# Morphologic characteristics of periprosthetic tissues from hip prostheses with ceramic-ceramic couples

## A comparative histologic investigation of 18 revision and 30 autopsy cases

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**ABSTRACT – Pseudocapsules and interface membranes from 18 revision cases having hip prostheses with ceramic-ceramic couples and 30 autopsy specimens (6 with ceramic-ceramic couples, 7 with ceramic-polyethylene combinations and 17 with metal-polyethylene combinations) were histomorphologically analyzed, including a semiquantitative grading of the wear particles and histologic changes. Unlike the revision cases, which usually showed ceramic wear particles in the adjacent tissues, only half of the autopsy cases revealed ceramic wear. As compared to the ceramic-polyethylene and metal-polyethylene couples, the alumina on alumina combinations showed a thinner synovial layer with reduced villous transformation and smaller infiltrates of macrophages and necroses, which can be explained by the absence of polyethylene wear. Metal-polyethylene couplings produced more than twice as many polyethylene wear particles with correspondingly more marked foreign body reaction than the ceramic-polyethylene couplings.**

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The ceramic-ceramic couple for hip prostheses was introduced by Boutin in 1970 to avoid polyethylene wear. Since then, more than 100,000 ceramic on ceramic implants have been inserted. Numerous simulator tests have shown that the ceramic components have excellent tribological properties, with only minimal ceramic wear during a short period of running in (Boutin and Blanquaert 1981, Willmann 2000).

Good clinical results have been reported after correct positioning and stable insertion (Mittelmeier and Heisel 1992, Heisel and Mittelmeier 1993, Riska 1993, Sedel et al. 1994, Huo et al. 1996). However, massive abrasion of the ceramic components has sometimes occurred, but it has usually been was attributed to incorrect positioning or dislocation after loosening. Unlike numerous experimental wear tests in vitro, only a few histological examinations of the periprosthetic tissues around hip prostheses with ceramic-ceramic couplings have been done (Lerouge et al. 1997).

Our study of revision and autopsy cases aimed to compare the tissue reactions around stable and loose ceramic components and to evaluate differences between the material combinations: ceramic-ceramic, ceramic-polyethylene and metal-polyethylene.

## Material and methods

Tissue specimens from 18 revision cases with ceramic-ceramic couplings, which had been removed because of aseptic loosening, and neocapsules from 6 autopsy specimens were examined histologically, including a semiquantitative grading of wear particles and histologic changes. For comparative purposes, we also performed histological studies of autopsy cases—7 ceramic-polyethylene couples and 17 metal-polyethylene couples.

Table 1. Semiquantitative grading of the wear particles and histologic changes

| Grade | Small granular foreign material [a] particle(s) / macropahge(s) | Polyethylene fragments per HPF [b] | Macrophages Percent extension of the synovial section | Percent villous transformation of the synovial surface | Percent necrotic tissue in the synovial section |
|---|---|---|---|---|---|

### Prostheses and patients

*Ceramic-ceramic couples.* 1 uncemented Mittelmeier prosthesis and 17 cemented revisions (Protasul-Allopro stems with spherical alumina sockets) were studied. The time between the primary operation and loosening was mean 9 (7–16) years. The average age of the patients at the time of the primary operation was 56 (20–77) years.

The 6 autopsy cases had cemented prostheses. The mean time in situ was 8 (7–9) years. All prostheses appeared stable. No radiolucent lines were seen on the radiographs. The patients had an average age of 79 (67—88) years.

*Ceramic-polyethylene couples.* 7 autopsy specimens with ceramic-polyethylene couples (Lübecker GHE-Modell) were studied in the same way. These components were judged to be stable. The time in situ was mean 9 (5–11) years. The patients' average age was 76 (72–80) years.

*Metal-polyethylene couples.* 17 autopsy specimens with metal-polyethylene couples from prostheses of various designs were studied. Mean implant duration was 9 (5–15) years. The patients had an average age of 74 (65–86) years.

### Histologic methods

Tissue specimens from specific locations were preserved during revision surgery or autopsy. In the light microscopic study, serial sections of the tissue fragments of the neocapsules and the soft tissue membranes around loosened sockets and stems of the revision cases were stained with hematoxylin-eosin, Goldner's trichrome and Prussian blue reaction (200 per case).

