20,21} 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,²⁸ three-dimensional (3D) profilometry is better than two-dimensional profilometry for capturing information about deposits.²³ 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 al¹⁵ measured mean peak-to-valley heights (R_t) of $3.72\ \mu\text{m}$ (SD 0.64) and roughness (R_a) of $0.54\ \mu\text{m}$

Fig. 5

Roughness measurements of the scraped regions of three measurement sites. The peak heights are measured from the un-scraped mean surface height.

Fig. 6

Size of the five peaks with the largest volume within each of the three sample sites (15 peaks in total). The boxes mark the median and inner quartiles and the whiskers mark the 10th and 90th percentiles. The size of the marker for each peak corresponds to its height, and the shape shows which of the three sample sites the peak was from (see legend in Figure 5).

(SD 0.1) on CoCr heads after recurrent dislocation. Bowsher et al¹⁶ 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_a) of up to 0.304 μm . On dislocated ceramic heads, titanium deposits of 3 μm in height have been reported by Kim, Ritchie and Hardaker²⁴ and 5 μm by Luchetti et al.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.^{26,27} It is possible that the volume of wear was increasing due to the raised peaks of the titanium deposits. McNie et al,¹⁹ Fisher et al,²⁸ and Dowson, Taheri and Wallbridge²⁹ 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.^{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.¹⁹ 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,^{24,32,33} but most studies on dislocated metallic heads only describe the damage as visible stripes or surface roughening.^{15,24,34} Titanium transfer to metallic heads has been reported in one other case¹⁶ and in one *in vitro* study.³⁵ 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.^{18,24,33} Caution and close monitoring has been recommended following dislocation of ceramic femoral heads,^{18,36} and this case illustrates that similar monitoring is appropriate for metallic femoral heads.

The authors would like to acknowledge the UC Berkeley Microlaboratory and the UC Berkeley Electron Microscope Laboratory.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

