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# Quantitative analysis of polyethylene wear debris, wear rate and head damage in retrieved Charnley hip prostheses

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Submicrometer- and micrometer-sized ultra-high molecular weight polyethylene (UHMWPE) wear particles have been associated with osteolysis and failure of total artificial joints. Previous studies have isolated predominantly submicrometer-sized particles at the expense of larger particles ( $>10\,\mu m$). This study aimed to isolate and characterize quantitatively all sizes of UHMWPE wear particles generated in 18 Charnley hip prostheses. In addition, to analyze the wear debris with respect to the total volumetric wear of the cup and damage to the femoral head. Particle size distributions ranged from 0.1 to - $>1000\,\mu m$. A significant proportion (3–82%) of the mass of the wear debris isolated was $>10\,\mu m$. The mode of the frequency distribution of the particles was in the range 0.1–0.5 $\mu m$ for all patients. However, analysis of the mass of wear debris as a function of its size allowed differentiation of the wear debris from different patients. Femoral head damage was associated with high volumetric wear and increased numbers of biologically active submicrometer-sized particles.


## 1. Introduction

In the last few years a number of studies of tissues from retrieved hip prostheses have found an association between micrometer- and submicrometer-sized ultra-high molecular weight polyethylene (UHMWPE) wear particles and osteolysis [1–6]. Using methods that isolate some of the wear particles from the tissues, the frequency distribution of the particle size has been quantified by scanning electron microscopy (SEM) and image analysis [3] or by automatic Coulter counting [4]. Other studies have independently associated high wear rates with osteolysis [7] and have related femoral head damage to high volumetric wear rates [8]. Recently, it has been shown that there is a wide distribution in the size of polyethylene wear particles in tissues surrounding Charnley hip prostheses, ranging from submicrometer and micrometer described above, to larger platelets and fibrils up to $1000\,\mu m$ in size [9]. Although the large particles may not be substantial in number, or indeed be particularly biologically active, they may constitute a significant proportion of the wear volume. Therefore, these large particles may lead to a substantial reduction in the total number of micrometer and submicrometer wear particles per unit volume of wear. Furthermore, it has recently been shown that polyethylene particles above $10\,\mu m$ in size have little biological activity when compared with micrometer- and submicrometer-sized particles [10]. These studies indicate that in order to predict the biological response, it is necessary to quantify all sizes of polyethylene particles found in tissues, in a size range extending from 0.1 to $1000\,\mu m$.

Laboratory studies have shown that there is a clear dependency between polyethylene wear rate and femoral head damage and roughness. Most importantly, it has been shown that single fine scratches, as found on explanted femoral heads, with an $R_{pm}$ (height above the mean line) of 0.2–1 $\mu m$ can cause increases in wear rates of up to 30 times [11]. In addition, qualitative analysis of UHMWPE wear debris from laboratory wear tests [9] has shown that rough counterfaces produce substantially higher numbers of particles in the size range 0.5–2 $\mu m$, compared to smooth counterfaces. The changes in particle morphology with variations in counterface roughness have been related to different wear mechanisms [12]. The clinical observations above, together with laboratory studies, have led to the postulation that as

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femoral heads become damaged *in vivo*, not only does the volume of wear of the polyethylene cups increase, but due to the change in wear mechanisms, the number of micrometer and submicrometer wear particles increases substantially.

The aim of this study was to quantify all sizes of polyethylene wear particles found in samples of retrieved tissues over a size range of 0.1–1000 μm. In addition, for the first time in the same prosthesis, to analyze the wear debris with respect to the total volumetric wear of the cup, the wear rate and the damage to the femoral head.

## 2. Materials and methods

### 2.1. Materials

Eighteen low friction Charnley hip prostheses were collected at revision, all of which were revised for loosening. The mean implant life was 12.88 years (range 10–19 years). Acetabular and femoral tissues were collected and stored in 10% (v/v) formalin at room temperature. Patient and implant histories were compiled. The femoral component of the Charnley hip prosthesis (De Puy International) was manufactured from stainless steel, the acetabular cup from RCH1000/GUR1120 UHMWPE and the components were sterilized with gamma irradiation in the presence of air prior to implantation.