In the autopsy cases, the thickness of the synovial layer was also measured in the histological sections with an eye-piece graticule. In each section the thickness was measured: 1) at the edge, where the synovium is in contact with the inner rim of the socket adjacent to the prosthetic head (the broadest point), 2) at the insertion at the periphery of the socket rim, 3) at the insertion at the collar of the stem and 4–5) at 2 additional points in the middle between these 3 points. The direction was perpendicular to the peripheral border of the synovium. The measurements were made in 4 sections of each quadrant of the synovium. The mean value was calculated from the 80 measurements per case.

### Semiquantitative grading

The following parameters were classified semiquantitatively into 1 of 5 grades: ceramic and bone cement wear particles, polyethylene wear particles, extension of the infiltrates of macrophages, villous transformation of the synovial surface, and necroses (Table 1).

The ceramic wear particles were identified by their size and their typical sharp-edged configuration. Light microscopically, they appear in the histologic sections as yellow-brown fragments of less than 1 µm up to 5 µm. The zirconium oxide particles (contrast medium of the bone cement), although similar, appear smaller (about 0.5 µm up to 1 μm), and are round. The smallest ceramic fragments can not be distinguished light microscopically from zirconium oxide particles with certainty, but their proportion can be estimated with electron microscopy.

The polyethylene wear particles were identified by their bright birefringence in polarized light together with their characteristic configuration and their translucent appearance on transmission light microscopy. They were measured on photographs of polyethylene fragments in polarized light at high magnification (×1500).

### *Measurements of abrasion*

The abrasion rates of the explanted ceramic components of 5 revision cases and 4 autopsy cases were measured at the CeramTec Company (Plochingen). The amount of wear from the articulating surfaces of the femoral head and acetabular cup was measured by determining the linear deviations from the mean circumference. Standard equipment with a hard pointer on the tip of a stylus touched the surface of the component and was driven over the surface. The points measured were recorded and printed out as a graph. On this graph, the highest value for deviation from the ideal (spherical) circumference was called the “abrasion rate”.

### *Lymph nodes*

All infradiaphragmatic lymph nodes (inguinal, parailiac and paraaortic) were studied in the autopsy cases. 20 sections were cut from each lymph node and stained in the same way as the sections of the neocapsules.

### *Electron microscopy*

Ultra-thin sections were cut from the neocapsule and a lymph node from the autopsy case having the alumina on alumina combination with the largest amount of ceramic wear particles being detected by light microscopy (Mittelmeier prosthesis). Electron microscopy was done to evaluate the range in size and the typical configuration of ceramic wear particles.

### *Statistics*

The Kruskal-Wallis test (non-parametric test for independent samples) was used to detect differences between ceramic-ceramic, ceramic-polyethylene and metal-polyethylene combinations as regards the amount of wear particles, the extension of infiltrates of macrophages, necroses and villous transformation of the neocapsule. The Mann-Whitney U-test was used to compare data from the revision and autopsy cases, and the amount of polyethylene wear particles from ceramic- and metal-polyethylene combinations. The amount of ceramic particles in the periprosthetic tissues and the data from the abrasion measurements were compared with the Spearman rank correlation coefficient.

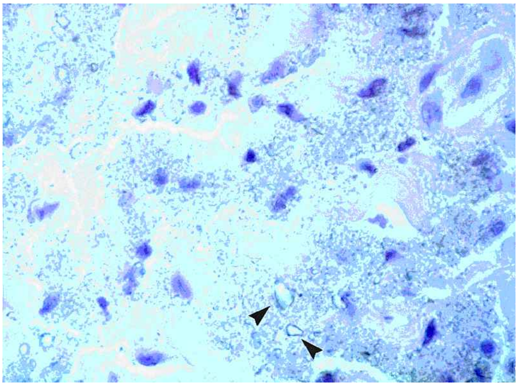

Figure 1. Macrophages with abundant ceramic and bone cement wear particles. Unlike small round zirconium oxide particles, irregularly shaped aluminum oxide wear particles are larger, and range in size from 0.5 μm up to 5 μm (arrow heads) (×470).

## Results

We found ceramic wear particles in all of the 18 neocapsules and interface membranes from loose prostheses with the alumina on alumina combination. Unlike round zirconium oxide particles, the ceramic particles have characteristic sharp edges on light and electron microscopy (Figures 1 and 2). The small granular wear particles were usually found phagocytosed in the cytoplasm of macrophages. After long-term implantation, large infiltrates of macrophages with abundant cytoplasm typify the histologic appearance of the pseudocapsules and interface membranes.

