Comparison of in vivo wear between polyethylene liners articulating with ceramic and cobalt-chrome femoral heads

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At yearly intervals we compared the radiological wear characteristics of 81 alumina ceramic femoral heads with a well-matched group of 43 cobalt-chrome femoral heads. Using a computer-assisted measurement system we assessed two-dimensional penetration of the head into the polyethylene liner. We used linear regression analysis of temporal data of the penetration of the head to calculate the true rates of polyethylene wear for both groups. At a mean of seven years the true rate of wear of the ceramic group was slightly greater (0.09 mm/year, so 0.07) than that of the cobalt-chrome group (0.07 mm/year, so 0.04). Despite the numerous theoretical advantages of ceramic over cobalt-chrome femoral heads, the wear performance in vivo of these components was similar.

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In an attempt to minimise polyethylene wear, manufacturers have introduced different types of material for use in total hip replacement (THR). In the past, most femoral heads have been made of stainless steel and titanium, but problems with wear of the metal and of the polyethylene liner have led to the development of harder, more scratch-resistant materials. Currently, cobalt-chrome and ceramic are widely used. Although both perform well in THR, the latter has advantages which make the ceramic-polyethylene wear couple theoretically superior to that of metal and polyethylene.\(^{1-7}\)

Ceramic is harder and more resistant to scratching than cobalt-chrome.\(^{1-3}\) Laboratory studies have shown that a single scratch on the surface of an articulating counterface can dramatically increase the rate of polyethylene wear.\(^{4,5}\) Since ceramic heads are not as easily scratched as those of metal, they should maintain a good surface finish with reduced rates of polyethylene wear.

Ceramic heads also have superior surface characteristics.\(^{2,3,6}\) The surface is more wettable and therefore better able to maintain surface lubrication than that of a metal head.\(^{2,7}\) Additionally, tribological studies have shown that ceramic has a more rounded surface profile with fewer sharp ridges than a metal surface,\(^{6}\) thus making it better suited for bearing or sliding applications.

A final advantage of ceramic is its chemical inertness.\(^{2,3}\) In the aqueous environment of the body, passive oxide films form on the surface of metal femoral heads.\(^{2,3}\) This passive film is constantly sheared off and recreated during articulation, a process which not only increases the surface roughness over time, but also releases potentially damaging third-body particles into the joint space.\(^{2,3}\) These consequences are averted with ceramic heads.

Ceramic heads articulating with polyethylene liners should therefore produce less wear than similar metal heads. In fact, studies using a hip simulator have reported lower rates of polyethylene wear with ceramic femoral heads than with metal heads.\(^{8,9}\) Laboratory tests cannot, however, accurately reproduce the complex environment of the body; it is important to assess in vivo the effects of such materials on polyethylene wear.

Therefore, using a matched series of patients, we have compared the wear performance of polyethylene liners articulating with ceramic heads with liners articulating with cobalt-chrome heads.

Patients and Methods

We analysed 124 patients who had had primary THR with a Triloc acetabular component (DePuy, Warsaw, Indiana), an uncemented porous-coated femoral component (DePuy) and a 32 mm diameter femoral head of either cobalt-chrome or alumina ceramic (DePuy). All operations were performed in the same institution using the same technique. The patients were required to be between 45 and 70 years of age, to have a minimum follow-up of four years and to have a minimum of three anteroposterior (AP) pelvic radiographs for analysis. We excluded patients under 45 and
over 70 years to reduce the bias towards using ceramic heads in younger and cobalt-chrome heads in older patients.

In the ceramic group there were 81 patients followed for a mean of 7.0 years (4.0 to 10.1) with a mean age at surgery of 58.8 years and a mean weight of 78.7 kg. In the cobalt-chrome group there were 43 patients followed for a mean of 6.8 years (4.2 to 9.3) with a mean age at surgery of 60.6 years and a mean weight of 78.4 kg (Table I). In the ceramic group 44% were men compared with 49% in the cobalt-chrome group (Table I).

**Radiological analysis.** Using a previously published protocol,10 we determined two-dimensional penetration of the femoral head into the polyethylene liner from AP pelvic radiographs at annual intervals.10 To eliminate interobserver error, all the measurements were performed by the same person. The positioning of the patients and the radiological technique were consistent. We included only patients with primary THR. If a patient later required revision, we included their annual radiographs before revision to avoid excluding individuals with possible high rates of wear.