### 2.2. Femoral heads

The retrieved prostheses were stored in 10% (v/v) formalin with the articulating surfaces of the heads and cups protected. The prostheses were then washed, cleaned and irradiated with 2.5 MRad gamma irradiation as a second stage of sterilization. The femoral head damage was quantified using a two-dimensional Rank Taylor Hobson Talysurf 6 profilometer. The surface roughness of the heads was measured at fixed positions on the articulating and non-articulating areas. Areas of macroscopically observed damage in the articulating area were also measured. The latter was used to quantify head damage, as traces taken in fixed positions on the head frequently missed localized areas of third body damage. The Talysurf 6 profilometer was used to measure a large number of surface roughness parameters ($R_a$, average surface roughness; $R_p$, peak height above the mean line; $R_{pm}$, average height above the mean line of the five highest scratches; $R_t$, peak to valley height; $R_v$, depth below mean line). In this study $R_{pm}$ was selected to quantify third body scratches as this has previously been shown to affect wear in laboratory tests markedly [11]. In order to study the effect of head damage, prostheses with an $R_{pm} > 0.2\,\mu m$ were classified as high damage heads and prostheses with an $R_{pm} < 0.2\,\mu m$ were classified as low damage heads.

### 2.3. Acetabular cups

A computer controlled co-ordinate measuring machine was used to measure the linear penetration and volume change associated with wear and creep of the cup [13]. The wear was always found in the superior position of the cup and the unworn region was used to fit the surface of the unworn cup. The difference between the fitted unworn surface and the measured worn surface allowed the maximum penetration, $P$, to be calculated. The total volume change was calculated using the modified tunneling formula [14]

$$V = P\left(\frac{\pi R_1^2}{1+\frac{\Delta R}{P}}\right)(mm^3)$$

Where $\Delta R$ is the radial clearance between the cup and the heads (0.125 mm), $P$ is the linear penetration (mm) and $R_1$ is the radius of the femoral head. When $P >> \Delta R$ (e.g. $P > 1$ mm), the relationship approximates to the simple tunneling formula. In order to compensate for creep, the wear volume was calculated by deducting $20\,mm^3$ from the total volume change. Hip joint simulator studies have shown a linear penetration of 0.1 mm and a volume change of approximately $20\,mm^3$ to be associated with creep. For most prostheses this resulted in only a minor correction to the volume change. The linear penetration rate (PR) and the volumetric wear rate (VWR) were calculated from the implantation life of the prostheses.

### 2.4. Quantitative isolation of UHMWPE wear-debris

Phagocytosis of UHMWPE wear debris by macophages and tissue drainage may lead to clumping and clearing of wear debris in the periprosthetic tissue. As a result, UHMWPE wear debris is not homogeneously distributed throughout the tissue. As the tissue samples collected during revision operations differed in both the volume of tissue collected and the exact site of sampling for individual patients, it was necessary to randomize the tissue sample that was digested. UHMWPE wear debris was isolated from the acetabular tissue using the following method: briefly, 1 g of randomly selected acetabular tissue from each patient was digested with 12 M potassium hydroxide at 60 °C for between two and five days. Lipids were extracted using chloroform : methanol (2 : 1) followed by centrifugation at 2000 g for 10 min. An equal volume of absolute ethanol was added and any remaining contaminating proteins were precipitated with stirring at 4 °C for 24 h. Proteins were removed by centrifugation at 2000 g at 4 °C for 2 h. The resulting supernatant was sequentially filtered through preweighed 10 and 0.1 μm polycarbonate cyclopore membranes (Whatman International Ltd, Maidstone, UK). The filters were dried under infrared lamps for a minimum of 4 h and weighed to determine the mass of UHMWPE wear debris in the two size ranges ( > 10 μm and 0.1–10 μm). A section of each filter was mounted on an aluminum stub and sputter coated with gold for SEM (Hitachi S700, Japan). Polyethylene wear debris was photographed using Agfa APX 400 black and white film and analyzed using Image-Pro Plus (Media Cybernetics, USA).

### 2.5. Quantification of the wear debris

Polyethylene wear debris was quantified as described by Besong *et al*. [15]. Particle size and shape were defined

by length, area, aspect ratio (length/width) and perimeter by image analysis. The experimentally determined masses provided the mass in each size range. The image analysis system provided the two-dimensional size distributions. Combining these two parameters allowed the mass distribution as a function of size to be determined. Initial analysis used an estimate of the total surface area of particles on the 0.1 μm filter, and the mass of debris on the filter to estimate a mean thickness of 0.48 μm of the wear debris. The total number of particles were determined using this mean thickness value, the mean area of the particles, the density of polyethylene and the mass of debris on the filter

$$N = \frac{M}{\rho \bar{A} \bar{t}}$$

Where $N$ is the total number of particles on the filter, $M$ is the mass of debris on the filter, $\rho$ is the density of UHMWPE, $\bar{A}$ is the mean area of the wear particles and $\bar{t}$ is the mean thickness of the particles, based on the area analysis.

