SIZE OF METALLIC AND POLYETHYLENE DEBRIS PARTICLES IN FAILED CEMENTED TOTAL HIP REPLACEMENTS

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Reports of differing failure rates of total hip prostheses made of various metals prompted us to measure the size of metallic and polyethylene particulate debris around failed cemented arthroplasties. We used an isolation method, in which metallic debris was extracted from the tissues, and a non-isolation method of routine preparation for light and electron microscopy. Specimens were taken from 30 cases in which the femoral component was of titanium alloy (10), cobalt-chrome alloy (10), or stainless steel (10).

The mean size of metallic particles with the isolation method was 0.8 to 1.0 μm by 1.5 to 1.8 μm. The non-isolation method gave a significantly smaller mean size of 0.3 to 0.4 μm by 0.6 to 0.7 μm. For each technique the particle sizes of the three metals were similar.

The mean size of polyethylene particles was 2 to 4 μm by 8 to 13 μm. They were larger in tissue retrieved from failed titanium-alloy implants than from cobalt-chrome and stainless-steel implants.

Our results suggest that factors other than the size of the metal particles, such as the constituents of the alloy, and the amount and speed of generation of debris, may be more important in the failure of hip replacements.

In the three decades since Sir John Charnley's pioneering efforts introduced total hip replacement it has become clear that particulate debris produced by wear of the prosthetic surfaces stimulates a biological response involving the recruitment of macrophages and the release of potent cytokines which induce progressive bone resorption (Goldring et al 1983). This response, well recognised in cemented implants (Mirra, Marder and Amstutz 1982; Johanson et al 1987), is now being seen also in uncemented implants (Buchert et al 1986; Maloney et al 1990).

The material composition of the particulate debris (Escalas, Galante and Rostoker 1976), its rate of production (Johanson et al 1987), the particles' size (Cohen 1959), shape (Matlaga, Yasenchak and Salthouse 1976), and surface characteristics (Salthouse 1984) all affect the biological response. Particle size, in particular, determines the type of response; as it decreases, the relative surface area available for physical and chemical reaction increases, as does the potential for detrimental effect. There is little reliable information on the size of metal and polyethylene particles generated in failed cemented total hip replacements of different alloys, but it has been shown that implants of different materials have different rates of clinical failure: titanium alloys have a higher rate of premature failure than other alloys (Agins et al 1988; Lombardi et al 1989; Robinson et al 1989; Black et al 1990; Witt and Swann 1991) suggesting that debris from titanium prostheses may be more harmful in some way.

We aimed, by two different methods, to determine the size of the particles of metal and polyethylene generated in failed cemented total hip replacements and to discover any differences between the three most frequently implanted alloys – titanium, cobalt-chrome, and stainless steel.

MATERIALS AND METHODS

All specimens were obtained at revision surgery from the periartricular tissues of failed, non-infected, cemented total hip arthroplasties.

Tissue from ten cases each of failed titanium alloy, cobalt-chrome alloy, and stainless steel implants were
stored, unfixed, at −20°C. Tissues from another 30 such cases were fixed in formalin, half of them from the same cases as the frozen tissues. Fresh tissues from three cobalt-chrome implants, two titanium-alloy, and two stainless-steel implants were processed for transmission electron microscopy. The material composition of the retrieved implants was confirmed from records held by the biomechanics department of The Hospital for Special Surgery.

Two methods of specimen preparation for light microscopy were used, an isolation and a non-isolation method. In the first, 1 to 2 g samples of the fresh-frozen specimens were digested in 10 ml of a commercial tissue solubiliser (Soluene 350, Packard Chemical, Illinois) for 96 hours at 65°C. The solution was then centrifuged at 2500 rpm for 15 minutes. Most of the supernatant was decanted and a small amount of xylene was added to reduce viscosity. One to two drops of the well-stirred liquid containing metallic particulate residue were placed on a glass slide for microscopic examination. The non-isolation method consisted of the routine processing of formalin-fixed samples by paraffin embedding, sectioning, and haematoxylin and eosin staining for histological examination. Metallic debris was studied using both methods, but polyethylene debris only by the routine histological method.

Specimens with metallic debris prepared by both methods were examined at an apparent magnification of × 2000 (× 100 oil immersion, × 2 optovar) on a Zeiss photomicroscope. At least five fields and 70 to 80 particles of metal debris were measured from each specimen prepared by the isolation method, and 30 to 40 particles by the non-isolation method. Slides with polyethylene debris were studied in polarised light at an apparent magnification of × 320 (× 100 oil immersion, × 2 optovar) with measurement of 30 to 40 particles. All particles were measured using a computer-assisted image analyser (Model 3000, Image Technology Corp, Deer Park, New York). Both the long dimension and the short dimension were recorded in all specimens.