Additional histologic changes included a marked villous transformation of the synovial surface (Figure 3), necroses, scar-like fibrosis and microhemorrhages. All cases with bone cement wear showed degenerative changes in the macrophages leading to single cell necroses. No such changes

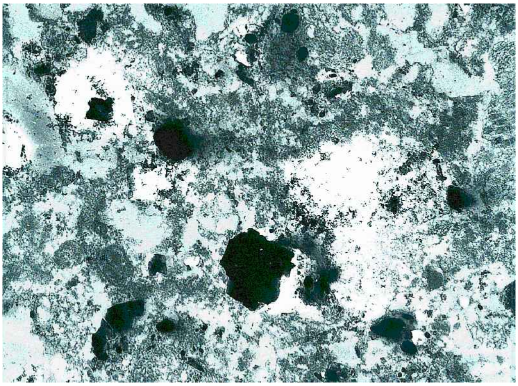

Figure 2. Electron microscopic presentation of ceramic wear particles and zirconium oxide particles. Sharp-edged large ceramic fragments of 0.2 to 0.7 μm and small round contrast medium particles (×17,000).

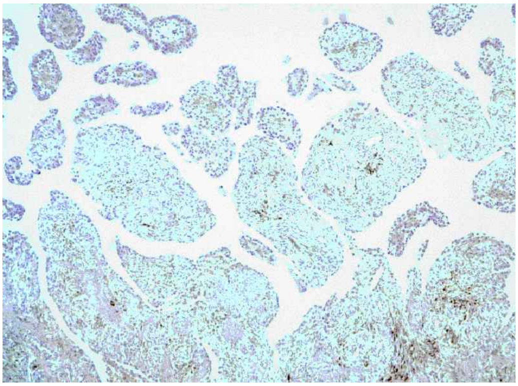

Figure 3. Neosynovialis from a prosthesis with metal-polyethylene couples with marked villous transformation, fibrosis and hemosiderin deposits (HE, ×60).

were found in the single case with a loose uncemented prosthesis with ceramic-ceramic couplings, which showed high-grade ceramic wear. Macrophages mainly having phagocytosed ceramic wear particles seemed smaller than cells mainly having bone cement wear. The smaller diameter of these macrophages may be because the cytoplasm of the bone cement containing cells is extended by large PMMA fragments, which are not visible in paraffin sections (Bos et al. 1990a, Bos and Löhrs 1991).

### Quantitative evaluation (revision cases)

By semiquantitative grading of the wear particles, we found small amounts of ceramic wear (grade 1) in one fourth of the cases, moderate ceramic wear (grades 2–3) in 3 and high-grade ceramic wear (grades 4–5) in more than half of the cases (Table 2). Numerous extensive necroses were seen in half of them. 2 cases, including the uncemented prosthesis had no necroses.

Table 2. 18 revision cases. Grading of the amount of wear particles and histologic changes of neocapsules-values on a scale of 1–5

| Patient | Implant duration (years) | Ceramic wear | Bone cement wear | Macrophages | Villous transformation | Necroses |
|---|---|---|---|---|---|---|
| 1 | 6 | 4 | 0 | 2 | 0 | 2 |
| 2 | 7 | 5 | 1 | 3 | 1 | 2 |
| 3 | 7 | 1 | 4 | 4 | 1 | 2 |
| 4 | 7 | 1 | 4 | 3 | 0 | 1 |
| 5 | 7 | 2 | 1 | 2 | 2 | 4 |
| 6 | 8 | 4 | 3 | 2 | 1 | 2 |
| 7 | 8 | 3 | 4 | 3 | 1 | 2 |
| 8 | 8 | 5 | 1 | 3 | 0 | 5 |
| 9 | 8 | 5 | 4 | 4 | 0 | 5 |
| 10 | 8 | 1 | 4 | 4 | 3 | 3 |
| 11 [a] | 8 | 4 | - | 3 | 4 | 0 |
| 12 | 9 | 1 | 4 | 4 | 3 | 3 |
| 13 | 9 | 2 | 3 | 3 | 3 | 4 |
| 14 | 10 | 5 | 4 | 4 | 4 | 3 |
| 15 | 11 | 5 | 4 | 5 | 4 | 4 |
| 16 | 13 | 5 | 4 | 3 | 0 | 4 |
| 17 | 15 | 1 | 5 | 4 | 2 | 4 |
| 18 | 16 | 5 | 5 | 5 | 3 | 0 |
| Average | 9.2 | 3.3 | 3.2 | 3.4 | 1.8 | 2.8 |

[a] uncemented

### Autopsy cases

Unlike the revision cases, the neocapsules of the 6 autopsy cases had far fewer ceramic wear particles ($p = 0.04$). In 3 cases, no ceramic wear particles were detected; in 2, moderate and in one high-grade ceramic wear was found (Table 4). The ceramic wear particles were located in the pseudocapsules and the interface membranes.

