CERAMIC-CERAMIC AND METAL-POLYETHYLENE TOTAL HIP REPLACEMENTS
COMPARISON OF PSEUDOMEMBRANES AFTER LOOSENING

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We made a semiquantitative study of the comparative histology of pseudomembranes from 12 loose cemented ceramic-ceramic and 18 metal-polyethylene total hip replacements. We found no significant difference in cellular reaction between the two groups, but there was a major difference in the origin of the particulate debris. In the metal-polyethylene group, polyethylene of articular origin was predominant, while in the ceramic-ceramic group the cellular reaction appeared to be a response to zirconia ceramic particles used to opacify cement used for fixation.

Isolation and characterisation of the debris showed that the zirconia particles formed the greatest proportion (76%) in ceramic-ceramic hips, while alumina debris of articular origin formed only 12%.

Our study has indicated that aseptic loosening of ceramic cups is not due to a response to debris generated at the articular interface, but to mechanical factors which lead to fragmentation of the cement.

It is now recognised that the biological response to wear debris is one of the main mechanisms of aseptic loosening of metal-polyethylene total hip replacements (THR). Study of the pseudomembranes from such cases has shown that polyethylene particles generated by friction at both articular and non-articular interfaces are the most frequent component of this debris.1,2 They are found in considerable concentration in the periprosthetic tissues, and are associated with intense cellular reactions. These are characterised by the presence of stimulated macrophages which secrete mediators of bone resorption.3-5

In response to the problems of polyethylene wear, Boutin6 introduced an alumina ceramic-ceramic load-bearing couple. Clinical experience with this has shown an 89.4% survivorship at ten years;7 most of the failures were due to aseptic loosening of the socket, but the role of the cellular reaction to debris in this loosening has not been established. In vivo the wear rate of ceramic-ceramic is 4000 times less than that of metal-polyethylene8 and alumina ceramic is known to be one of the most inert biomaterials. We therefore hypothesised that the foreign-body inflammatory response around ceramic joints should be less intense than that around metal-polyethylene prostheses.

Our present study was designed to provide a systematic histological comparison of pseudomembranes from the two joint couples which had been revised for aseptic loosening. We also isolated and characterised the debris from the ceramic pseudomembranes to establish parameters for the particles such as those already reported for polyethylene and metal.

MATERIALS AND METHODS

From 1990 to 1994, we collected the pseudomembranes from a series of 39 patients having revision operations for aseptic loosening of the socket at the Hôpital Saint-Louis in Paris. To allow comparison between ceramic and metal-polyethylene, we excluded the nine cementless sockets since they were heterogeneous in design. Thirty cemented sockets remained; 12 were ceramic-ceramic and 18 metal-polyethylene. All the membrane specimens came from the cup-bone interface.

The ceramic-ceramic prosthesis (Ceraver-Osteal, Roissy, France) had a collared, cemented Ti4Al6V femoral
stem. The modular head and the socket were matched pairs of dense alumina ceramic (Al$_2$O$_3$). The femoral stems in the metal-polyethylene hips were of either cobalt-chrome alloy or stainless steel. More details of the two series are given in Table I which shows no significant demographic variation between the groups, but two important differences should be noted. First, all but one ceramic THR failed by cup loosening alone, while loosening involved both components in most of the metal-polyethylene THRs. Secondly, different cements were used to fix the acetabular components. In the ceramic group, several different brands of cement had been used, but all of them contained zirconium dioxide (ZrO$_2$) ceramic granules as the radio-opacifying agent. In the metal-polyethylene group, which had been implanted in other hospitals, information on the type of cement used was not always available, but in most cases BaSO$_4$ was used as the radio-opacifying agent.

Histological examination. We studied 5 μm sections stained with haematoxylin and eosin under transmitted and polarised light. We graded each type of debris particle and foreign-body inflammatory cell (macrophage, giant cell) on a scale from 0 to 3 according to a modification of the method described by Willert and Semlitsch. Ten microscopic fields were examined on each of two different slides for each specimen by a single independent observer (SL) blinded to source and the grading allowed a semi-quantitative comparison between ceramic-ceramic and metal-polyethylene groups.

Debris characterisation. Debris from the ceramic pseudomembranes was isolated by tissue-digestion techniques using collagenase and formic acid. We then used SEM in association with energy-dispersive X-ray analysis (EDAX) and computer-assisted image analysis to study the debris characteristics. The ratio of each type of debris was calculated after the identification of 100 to 500 particles per specimen, and particle-size distribution curves were established by using the equivalent circle diameter which extrapolates the surface area of a particle to a circle.

We used non-parametric Spearman and Kolmogorov-Smirnov statistical tests to study correlations and differences between groups respectively.