In addition, the total number of particles per milligram of wear debris was also determined. Hence for a specimen it was possible to calculate the number and mass distribution of the particles as a function of their size, the number of particles per gram of wet tissue and the number of particles per milligram of wear debris. The wear volume and volumetric wear rate were used to estimate the total number of particles produced over the lifetime of the prosthesis and the number of particles produced per year [16]. It is important to recognize that the number of particles collected per gram of wet tissue is highly dependent on biological variations in the tissue, as 1 g is only a small sample. Biological filtering and removal of particles from the local tissues *in vivo* will also affect the number of particles isolated. In contrast, the cup volumetric wear rate is a direct measurement of wear with the particle mass and size distributions being used to estimate the number of particles per unit volume of wear debris, particle generation rate and the total number of particles produced over the lifetime of the prosthesis.

## 3. Results

### 3.1. Femoral head damage and wear of acetabular cups

Table I shows the mean and ranges of measurements of surface roughness and wear. The mean $R_a$ was 0.38 μm (range 0.01–4.3 μm) and the mean $R_{pm}$ was 0.81 μm (range 0.01–4.1 μm). The mean penetration rate for all 18 cups was 0.17 mm $yr^{-1}$ (range 0.005–0.33 mm $yr^{-1}$). The worn or articulating area of the cups was readily identified with a clear ridge separating the worn and unworn areas. The wear volumes were variable (range 10–1842 $mm^3$) with the mean total wear volume calculated at 785 $mm^3$.

TABLE I Mean and range of measurements of surface roughness and wear

| Measurement | Mean (range) |
|---|---|
| Implant life, years | 12.8 (10–19) |
| $R_a$, μm | 0.38 (0.01–4.3) |
| $R_{pm}$, μm | 0.81 (0.01–4.1) |
| Total penetration, mm | 2.25 (0.05–4.9) |
| Penetration rate, mm $yr^{-1}$ | 0.17 (0.005–0.33) |
| Total wear volume, $mm^3$ | 785 (10–1842) |
| Volumetric wear rate, $mm^3$ $yr^{-1}$ | 59.6 (1–124) |

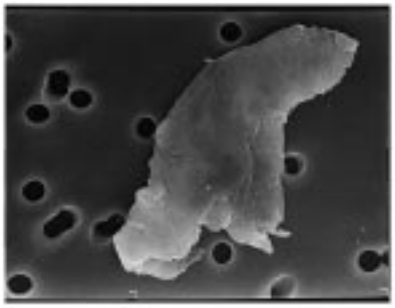
### 3.2. Quantitative isolation of UHMWPE wear debris

The mass of UHMWPE wear debris isolated from 1 g of acetabular tissue varied widely (range 21–1350 μg) as did the proportion of the mass of the wear debris that was smaller than 10 μm (range 18–97%). The majority of the particles isolated were in the size range 0.1–10 μm, although particles up to 1 mm in length were observed. The wear debris existed as discrete particles (Fig. 1a) and as aggregates (Fig. 1b). The majority of the samples contained large platelet-type particles (Fig. 1c and d), which ranged in size from 10 to 100 μm, as well as granules (Fig. 1e) and fibrils (Fig. 1f).

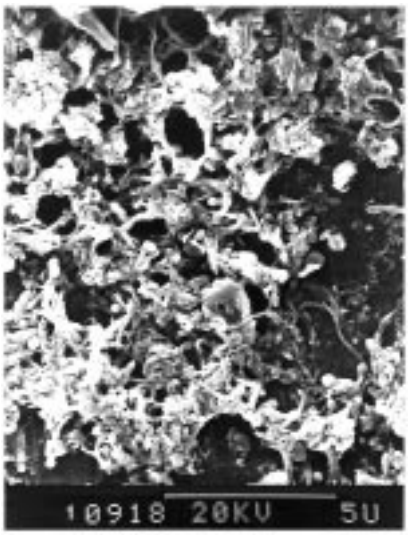
### 3.3. Quantification of the UHMWPE wear debris