There was no correlation between the amount of ceramic particles in the tissues

**Table 3. Correlation between the amount of ceramic wear particles in the neocapsules and the abrasion measurements. Semiquantitative grading of the wear particles in tissues on a scale of 1–5**

| Patient | Implant duration | Ceramic wear | Maximal abrasion (μm) | |
|---|---|---|---|---|
| | | | head | socket |
| 1 R | 7 | 1 | 15 | 5 |
| 2 R | 7 | 5 | 1300 | 3200 |
| 3 R | 7 | 1 | 5 | 2 |
| 4 R | 8 | 3 | 10 | 5 |
| 5 R [a] | 8 | 4 | 25 | 8 |
| 1 A | 7 | 0 | – | 3 |
| 2 A | 7 | 0 | 15 | 12 |
| 3 A | 8 | 2 | 25 | 3 |
| 4 A | 8 | 3 | 135 | 3 |

[a] uncemented
R revision case, A autopsy case

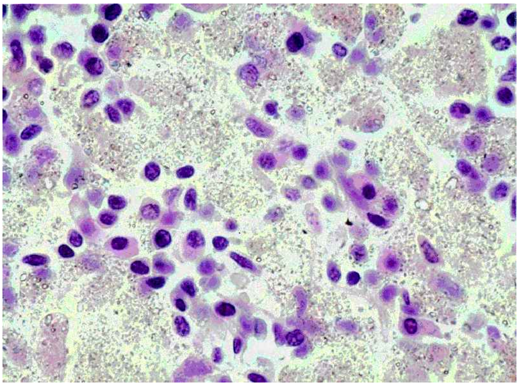

Figure 4. Parailiac lymph node of the autopsy case with high-grade ceramic and bone cement wear. Histiocytic infiltration with large ceramic and abundant contrast medium particles (×700).

and the abrasion measurements of the explanted components (r = 0.65, p = 0.08). The revision case with maximal abrasion, however, had the largest amount of ceramic particles in the periprosthetic tissues (Table 3).

As compared to the revision cases, the resorptive inflammatory and reactive histologic changes, especially the villous transformation of the synovial surface and necroses, seemed less pronounced in the autopsy cases with stable prostheses.

In the infradiaphragmatic lymph nodes of the autopsy case with high-grade ceramic wear, we found infiltrates of macrophages containing ceramic and bone cement wear particles (Figure 4). The other 2 cases with moderate ceramic wear in the pseudocapsules showed minimal amounts of ceramic wear particles in the parailiac lymph nodes. In the other 3 cases, only bone cement particles could be detected.

**Table 4. Autopsy cases. Grading of the amount of wear particles and histologic changes in neocapsules**

| Patient | Implant duration | Ceramic wear | Bone cement wear | Macrophages | Villous transformation | Necroses |
|---|---|---|---|---|---|---|
| 1 | 7 | 0 | 1 | 3 | 1 | 2 |
| 2 | 7 | 0 | 4 | 3 | 0 | 3 |
| 3 | 8 | 0 | 3 | 2 | 2 | 1 |
| 4 | 8 | 2 | 3 | 3 | 0 | 1 |
| 5 | 8 | 3 | 3 | 3 | 0 | 2 |
| 6 | 9 | 4 | 1 | 3 | 2 | 1 |
| Average | 7.8 | 1.5 | 2.5 | 2.8 | 0.8 | 1.7 |

**Table 5. Comparison of the results of the grading of wear particles and histologic changes in autopsy specimens with various combinations of material > 5 years in situ (average values on a scale of 1–5 and ranges)**

| Material combination | Ceramic – ceramic n 6 | Ceramic – polyethylene n 7 | Metal – polyethylene n 17 |
|---|---|---|---|
| Synovial layer (mm) | 2.1 (1.1–2.9) | 2.5 (1.8–3.5) | 3.1 (1.9–5.6) |
| Polyethylene wear | – | 1.2 (1–3) | 2.9 (1–5) |
| Macrophages | 2.8 (2–3) | 3.6 (2–5) | 3.9 (1–5) |
| Villous transformation | 0.8 (0–2) | 2.1 (0–3) | 3.0 (0–5) |
| Necroses | 1.7 (1–3) | 3.7 (3–4) | 4.1 (2–5) |

