The significance of surface changes on retrieved femoral components after total knee replacement

A. Lakdawala, S. Todo, G. Scott

From the Royal London Hospital, London and the Holly House Hospital, Essex, England

We investigated the changes in surface roughness of retrieved femoral components in 18 men and four women at revision knee surgery. The mean age at revision was 68.4 years and the mean period of implantation was for 55.6 months. Eighteen implants were retrieved for aseptic loosening and four for infection. The surface changes in the articulating areas were inspected visually and the roughness (Ra) analysed with a profilometer. Parallel scratching and burnishing were the two main forms of damage. The mean Ra measurements in the articulating areas showed no statistically significant difference when compared with those in a control area on either side of the patellar groove at the apex of the femoral flange. This suggests that it is not essential to revise a well-fixed and correctly aligned femoral component where the polished surface has become burnished or bears fine parallel scratches, if the revision is conducted solely for failure of the tibial component.

Aseptic loosening is a mode of long-term failure in total knee arthroplasty (TKA). The view is widely-held that wear of the ultra-high-molecular-weight polyethylene (UHMWPE) of tibial components is an important cause of osteolysis and leads to component loosening.1,2 Many studies have analysed retrieved UHMWPE,3-7 but little interest has been shown in the surface finish of the articulating areas of retrieved femoral components in TKA and its role in the creation of polyethylene wear.

The aim of our study was to investigate the changes in vivo in surface roughness (Ra) of retrieved femoral components. Our hypothesis was that the surface finish of these components, articulating with the tibial polyethylene inserts, deteriorated in line with the duration of implantation.

Patients and Methods

We retrieved 22 paired tibial and femoral components at revision TKA between 1988 and 2000 from 18 men and four women who had undergone their primary procedure at our institution. All prostheses were Freeman-Samuelson femoral and tibial components (Sulzer, Baar, Switzerland) and all revision procedures were performed by the senior author (GS). The mean age at revision was 68.4 years (49 to 80) and the mean period of implantation was for 55.6 months (8 to 103). Revision was performed for aseptic loosening in 18 knees and infection in four. The femoral component had been fixed with polymethylmethacrylate (PMMA) cement in three knees, three were hydroxyapatite-coated (HA) and 16 were press-fit and not porous-coated. The tibial component had been fixed with cement in 18 knees, three had HA-coating and one was press-fit and not porous-coated. All tibial components had metal-backed trays. The components were carefully cleaned with aqueous mild detergent before being studied.

The Ewald method8 of examining both the orientation of the components and the axes of the femur and tibia was used to derive the coronal angle of the knee. This was measured on weight-bearing anteroposterior (AP) radiographs taken with the knee in full extension. The most representative radiographs obtained within six weeks after surgery were used.

The femoral components were made of cobalt-chromium-molybdenum (CoCrMo) alloy. Their condyles had a single continuous radius of 24 mm in the sagittal plane and were flat in the coronal plane. Both condyles were examined separately as they articulated with the tibial components from both 0˚ to 60˚ and 61˚ to 120˚ of knee flexion. Measurements of surface roughness from the sides of the patellar groove at the apex of the femoral flange, an area which does not articulate with either the patella or tibia, were taken as controls. In the Freeman-Samuelson prosthesis, the anterior femoral flange is longer than in most other
designs. This concept was adopted to ensure that the patella and its resurfacing inlay never travelled off the top of the flange even when the knee was fully extended. This results in an area proximal to the patella which does not articulate with either polyethylene or bone. Only the soft tissues of the extensor apparatus can contact the flange in this location. In the absence of any evidence to show that the soft tissues of the extensor mechanism possess abrasive qualities, we considered this site to be an acceptable control. The surfaces of the retrieved femoral components were visually inspected for four modes of damage in their articulating areas. These were scratching with score marks visible as separate lines, burnishing with areas of multiple fine scratching which had dulled the polished areas, abrasion seen as areas which had a tufted appearance and pitting with depressions in the surface.

These modes of damage were derived from an established definition used to describe damage to polyethylene inserts. The original definition identified seven modes of damage on an insert but we excluded surface deformation, embedded PMMA debris and delamination, as they were not found in our femoral components.

The measurements of surface finish were performed with a contact stylus profilometer (Surftest SV400, Mitutoyo Corporation, Tokyo, Japan) (Fig. 1). The diameter of its tungsten-tipped stylus is 0.005 mm, with a resolution of 0.01 x 10^{-6} m and a Ra maximum uncertainty of ± 0.005 x 10^{-6} m. The maximum length of each measurement was 0.8 mm. Mathematically, Ra is the arithmetical mean of the absolute values of the measured deviations of height taken within the area evaluated and is measured from the main line or surface. Over one sampling length it represents mean roughness and eliminates the effect of a single spurious, atypical peak or valley. Lower Ra values generally indicate a smoother surface. The Ra value (µm) was calculated as the mean of eight measurements taken in the coronal plane in the areas of surface damage within the articulating arc.