The wear particles were characterized using both length (maximum diameter) and area. The mode of the frequency distribution of the particle sizes was in the range 0.1 to 0.5 μm for all patients (Fig. 2). However, analysis of the mass distribution as a function of size revealed that the majority of the mass fell into one of two size ranges, 1.0–5.0 μm (six out of 14 patients) or $> 10$ μm (eight out of 14 patients) (Fig. 3). Analysis of the mass as a function of its size allowed differentiation between the wear debris from different patients (Fig. 3). Analysis of the wear debris by area revealed that the mode of distribution of the particle sizes was in the 0.01–0.1 $\mu m^2$ size range for all patients (Fig. 4). Analysis of the mass distribution by area also differentiated the wear debris from different patients (Fig. 5). The calculated mean aspect ratio (length/width) $\pm$ 95% confidence limits of the wear particles was $2.16 \pm 0.14$ μm (range 1.52–2.47 μm) and 68.7% of the mass of wear debris isolated was smaller than 10 μm. Table II shows the mean numbers of particles determined for all 18 patients. The mean number of particles isolated per gram of tissue digested ($\pm$ 95% confidence limits) was $3.87 \pm 1.99 \times 10^9$. The mean number of particles per milligram of wear debris ($\pm$ 95% confidence limits) was $1.32 \pm 0.51 \times 10^{10}$ (range $1.43 \times 10^9$–$3.75 \times 10^{10}$). The total number of particles generated over the lifetime of the prosthesis was calculated to be $5.68 \pm 2.16 \times 10^{12}$, with the number of particles released per year estimated at $4.31 \pm 1.52 \times 10^{11}$. There was no correlation between the mass of wear debris isolated per gram of tissue and the wear volume, *i.e.* those patients with high wear volumes did not necessarily have higher masses of wear debris in the tissue surrounding the acetabular cup.

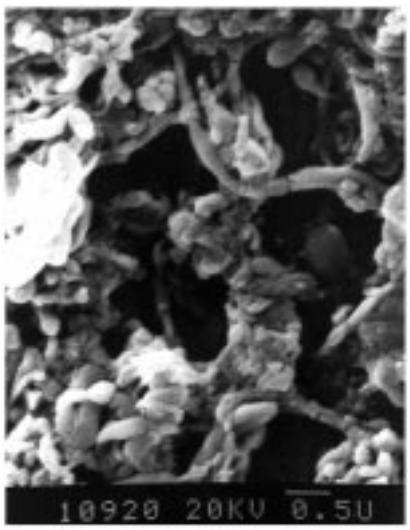

(a)



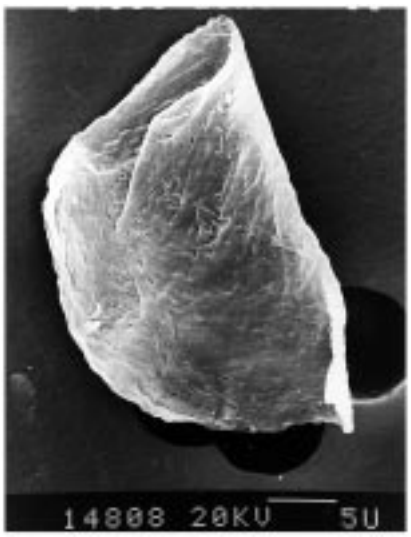
(d)




(b)




(e)

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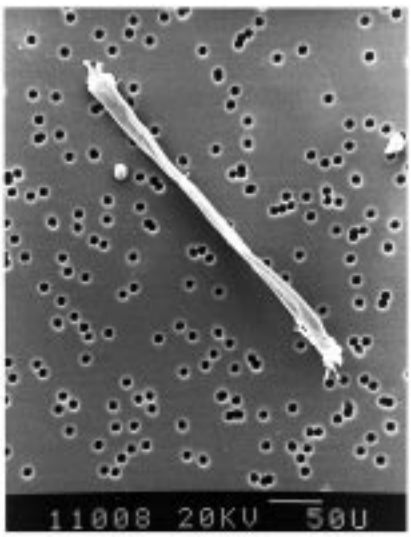


(f)

*Figure 1* Scanning electron micrographs of UHMWPE wear particles isolated from explanted acetabular tissue surrounding Charnley prostheses: (a) discrete particles isolated on a 0.1 μm filter membrane, (b) aggregated particles isolated on a 0.1 μm filter membrane, (c) large platelet-type of particle isolated on a 10 μm filter membrane, (d) large platelet-type of particle isolated on a 10 μm filter membrane ( × 3000), (e) small granule particles isolated on a 0.1 μm filter membrane, (f) large fibril-type particle isolated on a 10 μm filter membrane.

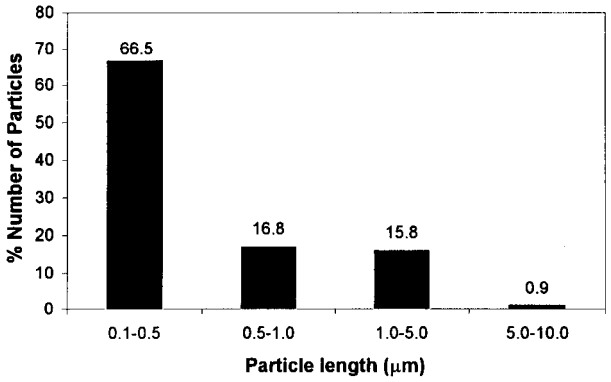


*Figure 2* Percentage distribution of the total number of particles as a function of length. Very few particles were > 10 μm in length and therefore have not been included.