- Kurtz SM, Muratoglu OK, Evans M, Edidin AA. Advances in the processing, sterilization, and crosslinking of ultra-high molecular weight polyethylene for total joint arthroplasty. *Biomaterials* 1999;20:1659-88.
- Glynn-Jones S, McLardy-Smith P, Gill HS, Murray DW. The creep and wear of highly cross-linked polyethylene: a three-year randomised, controlled trial using radiostereometric analysis. *J Bone Joint Surg [Br]* 2008;90-B:556-61.
- Garcia-Rey E, Garcia-Cimbrelo E, Cruz-Pardos A, Ortega-Chamarro J. New polyethylenes in total hip replacement: a prospective, comparative clinical study of two types of liner. *J Bone Joint Surg [Br]* 2008;90-B:149-53.
- Triclot P, Grosjeau G, El Masri F, Courpied JP, Hamadouche M. A comparison of the penetration rate of two polyethylene acetabular liners of different levels of cross-linking: a prospective randomised trial. *J Bone Joint Surg [Br]* 2007;89-B:1439-45.
- McKellop H, Shen FW, Lu B, Campbell P, Salovey R. Development of an extremely wear-resistant ultra high molecular weight polyethylene for total hip replacements. *J Orthop Res* 1999;17:157-67.
- Muratoglu O, Bragdon CR, O'Connor D, et al. Larger diameter femoral heads used in conjunction with a highly cross-linked ultra-high molecular weight polyethylene: a new concept. *J Arthroplasty* 2001;16(Suppl):24-30.
- McKellop H, Shen FW, DiMaio W, Lancaster JG. Wear of gamma-crosslinked polyethylene acetabular cups against roughened femoral balls. *Clin Orthop* 1999;369:73-82.
- Saikko V, Caloni O, Keränen J. Wear of conventional and cross-linked ultra-high-molecular-weight polyethylene acetabular cups against polished and roughened CoCr femoral heads in a biaxial hip simulator. *J Biomed Mater Res* 2002;63:848-53.
- Salineros MJ, Crowninshield RD, Laurent M, Wimmer MA, Jacobs JJ. Analysis of retrieved acetabular components of three polyethylene types. *Clin Orthop* 2007;465:140-9.
- Muratoglu OK, Greenbaum ES, Bragdon CR, et al. Surface analysis of early retrieved acetabular polyethylene liners: a comparison of conventional and highly crosslinked polyethylenes. *J Arthroplasty* 2004;19:68-77.
- Knahr K, Pospischill M, Kötting P, Schneider W, Plenk H Jr. Retrieval analyses of highly cross-linked polyethylene acetabular liners four and five years after implantation. *J Bone Joint Surg [Br]* 2007;89-B:1036-41.
- Bradford L, Baker DA, Graham J, et al. Wear and surface cracking in early retrieved highly cross-linked polyethylene acetabular liners. *J Bone Joint Surg [Am]* 2004;86-A:1271-82.
- Muratoglu OK, Burroughs BR, Bragdon CR, et al. Knee simulator wear of polyethylene tibias articulating against explanted rough femoral components. *Clin Orthop* 2004;428:108-13.
- Kennedy FE, Currier BH, Van Citters DW, et al. Oxidation of ultra-high molecular weight polyethylene and its influence on contact fatigue and pitting of knee bearings. *Tribology Transactions* 2003;46:111-18.
- Ito H, Maloney CM, Crowninshield RD, et al. In vivo femoral head damage and its effect on polyethylene wear. *J Arthroplasty* 2010;25:302-8.
- Bowsher JG, Donaldson TK, Williams PA, Clarke IC. Surface damage after multiple dislocations of a 38-mm-diameter, metal-on-metal hip prosthesis. *J Arthroplasty* 2008;23:1090-6.
- Kop AM, Whitewood C, Johnston DJ. Damage of oxinium femoral heads subsequent to hip arthroplasty dislocation: three retrieval case studies. *J Arthroplasty* 2007;22:775-9.
- Jaffe WL, Strauss EJ, Cardinale M, Herrera L, Kummer FJ. Surface oxidized zirconium total hip arthroplasty head damage due to closed reduction effects on polyethylene wear. *J Arthroplasty* 2009;24:898-902.
- McNie CM, Barton DC, Ingham E, et al. The prediction of polyethylene wear rate and debris morphology produced by microscopic asperities on femoral heads. *J Mater Sci Mater Med* 2000;11:163-74.
- Hall RM, Siney P, Unsworth A, Wroblewski BM. The effect of surface topography of retrieved femoral heads on the wear of UHMWPE sockets. *Med Eng Phys* 1997;19:711-19.
- Affatato S, Bersaglia G, Jungiang Y, et al. The predictive power of surface profile parameters on the amount of wear measured in vitro on metal-on-polyethylene artificial hip joints. *Proc Inst Mech Eng* 2006;220:457-64.
- Que L, Topoleski LD. Surface roughness quantification of CoCrMo implant alloys. *J Biomed Mater Res* 1999;48:705-11.
- Jiang XQ, Blunt L, Stout KJ. Three-dimensional surface characterization for orthopedic joint prostheses. *Proc Inst Mech Eng H* 1999;213:49-68.
- Kim YH, Ritchie A, Hardaker C. Surface roughness of ceramic femoral heads after in vivo transfer of metal: correlation to polyethylene wear. *J Bone Joint Surg [Am]* 2005;87-A:577-82.
- Luchetti WT, Copley LA, Vresilovic EJ, Black J, Steinberg ME. Drain entrapment and titanium to ceramic head deposition: two unique complications following closed reduction of a dislocated total hip arthroplasty. *J Arthroplasty* 1998;13:713-17.
- McKellop HA. The lexicon of polyethylene wear in artificial joints. *Biomaterials* 2007;28:5049-57.
- Muratoglu OK, Ruberti J, Melotti S, et al. Optical analysis of surface changes on early retrievals of highly cross-linked and conventional polyethylene tibial inserts. *J Arthroplasty* 2003;18(Suppl):42-7.
- Fisher J, Firkins P, Reeves EA, Hailey JL, Isaac GH. The influence of scratches to metallic counterfaces on the wear of ultra-high molecular weight polyethylene. *Proc Inst Mech Eng H* 1995;209:263-4.
- Dowson D, Taheri S, Wallbridge NC. The role of counterface imperfections in the wear of polyethylene. *Wear* 1987;119:277-93.
- Baker DA, Bellare A, Pruitt L. The effects of degree of crosslinking on the fatigue crack initiation and propagation resistance of orthopedic-grade polyethylene. *J Biomed Mater Res A* 2003;66:146-54.
- Furmanski J, Anderson M, Bal S, et al. Clinical fracture of cross-linked UHMWPE acetabular liners. *Biomaterials* 2009;30:5572-82.
- Yoo JJ, Kim HJ, Kim YM. Damage of an alumina-on-alumina bearing surface from a difficult reduction of a total hip arthroplasty: a report of three cases. *J Bone Joint Surg [Am]* 2004;86-A:376-8.
- Della Valle AG, Doty S, Gradl G, Labissiere A, Nestor BJ. Wear of a highly cross-linked polyethylene liner associated with metallic deposition on a ceramic femoral head. *J Arthroplasty* 2004;19:532-6.
- Verioti C, D'Lima DD, Colwell CW Jr, Ezzet KA, Mai K. Surface roughness of femoral head prostheses after dislocation [P001]. Procs Annual Meeting of American Association of Orthopaedic Surgeons, 2009. Las Vegas: AAOS, 2009. <http://www3.aaos.org/education/anmeet/anmt2009/poster/poster.cfm?Pevent=P001> (date last accessed 22 April 2010).
- Chang CB, Yoo JJ, Song WS, et al. Transfer of metallic debris from the metal surface of an acetabular cup to artificial femoral heads by scraping: comparison between alumina and cobalt-chrome heads. *J Biomed Mater Res B Appl Biomater* 2008;85:204-9.
- Schuh A, Mittelmeier W, Zeiler G, et al. Severe damage of the femoral head after dislocation and difficult reduction maneuvers after total hip arthroplasty. *Arch Orthop Trauma Surg* 2006;126:143-7.