The method uses a computer system, digitiser tablet, and specially designed software. After aligning a radiograph on the digitiser tablet so that the interteardrop line is parallel to the edge of the tablet, the computer operator digitises at least five points around the circumference of the head of the implant, at least five points around the circumference of the acetabular cup, and three points along the face of the cup. After correcting for magnification and distance from the centre of the X-ray beam, the computer software fits circles to the digitised points and determines their centres. Two-dimensional penetration of the head is defined by the movement of the centre of the head relative to the centre of the cup between the time of the immediate postoperative AP radiograph and the most recent film. A previous study has documented validation of this measurement system.10 Additionally, the computer software uses points lying along the face of the cup to calculate tilt and anteversion of the acetabular component.

**Analysis of data separating true wear from bedding-in.** Using linear regression analysis, we determined the line of best fit for data on penetration of the head against time for each patient. This allowed the true wear of the polyethylene liner to be separated from other processes, such as creep or lip deformation, the bedding-in process, which contribute to the initial movement of the head of the femur into the liner. Each line of best fit was characterised by its own slope and its own intercept. As shown in previous studies, the slope of the line of best fit describes the true rate of wear for a patient, and the intercept estimates the amount of penetration of the head caused by the bedding-in process.11,12

We defined osteolysis of the pelvis as a circumferential, expansile lytic area with a distinct border and osteolysis of the femur as loss of structure of the trabecular bone and endosteal cortical erosion. Osteolysis was evaluated by comparing each patient’s most recent annual follow-up radiograph with their postoperative film. From the most recent radiograph, the size of the lesion was calculated as the product of its length and width. Only lesions greater than 1.5 cm² were considered to be clinically relevant.

We used the Mann-Whitney U test to determine if slope, intercept, age, weight, or length of follow-up data differed statistically between the groups. Chi-squared analysis assessed statistical differences in gender distribution, head material distribution, and frequency of osteolysis between the groups.

**Results**

Both groups were matched on the following factors: the acetabular and femoral components, the size of the head, manufacturer of the head, surgical technique, and method of polyethylene sterilisation. There was no statistical difference in age (p = 0.12) and weight (p = 0.88) at surgery or in gender distribution (p = 0.71) between the groups (Table I). In addition, there was no difference in the mean tilt of the component between the groups (43.3° v 43.2°, respectively, p = 0.95) or in anteversion of the cups (18.9° v 18.8°, respectively, p = 0.97).

The true rate of wear of cups which articulated with ceramic heads (0.09 mm/year; sd = 0.07) was higher than that of cups articulating with cobalt-chrome heads (0.07 mm/year; sd = 0.04; p = 0.03) (Fig. 1). The magnitudes of the bedding-in process for these cups, represented by the intercepts for the two groups, were not statistically different. The mean amount of bedding-in was 0.31 mm for the ceramic group (sd = 0.29) and 0.26 mm (sd = 0.18) for the cobalt-chrome group (p = 0.33).

Despite a difference in the true rates of wear, there was no difference in the occurrence of clinically relevant osteo-

<table>
<thead>
<tr>
<th>Details of the patients in both groups</th>
<th>Ceramic</th>
<th>Cobalt-chrome</th>
<th>p value</th>
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<tbody>
<tr>
<td>Number of patients</td>
<td>81</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>Number of radiographs</td>
<td>419</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>Mean age in years</td>
<td>58.8</td>
<td>60.6</td>
<td>0.12</td>
</tr>
<tr>
<td>Mean weight in kg</td>
<td>78.7</td>
<td>78.4</td>
<td>0.88</td>
</tr>
<tr>
<td>Male:female</td>
<td>36:45</td>
<td>21:22</td>
<td>0.71</td>
</tr>
<tr>
<td>Mean follow-up in years (range)</td>
<td>7.0 (4.0 to 10.1)</td>
<td>6.8 (4.2 to 9.3)</td>
<td>0.60</td>
</tr>
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</table>
lytic lesions between the two groups (Table II). The ceramic group had an incidence of clinically relevant pelvic lesions of 1.2% and of clinically relevant femoral lesions of 0.0%, compared with 2.3% (p = 0.65) and 0.0% respectively, in the cobalt-chrome group.