Tissues studied by transmission electron microscopy (CM12, Philips, The Netherlands) for metallic debris were fixed with 0.5% glutaraldehyde and 2% paraformaldehyde in 0.05 M cacodylate buffer at pH 7.4, for 18 hours, post-fixed with 2% osmium tetroxide, dehydrated in alcohols, and embedded in Spurr’s resin. Thin sections, 70 to 80 nm in thickness, were examined.

Statistical analysis was performed using multivariate analysis of variance (ANOVA), and p < 0.05 was considered to be statistically significant.

RESULTS

Microscopic examination of tissue sections showed metallic particulate debris both within histiocytes and sometimes extracellularly. The mean size of metallic debris measured by the isolation method was 0.8 to 1.0 μm in short dimension and 1.5 to 1.8 μm in long dimension: by the non-isolation method the values were 0.3 to 0.4 μm and 0.6 to 0.7 μm respectively. Thus the size of the metallic debris measured by the isolation method was significantly larger than that obtained by the non-isolation method (p < 0.0001). Since metallic particles measuring over 3 to 4 μm were found only in samples studied by the isolation method, it seems that the larger particles may be pulled out of the tissue during their microsection. The size did not differ significantly for each metal alloy, when measured using the same method, except for the mean short dimension for stainless steel, which was larger (p < 0.001) with the isolation method.

The mean size of polyethylene debris was 2 to 4 μm in the short dimension and 8 to 13 μm in the long dimension. The sizes of the polyethylene particles from titanium-alloy implants were significantly larger (p < 0.001) than those from either cobalt-chrome alloy or stainless-steel implants, which did not differ significantly from each other.

The long and short dimensions (mean ± sd) obtained by both methods are presented in Tables I and II (metallic debris) and Table III (polyethylene debris). The distribution of the size of metallic debris of titanium alloy by the two methods is illustrated in Figures 1 and 2 and that of polyethylene debris from stainless-steel prostheses in Figure 3.

By transmission electron microscopy, metallic particles from cobalt-chrome failures were identified in both intracellular and extracellular spaces. The largest dimension was not determined since its value was limited by the thinness of the section (< 0.1 μm). Titanium-alloy and stainless-steel failures showed a similar distribution of metallic debris. Cellular deposits of debris particles had a range of size, most being less than the section thickness. Some particles were found to be 0.5 μm or larger, but these were not numerous. The titanium debris differed from other metallic debris observed in that it frequently showed angular or shard-shaped particles (Fig. 4).

DISCUSSION

Loosening of the implants is still the most frequent long-term complication of total hip replacement. Mechanical factors (Linder, Lindberg and Carlsson 1983; Jasty et al 1991), metallic debris (Pazzaglia et al 1985; Lombardi et al 1989; Witt and Swann 1991), polyethylene debris (Mirra et al 1982), cement debris (Willert, Ludwig and Semlitsch 1974; Mirra et al 1982), metal allergy (Lalor et al 1991), vascular insult from preparation and cementing (Rhinelander et al 1979), and thermal necrosis due to the exothermic reaction of cement (Mjöberg 1986) have all been suggested as contributory factors.

We have twice reported the presence of unusually large amounts of metal debris in the tissues around titanium-alloy prostheses showing early failure (Agins et
components. Distribution is isolation specifically Swann a!.

FIG. 1

Distribution of size of metallic debris particles measured by the isolation method (titanium-alloy prosthesis).

FIG. 2

Distribution of size of metallic debris particles measured by the non-isolation method (titanium-alloy prosthesis).

FIG. 3

Distribution of size of polyethylene debris particles from acetabular components which articulated with three types of femoral head.