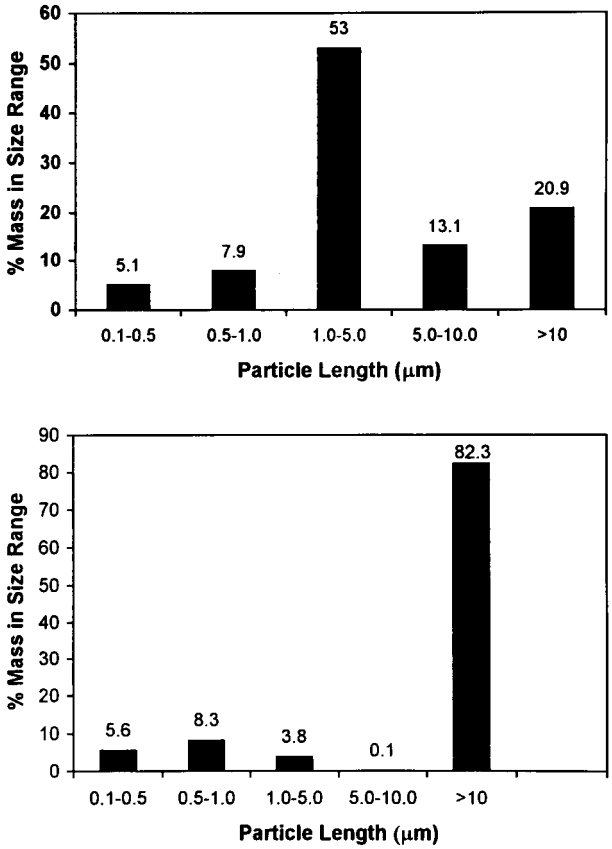


*Figure 3* Mass distributions of UHMWPE wear debris as a function of length for two different patients.

## 3.4. Analysis by head damage

Localized damage to the articulating superior quadrant of the femoral head was quantified using $R_{pm}$, the average height above the mean line of the five highest peaks. The femoral heads were separated into low [$R_{pm} < 0.2\,\mu m$ $(n = 9)$] and high damage [$R_{pm} > 0.2\,\mu m$ $(n = 9)$] groups. The $R_{pm} \pm 95\%$ confidence limit of the high damage group was statistically significantly higher at $1.54 \pm 0.97\,\mu m$ than the $R_{pm}$ of the low damage group, which was $0.07 \pm 0.02\,\mu m$ ($p < 0.05$ student's $t$-test) (Table III). The penetration rate $\pm$ 95% confidence limits of the acetabular cups for the high damage group was $0.22 \pm 0.05\,mm\ yr^{-1}$ while the mean penetration rate $\pm$ 95% confidence limits for the low damage group

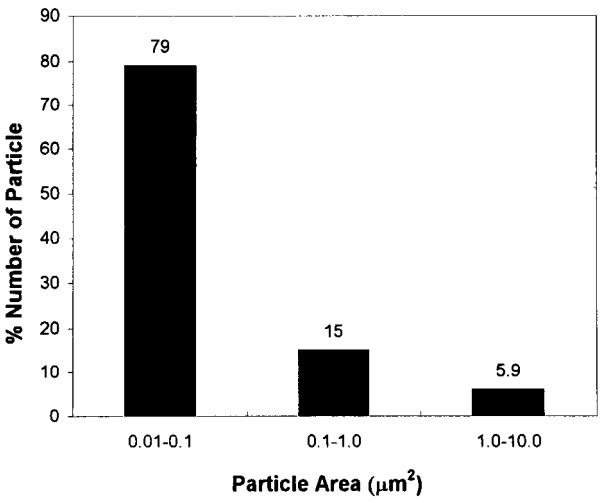


*Figure 4* Percentage distribution of the total number of particles as a function of particle area.