Discussion

The results from studies comparing the wear characteristics of ceramic with metal femoral heads have varied considerably. Most laboratory and hip simulator studies have shown a clear advantage of ceramic over metal heads, but studies on the wear of components in vivo have yet to confirm this. Some radiological studies in vivo have shown the performance of the ceramic head to be superior when compared with that of the metal head. The opposite results were reported, however, in a recent study by Devane, Horne and Botsford which used a more sophisticated radiological method. Their three-dimensional analysis found no statistical difference between the mean rate of polyethylene wear of ceramic heads (0.32 mm/year) and a well-matched group of stainless-steel heads (0.26 mm/year) after 5.7 years.

Recent tribological examinations of ceramic and metal femoral heads in vivo have further questioned the superiority of ceramic. Bragdon et al examined four yttrium-stabilised alumina ceramic heads retrieved at revision and reported surface damage in the form of scratches and relief polishing on all heads. They point out that their results should not be extrapolated to other ceramic femoral heads, but they do show the susceptibility of some ceramics to third-body abrasive damage in vivo. In addition, we have recently evaluated a series of 24 cobalt-chrome and alumina ceramic heads retrieved at post-mortem from well-functioning THRs. Despite the fact that the ceramic heads had lower mean values for surface roughness and little evidence of surface damage, they had slightly higher rates of polyethylene wear than the cobalt-chrome heads. Although the groups were small and not matched, the results showed the need for further investigations comparing the wear performance in vivo between ceramic and cobalt-chrome femoral heads.

Our study was an attempt to examine more precisely the wear performance of ceramic and cobalt-chrome femoral heads in vivo using computer-assisted radiological techniques and a new method of analysis of data. We have found that polyethylene liners articulating with ceramic femoral heads did not have lower true rates of wear than a matched group of liners articulating with cobalt-chrome heads. The reason for the similarity in true wear, despite all the theoretical advantages of ceramic heads, remains uncertain.

One explanation could lie in the multifactorial nature of the process of polyethylene wear in vivo. Although ceramic heads have been shown to be superior to cobalt-chrome during testing in vitro, numerous confounding factors acting together in vivo may neutralise the advantages of the ceramic surface, rendering its performance in vivo similar to that of cobalt-chrome. Although our study has negated the influence of some confounding factors by comparing groups of similar age, weight, and component, other uncontrollable and unquantifiable factors invariably remain. Some of these, such as third-body debris and the level of activity of the patients, can significantly affect wear.

When particles of third-body debris become interposed between the articulating surfaces, the effect on the polyethylene surface can be devastating. Multiple studies on polyethylene liners and femoral heads retrieved at revision surgery and at post-mortem have shown scratching on almost all components, indicating the presence of third-body particles during articulation. In the presence of considerable third-body debris, the increased scratch resistance of ceramic may protect the head from damage, but it cannot protect the polyethylene liner from increased abrasive wear.

In addition to third-body debris, the level of activity of the patient may also have influenced our findings. Although the tendency has been to use ceramic heads in younger, more active patients, we attempted to negate this bias by selecting patient groups of similar distribution of age,

<table>
<thead>
<tr>
<th>Table II. Rates of wear and osteolysis in both groups</th>
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<tr>
<td>True rate of wear (mm/year ± SD)</td>
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<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>Pelvic</td>
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<tr>
<td>Osteolysis (%)</td>
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<td>Femoral</td>
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Fig. 1

Graph showing the mean temporal data for penetration of the head for the two groups. The true rate of wear (slope) of cups which articulated with ceramic heads (0.09 mm/year, ± 0.07) was higher than that of cups articulating with cobalt-chrome heads (0.07 mm/year, ± 0.04; p = 0.03).
weight, and gender. However, because these criteria do not explicitly characterise a patient’s level of activity, we acknowledge that a bias in this could have remained and contributed to the increased rate of wear in the ceramic group.

Our findings have shown that for the particular components studied, an alumina ceramic femoral head has little advantage over a cobalt-chrome head in decreasing in vivo polyethylene wear. Our study demonstrates that although changes in component designs and materials may offer theoretical advantages over current components, their effect in vivo remains questionable. For new components and materials, long-term serial radiological studies on a large number of patients in a well-controlled environment will be necessary to determine their true wear performance in vivo.

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References