We visually inspected the UHMWPE inserts in order to identify any damaged areas which might have caused corresponding attrition to the articulating areas of the femoral components. In particular, we looked for the presence of embedded PMMA debris. Statistical analysis of the data was performed using SPSS version 11.5 (SPSS Inc, Chicago, Illinois). The mean Ra values of the damaged areas on the condyles within the articulating arc were compared with those on the control area. A two-sample t-test assuming unequal variances was used. Values for p < 0.05 were regarded as significant.

**Results**

The overall coronal alignment of all the femoral prostheses was satisfactory with a mean coronal angle of 7.2 (± 1°).

**Macroscopic appearances.** Dull-edged parallel scratching (Fig. 2) in the direction of the sliding motion was the principal damage seen in all the femoral components. Artefactual marks produced by surgical instruments were readily distinguishable from parallel scratching because of the nature of the aspect ratio, which is the ratio of section of height to section of width. Artefactual lines were not considered in this study. Burnishing (Fig. 2) was frequently seen and occurred in 16 (72.7%) of the components. Pitting and abrasion were not seen. None of these changes was observed at the control area on the sides of the patellar flange. Our visual analysis of the UHMWPE insert failed to identify embedded PMMA debris, or any other damage, which matched the location of the altered surface finish on the femoral side.
**Table I. Mean Ra values**

<table>
<thead>
<tr>
<th>Region assessed</th>
<th>Mean Ra (SD) in µm</th>
<th>p values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial femoral condyle 0˚ to 60˚</td>
<td>0.0225 (0.00797)</td>
<td>0.832</td>
</tr>
<tr>
<td>Medial femoral condyle 61˚ to 120˚</td>
<td>0.0244 (0.00532)</td>
<td>0.189</td>
</tr>
<tr>
<td>Lateral femoral condyle 0˚ to 60˚</td>
<td>0.0263 (0.00694)</td>
<td>0.078</td>
</tr>
<tr>
<td>Lateral femoral condyle 61˚ to 120˚</td>
<td>0.0253 (0.00758)</td>
<td>0.286</td>
</tr>
<tr>
<td>Control</td>
<td>0.0230 (0.00821)</td>
<td>-</td>
</tr>
</tbody>
</table>

* p < 0.05 are significant

Surftest SV400 stylus profilometry. The two-sample *t*-test was used to compare the mean Ra values obtained from the articulating and control areas (Table I). No statistically significant difference was seen in the mean roughness (Ra) of the articulating areas on the femoral condyles when compared with the mean roughness (Ra) of the control areas (p < 0.05). This suggests that the surface finish of these implanted femoral components does not deteriorate in the weight-bearing area any more than in a less load-bearing zone.

**Discussion**

We have analysed the changes in surface finish of retrieved femoral components. Surprisingly, only a few investigations have studied the wear of the femoral component and none has evaluated the surface changes on the articulating areas. This may be because the surface damage to femoral components is generally small when compared with the wear of a tibial UHMWPE insert. However, with careful observation, damage to the femoral components could be characterised. All had scratching on the articular surface which was parallel to the plane of the sliding movement. These scratches had fine grooves with dull edges. Their direction and dull edges enabled them to be distinguished from artefactual, sharp-edged scratches that had been created by the surgical removal of the implants. Artefactual marks produced displacement of the metal surface whereas the fine scratches had dull edges. Although it seems reasonable to assume that third-body particles trapped between the articulating surfaces would have created these fine scratches, inspection with the naked eye failed to identify these particles embedded within the UHMWPE inserts. The inserts used in these patients were irradiated in air rather than a vacuum, which may have predisposed them to delamination by oxidative chain scission.

In our study, only a few femoral components were cemented at the primary procedure. However, they were designed to enable removal, via the intercondylar space, of any cement spill from the posterior condyles of the knee. When a femoral component was cemented, the knee was always subluxed to check for cement at the back of the joint. Although little or no cement was used for many of the arthroplasties, more bone debris could have been created because it is known that uncemented fixation can lead to early implant failure and femoral bone loss. Scratches could have been caused by either bone or polyethylene particles acting as third-body debris.

Most studies which assess femoral component and polyethylene wear are in vitro and use knee simulators. However, these studies may not reflect the changes that occur in vivo. Experimental studies have shown that a threefold increase in the roughness of the femoral surface can cause a minimum tenfold increase in the rate of polyethylene wear.