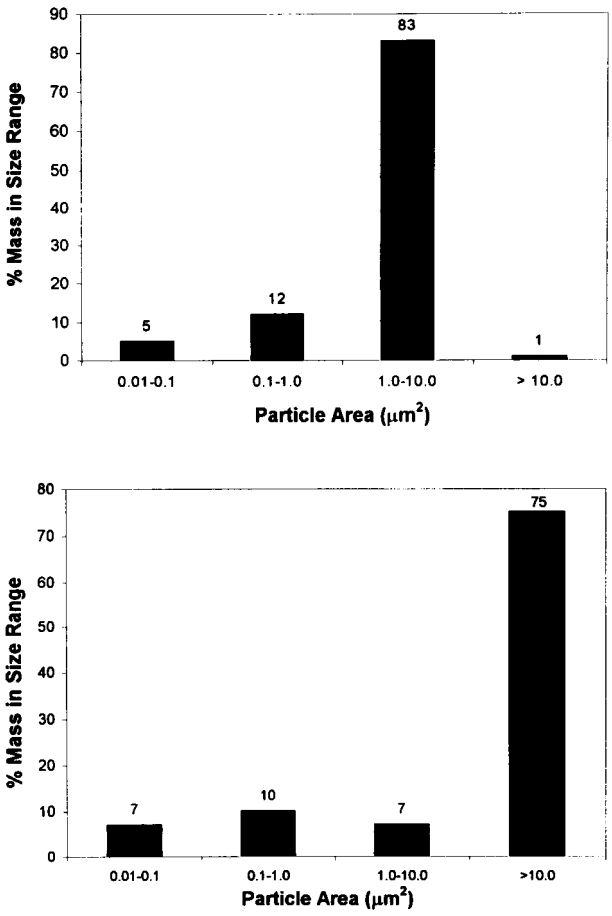


*Figure 5* Percentage of the mass of wear debris as a function of particle area for two different patients.

TABLE II Total number of particles determined for all 18 patients

| Measurement | Mean ± 95% confidence limits |
|---|---|
| Total No. particles/prosthesis lifetime ( × $10^9$) | 5684 ± 2159 |
| No. particles released $yr^{-1}$ ( × $10^9$) | 431 ± 152 |
| Mass particles $g^{-1}$ tissue, μg | 367 ± 151 |
| No. particles $g^{-1}$ tissue ( × $10^9$) | 3.87 ± 1.99 |
| No. particles $mg^{-1}$ wear debris ( × $10^9$) | 13.2 ± 5.13 |
| % Mass < 10 μm | 68.7 ± 10.2 |

TABLE III Mean measurements ± 95% confidence limits (CL) of surface roughness, wear and particle numbers of high and low head damage groups

| Measurement | Low head damage ± 95% CL | High head damage ± 95% CL |
|---|---|---|
| Implant life, years | 13.8 ± 2.16 | 11.9 ± 1.40[a] |
| $R_a$ μm | 0.02 ± 0.005 | 0.74 ± 0.89 |
| $R_{pm}$ μm | 0.07 ± 0.02 | 1.54 ± 0.97[a] |
| Total penetration, mm | 1.94 ± 1.25 | 2.56 ± 0.66 |
| Penetration rate, mm $yr^{-1}$ | 0.13 ± 0.07 | 0.22 ± 0.05[b] |
| Total wear volume, $mm^3$ | 627 ± 424 | 942 ± 258 |
| Volumetric wear rate, $mm^3$ $yr^{-1}$ | 39.5 ± 22.6 | 79.6 ± 21.2[a] |
| Total No. particles per prosthesis lifetime ( × $10^9$) | 4544 ± 3431 | 6824 ± 2608 |
| No. particles released $yr^{-1}$ ( × $10^9$) | 285 ± 183 | 577 ± 212[b] |
| Mass particles $g^{-1}$ tissue, μg | 533 ± 250 | 200 ± 91.7[a] |
| No. particles $g^{-1}$ tissue ( × $10^9$) | 5.94 ± 3.31 | 1.80 ± 1.60[a] |
| No. particles $mg^{-1}$ wear debris ( × $10^9$) | 16.6 ± 9.96 | 9.86 ± 4.97 |
| % Mass < 10 μm | 71.7 ± 15.8 | 65.7 ± 13.5 |

[a]Statistically significantly different ($p<0.05$) (student's $t$-test).
[b]Significant at $p<0.06$ (student's $t$-test).

was 0.13 ± 0.07 mm $yr^{-1}$ (Table III). This difference was significant at the 94% level ($p<0.06$ student's $t$-test). The volumetric wear rate was significantly higher ($p<0.05$ student's $t$-test) in the high head damage group, indicating that head damage was associated with high wear. Although the values for total penetration, total wear volume and the total number of particles released over the lifetime of the prosthesis were higher in the high head damage group, they were not statistically significant. The number of particles released per year were higher in the high head damage group ($p<0.06$). Interestingly, both the mass and number of particles per gram of tissue digested were statistically significantly lower ($p<0.05$ student's $t$-test) in the high head damage group. The number of particles per unit mass of wear debris (milligrams) was also lower (not significant) in the high head damage group. There was an association between the proportion of the wear debris that was smaller than 10 μm and head damage $R_{pm}$ (Fig. 6). When $R_{pm}$ was high a large proportion ( > 60%) of the wear debris was smaller than 10 μm, however, when $R_{pm}$ was low, a large or small proportion of the wear debris was smaller than 10 μm.