Table I. Size of metallic particles measured by the isolation method (mean ± SD in µm)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium alloy</td>
<td>0.88 ± 0.1</td>
<td>1.64 ± 1.95</td>
</tr>
<tr>
<td>Co–Cr alloy</td>
<td>0.86 ± 0.105</td>
<td>1.57 ± 1.82</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>1.06 ± 1.30</td>
<td>1.79 ± 2.07</td>
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</tbody>
</table>

Table II. Size of metallic particles measured by the non-isolation method (mean ± SD in µm)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium alloy</td>
<td>0.39 ± 0.13</td>
<td>0.67 ± 0.27</td>
</tr>
<tr>
<td>Co–Cr alloy</td>
<td>0.40 ± 0.15</td>
<td>0.69 ± 0.28</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>0.36 ± 0.12</td>
<td>0.64 ± 0.26</td>
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</table>

Table III. Size of polyethylene particles in debris

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium alloy</td>
<td>4.1 ± 3.2</td>
<td>12.8 ± 11.0</td>
</tr>
<tr>
<td>Co–Cr alloy</td>
<td>2.7 ± 1.4</td>
<td>8.1 ± 5.2</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>3.1 ± 3.3</td>
<td>8.4 ± 7.5</td>
</tr>
</tbody>
</table>

response to the metal-wear debris [which] may have contributed to the early failure of these implants”.

In the July 1991 issue of the Journal of Bone and Joint Surgery [Br], an editorial by Scales addressed these issues. He suggested that the histiocytic and giant-cell reactions, described by Witt and Swann, were the result of polyethylene and cement wear and are no different from those seen with cobalt-chrome. This seems unlikely: in our experience of more than 80 cases of failed titanium implants, the histiocytic reaction and the quantity of intracellular metallic debris are orders of magnitude greater than those seen around cobalt-chrome implants.

Furthermore, Scales concluded from the earlier of our papers (Agins et al 1988) that we agreed with the findings of Dobbs and Scales in 1983 that titanium alloy was “both safe and efficacious in clinical use”. On the contrary, we intended to emphasise the high rate of failure and the large amount of metallic debris, both of which have been remarked by a number of other observers.

The measurement of particulate debris in the tissue of failed cemented hip replacements poses a number of problems. In histological sections prepared from a paraffin block, larger metal particles and some polyethylene particles may be pulled out of the tissues during sectioning. There is also a sampling problem; metallic debris may be unevenly distributed. Only very small amounts of tissue can be studied by transmission electron
microscopy and the thinness of the section prevents the measurement of large particles, some of which are often pulled out, even when diamond knives are used. Electron microscopy indicated that metallic debris was concentrated intracellularly within lysosomes and multivesicular bodies, although some particles were also found free in the extracellular matrix. The metal fragments ranged in size from 0.05 to 0.5 μm, most being smaller than 0.1 μm. Titanium debris also differed morphologically: other types of metallic debris were generally rounded in outline, but titanium was in the form of shards (Fig. 4).

Collecting debris by dissolving the tissue had the advantage of using all available material, but the dissolving agent may also dissolve the metallic debris, or produce aggregation of particles. We tried to overcome these problems by using Soluene, an organic and non-aqueous agent, as the dissolving agent. Metal is relatively insoluble in it, and it leaves a thin coating on the metal which results in less aggregation.

We found that the size of metallic particles for each of the metal alloys was much the same when measured by the same method. The particles in histological slides were, however, significantly smaller than those measured after solution of the tissues: particles over 3 to 4 μm were present only in the latter. Histological sections are approximately 4 to 5 μm thick and it is likely therefore that larger particles are lost during microsectioning. Small particles may aggregate during the isolation process, which would underestimate their frequency and overestimate their average size. Not surprisingly, the isolation method found metallic debris more easily, especially from failed cobalt-chrome and stainless-steel prostheses in which a standard histological search would usually fail to detect such particles.

We found larger polyethylene particles in tissues from failed titanium-alloy than from cobalt-chrome or stainless-steel prostheses. Issac et al (1987) showed that the femoral head may be severely burnished and scratched by methylmethacrylate particles when cement has been used. Such debris may be found embedded in the polyethylene surface. Titanium alloy is very susceptible to such scratching; its surface is, therefore, more likely to produce larger polyethylene particles than the smooth, well-polished surface of a cobalt-chrome head (Salvati, Huo and Buly 1991). All our specimens were from cemented arthroplasties, and a similar study of cementless failures is therefore required to assess the effect of cement debris.

We consider that our work has shown that the accelerated loosening seen in some cases after implantation of titanium prostheses cannot be explained by the size of the metallic particulate debris. It seems that the constituents of the alloy, the amount and speed of generation of both metallic and polyethylene debris, and the tissue response to them are more likely to be responsible for the early clinical failure of some of these arthroplasties.

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.

An electron micrograph showing macrophages and other cells from the periarticular soft tissue of a case of titanium implant failure. X-ray microanalysis of particles within the cells showed that the small rounded inclusions (straight arrows) contained osmium (lipid?) but no metal, whereas the angular or shard-shaped particles (curved arrows) contained titanium but no osmium.
REFERENCES