Siddique et al. studied 60 patients whose uncemented, porous-coated anatomic knees had been revised to a cemented prosthesis. Six of 14 patients (42%) in whom the femoral component had been retained required an early re-revision at a mean of 2.1 years. However, only seven of 45 patients (15%) in whom both components were revised (group 2) needed a re-revision after a mean of 6.8 years. UHMWPE failure in porous-coated anatomical knees is well described. Babis, Trousdale and Morrey also observed a high rate of early failure with isolated insert exchange in 56 knees. Of these, 27 knees were treated by an exchange to a thicker insert for instability and 24 underwent exchange of the insert for wear. Of the 27 knees revised for instability, 12 were considered failures and eight were re-revised for continued painful ligamentous instability (five knees), deep infection (one), tibial component loosening (one) and painful stiffness (one). Of these 12 knees, four were considered failures because of severe pain. Of the 24 knees where exchange of the insert was undertaken for wear, eight failed and five of these were re-revised for recurrent wear. The unifying feature of these reports on the porous-coated anatomical knee is the poor quality of the UHMWPE components, resulting in a massive particle load. If re-used, these implants cannot be expected to give a satisfactory outcome, especially if any concealed debris beneath the femoral component is not removed. The primary reason for further failure in these patients cannot be attributed to the surface finish of the femoral component.

Despite scratches and burnishing on the articular surfaces of the femoral components, the differences in surface roughness between the articulating surfaces and the controls were not statistically significant. Newly manufactured femoral components must conform to British Standard 7251 - 14:1998 with a surface finish not exceeding 0.05 µm. Experimental studies have shown that a threefold increase in the roughness of the femoral surface can cause a minimum tenfold increase in the rate of polyethylene wear.

In our study, only a few femoral components were cemented at the primary procedure. However, they were designed to enable removal, via the intercondylar space, of any cement spill from the posterior condyles of the knee. When a femoral component was cemented, the knee was always subluxed to check for cement at the back of the joint. Although little or no cement was used for many of the arthroplasties, more bone debris could have been created because it is known that uncemented fixation can lead to early implant failure and femoral bone loss. Scratches could have been caused by either bone or polyethylene particles acting as third-body debris.

Most studies which assess femoral component and polyethylene wear are in vitro and use knee simulators. However, these studies may not reflect the changes that occur in vivo. Experimental studies have shown that a threefold increase in the roughness of the femoral surface can cause a minimum tenfold increase in the rate of polyethylene wear.

Siddique et al. studied 60 patients whose uncemented, porous-coated anatomic knees had been revised to a cemented prosthesis. Six of 14 patients (42%) in whom the femoral component had been retained required an early re-revision at a mean of 2.1 years. However, only seven of 45 patients (15%) in whom both components were revised (group 2) needed a re-revision after a mean of 6.8 years. UHMWPE failure in porous-coated anatomical knees is well described. Babis, Trousdale and Morrey also observed a high rate of early failure with isolated insert exchange in 56 knees. Of these, 27 knees were treated by an exchange to a thicker insert for instability and 24 underwent exchange of the insert for wear. Of the 27 knees revised for instability, 12 were considered failures and eight were re-revised for continued painful ligamentous instability (five knees), deep infection (one), tibial component loosening (one) and painful stiffness (one). Of these 12 knees, four were considered failures because of severe pain. Of the 24 knees where exchange of the insert was undertaken for wear, eight failed and five of these were re-revised for recurrent wear. The unifying feature of these reports on the porous-coated anatomical knee is the poor quality of the UHMWPE components, resulting in a massive particle load. If re-used, these implants cannot be expected to give a satisfactory outcome, especially if any concealed debris beneath the femoral component is not removed. The primary reason for further failure in these patients cannot be attributed to the surface finish of the femoral component.

Despite scratches and burnishing on the articular surfaces of the femoral components, the differences in surface roughness between the articulating surfaces and the controls were not statistically significant. Newly manufactured femoral components must conform to British Standard 7251 - 14:1998 with a surface finish not exceeding 0.05 µm. Even after our mean implantation period of 55.6 months, the surface roughness was within this standard. We do not know the pre-implantation surface roughness of the femoral components in order to make direct comparisons. However, the pre-implantation surface finish should be similar to the non-articulating part of the implant. It was for this reason that the top of the metal flange of the femoral component on either side of the patellar groove was taken as the control area.

Our study showed that the surface finish of these implants did not deteriorate during the period of implantation. Loss of reflectivity of an implant does not equate to an increase in roughness. A rough surface can still be polished...
and, when subsequently articulated, peaks can be worn and cause the component to become dull. In these circumstances the Ra value may either remain unchanged or even improved. Our observations may be prosthesis-specific and not applicable generally. However, on the basis of our results, when revision of a TKA is undertaken for tibial failure in the presence of a correctly-aligned and securely fixed femoral component with no accumulated wear debris beneath it, the fine scratches and burnishing marks visible to the naked eye should not prevent retention of the femoral component.

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.