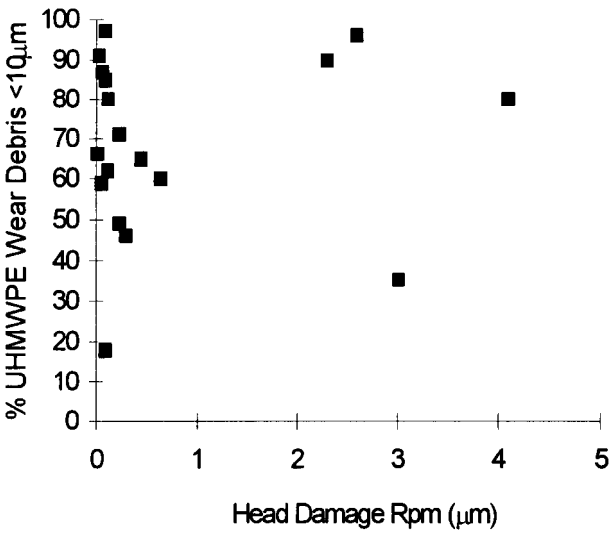


*Figure 6* Percentage of UHMWPE wear debris smaller than 10 μm against head damage $R_{pm}$ for all 18 patients.

## 3.5. Analysis by wear rate

These data could also be split into two groups on the basis of low and high wear using penetration rate. Those with a penetration rate below 0.19 mm $yr^{-1}$ ($n=8$) were classed as having a low wear rate and those with a penetration rate ≥0.19 mm $yr^{-1}$ ($n=10$) were classed as having a high wear rate. The high wear group had higher values of $R_a$ and $R_{pm}$, although these were not statistically significant. The high wear group had significantly higher ($p<0.05$ student's $t$-test) total penetration, penetration rates, wear volumes and volumetric wear rates (Table IV). In addition, the total number of particles released per lifetime and the number of particles released per year were significantly higher ($p<0.05$) in the high wear group. The mass and number of particles isolated per gram of tissue digested were lower in the high wear group indicating that there was no correlation between wear rate and mass of debris per gram of tissue. There was an association between the proportion of wear debris smaller than 10 μm and penetration rate (Fig. 7). At high penetration rates, there was a large proportion ( > 60%) of the wear debris that was smaller than 10 μm in size, however, at low penetration rates a large or small proportion of the wear debris was smaller than 10 μm.

## 4. Discussion

Until recently wear particles in periprosthetic tissues were characterized by histological methods [5]. These techniques were limited as the light microscope can only resolve particles greater than 1 μm in size. Submicrometer-sized particles have been identified in periprosthetic tissues by transmission electron microscopy [5]. However, tissue processing and sectioning may affect the final appearance of these particles. In the past five years, several tissue digestion techniques have been developed [3, 4, 6], which have allowed the isolation of submicrometer-sized UHMWPE wear particles from tissues. However, these methods tended to concentrate on isolating predominantly submicrometer-sized UHMWPE particles. The tissue digestion method reported in this study allowed isolation of all

TABLE IV Mean measurements ± 95% confidence limits (CL) of surface roughness, wear and particle numbers for high and low wear groups

| Measurement | Low wear rate ± 95% CL | High wear rate ± 95% CL |
|---|---|---|
| Implant life, years | 11.9 ± 1.36 | 13.6 ± 2.07 |
| $R_a$ μm | 0.12 ± 0.19 | 0.58 ± 0.82 |
| $R_{pm}$ μm | 0.75 ± 0.88 | 0.85 ± 0.82 |
| Total penetration, mm | 0.84 ± 0.31 | 3.39 ± 0.61[a] |
| Penetration rate, mm $yr^{-1}$ | 0.07 ± 0.03 | 0.25 ± 0.03[a] |
| Total wear volume, $mm^3$ | 261 ± 110 | 1203 ± 200[a] |
| Volumetric wear rate, $mm^3$ $yr^{-1}$ | 22 ± 9.51 | 89.6 ± 12.3[a] |
| Total No. particles per prosthesis lifetime ( × $10^9$) | 1666 ± 1010 | 8897 ± 2303[a] |
| No. particles released $yr^{-1}$ ( × $10^9$) | 150 ± 100 | 656 ± 155[a] |
| Mass particles $g^{-1}$ tissue, μg | 501 ± 291 | 260 ± 120 |
| No. particles $g^{-1}$ tissue ( × $10^9$) | 4.10 ± 4.01 | 3.70 ± 2.85 |
| No. particles $mg^{-1}$ wear debris ( × $10^9$) | 13.7 ± 6.76 | 12.8 ± 9.02 |
| % Mass < 10 μm | 69 ± 20.5 | 68.5 ± 9.39 |

[a]Statistically significantly different ($p < 0.05$) by student's *t*-test.