RESULTS

Grading of cellular reaction and wear debris. The mean grade of macrophages, of giant cells and both cell types together for each group is shown in Figure 1. We found no difference in the mean grade of cellularity between ceramic and metal-polyethylene membranes. The mean grade of each type of debris particle for the two groups is shown in Figure 2. In the polyethylene group of 18, we identified polyethylene in all and metal in 16; there were empty cement vacuoles corresponding to cement dissolved during preparation in 13. Particles of radio-opacifying

<table>
<thead>
<tr>
<th>Joint</th>
<th>Ceramic-ceramic</th>
<th>Metal-polyethylene</th>
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</thead>
<tbody>
<tr>
<td>Number of cemented cups revised</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Mean age in years (± SD)</td>
<td>64 ± 14</td>
<td>61 ± 16</td>
</tr>
<tr>
<td>Male:female</td>
<td>1:11</td>
<td>5:13</td>
</tr>
<tr>
<td>Implantation time in years (± SD)</td>
<td>8.7 ± 3.4</td>
<td>10.3 ± 4.0</td>
</tr>
<tr>
<td>Cement radio-opacifying agent</td>
<td>ZrO$_2$</td>
<td>BaSO$_4$*</td>
</tr>
<tr>
<td>Loose component at revision</td>
<td>Acetabulum</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Both</td>
<td>1</td>
</tr>
</tbody>
</table>

* in the MPE group, information on the type of cement was not always available, but in most cases BaSO$_4$ was used as the radio-opacifying agent.

Fig. 1
Mean grade of macrophage, giant cell, and of both cell types in pseudomembranes collected from ceramic-ceramic (CC) and metal-polyethylene (MPE) THRs.
agent were found occasionally in the empty vacuoles. Depending on the size of each particle, we saw typical macrophage and giant-cell reactions to both metal and polyethylene debris. Particles larger than 5 to 10 μm were usually found within giant cells. The mean grade of polyethylene debris was higher than that of other types of debris.

In the 12 ceramic-ceramic pseudomembranes, we identified particles of titanium in 7 and ceramic in 11, with empty cement vacuoles in 10. Surprisingly, and in contrast to the polyethylene group, the presence of the radio-opacifying particles (ZrO₂) in the ceramic-ceramic pseudomembranes were not limited to the empty cement vacuoles. Numerous small ZrO₂ particles were found dispersed in the tissue, their size and colour being very similar to those of alumina debris. Both types of ceramic particle were yellow amber in colour with brown outlines, and most were submicron in size both intra- and extracellularly. Light microscopy could not clearly distinguish submicron Al₂O₃ from submicron ZrO₂ ceramic debris, and for histological grading, the two types of ceramic particle were placed in one category. In five specimens, grade-3 ceramic debris was found in association with grade-2 or grade-3 macrophage reactions (Fig. 3). Giant cells were very rare and associated only with cement vacuoles.

We found no significant differences between the mean grade of particulate debris in ceramic and polyethylene groups.

**Debris from ceramic pseudomembranes.** EDAX analysis allowed us to identify the debris in the ceramic-ceramic pseudomembranes, confirming the presence of particles of alumina ceramic (Al₂O₃), titanium alloy (TiAlV) and zirconia ceramic (ZrO₂). These represented 12%, 12% and 76% of the total particle load, respectively. Of the ceramic debris, 86% was ZrO₂ and only 14% Al₂O₃. In the five hips showing grade-3 ceramic debris, the isolated particles were ZrO₂ of cement origin and not Al₂O₃ of prosthetic origin. Size-distribution analysis showed that Al₂O₃ and ZrO₂ particles had overlapping size distributions, but that the latter were on average smaller (0.28 ± 0.08 μm) with a smaller size distribution than Al₂O₃ (0.44 ± 0.25 μm) or TiAlV (0.61 ± 0.31 μm) (Fig. 4).

**DISCUSSION**

According to the mechanism of metal-polyethylene loosening, polyethylene of articular origin migrates within the effective joint space, and provokes an inflammatory action leading to periprosthetic osteolysis. Our results support other studies which have identified polyethylene as the most abundant debris generated in such joints (Shanbhag...
in comparison with human cortical bone (20 GPa) and 
finite-element analysis has shown that this mismatch leads 
to a very different pattern of stress-distribution than that 
seen for a polyethylene cup or a natural joint. The 
relative rigidity of a ceramic socket causes stress shielding 
of the adjacent acetabular bone leading to atrophy and 
progressive lack of support for the cement mantle. It 
seems likely that cement sandwiched between stiff 
ceramic and compliant bone may then fracture. An 
additional factor is the low damping capacity of alumina 
ceramic; this may also increase the risk of cement or bone 
microfractures by excess transmission of impact loading. 
The role of mechanical factors in the aseptic loosening of 
ceramic joints is supported by our clinical observations.

We found better long-term results for ceramic hips in 
young patients whose supporting acetabular bone is less 
osteopenic and therefore less subject to microfractures.

We conclude that the cemented ceramic cups reported in 
this series probably became loose as a result of cement 
fragmentation at the ceramic bone interface leading to a 
macrophage reaction to polymethylmethacrylate and also 
to zirconia ceramic particles derived from the cement. Our 
finding of small amounts of alumina debris of prosthetic 
origin confirms its theoretical and reported wear proper-
ties, but this wear reduction can be used to clinical advan-
tage only when future designs focus on the reduction of 
mechanical factors, such as the lack of damping properties 
and the large mismatch in Young’s modulus between 
ceramic and bone.

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