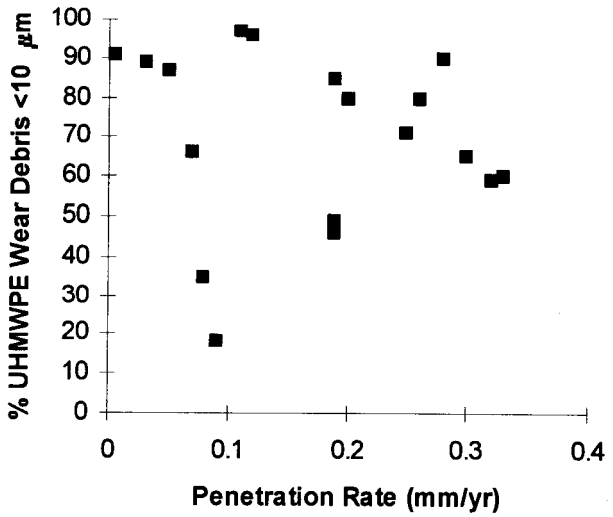


*Figure 7* Percentage of UHMWPE wear debris smaller than 10 μm against penetration rate for all 18 patients.

sizes of UHMWPE wear debris, from 0.1 to > 1000 μm in size. The UHMWPE wear debris isolated using this method was morphologically similar to that isolated in previous studies [3, 4, 6]. The mode of the frequency distribution of the particle sizes was 0.1–0.5 μm, slightly smaller than the 0.2–0.8 μm reported previously [3, 4, 6]. Analysis of the frequency and the mode of particle size distribution were not adequate to differentiate the UHMWPE wear debris isolated from different patients. However, analysis of the UHMWPE wear debris using the mass distribution as a function of size, differentiated the wear debris from different patients, which had similar particle size distributions. This technique allowed differentiation since it took account of the contribution made by the larger debris ( > 10 μm) to the total mass of wear debris isolated. This in turn allowed the quantification of the total number of particles per unit mass of wear debris, which when used in conjunction with the measured wear volumes demonstrated large differences in the total number of particles generated. As mass was used as one of the parameters to quantify the wear debris, the method was sensitive to biological contamination, and therefore careful and complete digestion and removal of all biological material was required. During development of the digestion procedure, contaminating proteins and lipids were observed as a smooth layer blanketing the UHMWPE wear debris. Repeat extractions with chloroform/methanol followed by ethanol precipitation ensured complete removal of these contaminants. As UHMWPE cannot be positively identified by techniques such as energy dispersive analysis of X-rays (EDAX), all filters were inspected closely by SEM to ensure that no contaminating lipids or proteins remained.

The mean penetration rate and volumetric wear rate were consistent with previous data for Charnley explants [17]. High femoral head damage, or high $R_{pm}$ values, were associated with increased total wear volumes, volumetric wear rates, penetration rates and total number of particles generated over the lifetime of the prosthesis. In addition, there was an indication that femoral head damage may influence the size of the UHMWPE wear debris. When the femoral heads were highly damaged ($R_{pm} > 0.2$ μm), a large proportion of the wear debris produced was in the range 0.1–10 μm, which is the biologically active size range [1, 2, 10]. Conversely, the mass and number of particles isolated per gram of tissue were lower in the high head damage and high wear groups. This may indicate that those patients that had high wearing acetabular cups may have cleared the wear particles from the tissue at an increased rate compared with the low wearers. Alternatively, since previous reports suggest that high linear and volumetric wear is associated with the production of a distended fibrous capsule around the acetabular component [18], particles may be less densely distributed throughout the capsule of the high wear group of patients, explaining why fewer particles were isolated per gram of tissue.

Other factors that may influence the total number of particles retrieved from the tissue include the random nature of the tissue sampling technique, variations in the material properties of the UHMWPE, such as oxidative degradation, and patient factors, such as activity and tissue response. The adverse cellular reactions leading to osteolysis are governed by the total mass of the wear particles, the total number of particles and their size distribution. It is therefore critical that all three parameters are considered when evaluating both existing and new or improved bearing materials and designs for artificial joints. This paper quantifies, for the first time, all three parameters *in vivo* by isolating and characterizing all sizes of UHMWPE wear debris from samples of

periprosthetic acetabular tissues, and in conjunction with direct measurements of wear volumes, it has shown a significant increase in the wear particle generation rate with femoral head damage.

The authors are currently analyzing the femoral tissues from these patients, in order to compare UHMWPE wear particle morphology and numbers isolated from different periprosthetic sites within the same patient and prosthesis.

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