### *Comparison of ceramic wear couples and other combinations*

The synovial tissue from ceramic-ceramic couples had far less villous transformation grossly and histologically (Figure 5) than the ceramic-polyethylene couples and especially the metal-polyethylene couples (p = 0.006). The

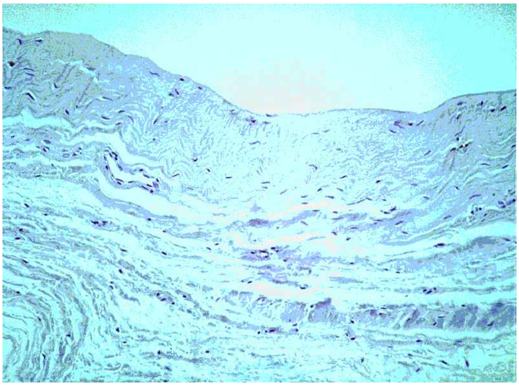

Figure 5. Neocapsule of an autopsy specimen with ceramic-ceramic couple after 8 years in situ without ceramic wear. Smooth synovial surface and moderate fibrosis (×150).

thickness of the synovial layer (p = 0.003), the number of macrophages (p = 0.03) and the extent of necroses (p = 0.001) were also much less than in the metal-polyethylene couples (Table 5).

None of the ceramic-polyethylene couples produced any ceramic wear, but polyethylene wear particles were usually found, at times in large amounts, after long-term implantation. We assessed all autopsy cases with polyethylene sockets more than 5 years in situ, and found moderate (grades 2–3) polyethylene wear in 12 and severe (grades 4–5) in 6 of 24 cases. In contrast to ceramic-polyethylene combinations, metal-polyethylene combinations produced more than twice as many polyethylene wear particles (p = 0.005) (Table 5).

The size of the polyethylene fragments detectable on light microscopy varied between 0.5 μm and 1.5 mm. Unlike the histologic appearance of ceramic-ceramic combinations, the larger polyethylene particles induced a foreign-body reaction rich in foreign-body giant cells.

In contrast to the pseudocapsules, we found only few small polyethylene wear particles in the lymph nodes. These induced phagocytosis by macrophages, but no foreign-body giant cells.

## Discussion

Laboratory tests have shown excellent results with ceramic wear couples. Due to the smooth surface of the polished ceramic components and the high wettability of this material, friction and wear are markedly reduced in comparison to other material combinations (Heimke et al. 1974, Dörre et al. 1975, 1983, Clarke et al. 1988, Clarke 1992, Willmann et al, 1994, Saikko and Pfaff 1998, Willmann and Kramer 1998). Friction in ceramic-ceramic couples is still lower than in ceramic-polyethylene couples. Clarke et al. (1988) found a wear rate 5000 times lower than in metal-polyethylene combinations.

Unlike many reports of good clinical results (Mittelmeier and Harms 1979a,b, Griss and Heimke 1981, Heisel and Schmitt 1987, Mittelmeier and Heisel 1992, Heisel and Mittelmeier 1993, Riska 1993, Sedel et al. 1994, Huo et al. 1996) some authors have described severe wear of the ceramic components from loosened prostheses retrieved at the time of revision surgery (Borssen et al. 1991, Winter et al. 1992, Nevelös et al. 1993).

Plitz et al. (1984) postulated that excessive wear may occur after initial grain excavations from the high gloss polished sliding surface. Other authors ascribe this rare massive abrasion mainly to loosening (Heisel and Schmitt 1987, Böhler et al. 1994). Primary malpositioning of the cup with consecutive dry friction at the socket rim may also cause high-grade ceramic wear (Heisel and Schmitt 1987, Walter 1992). Our findings accord with these observations.

However, retrieval studies are needed to obtain reliable data on tissue reactions to ceramic wear particles. The revision cases do not seem to be appropriate for a comparative study of prostheses with varous material combinations because they mostly undergoe high-grade wear from articulating surfaces and bone cement, partly due to loosening. Up till now, histological examinations of specimens with stable, precisely implanted prostheses with ceramic-couples have not been extensive enough.

In our study, only 3 of 6 stable prostheses showed ceramic wear particles in the periprosthetic tissues after 7–9 years in situ; in 2 cases moderate, in 1 case severe wear. This finding supports the hypothesis that ceramic wear develops at least partly, because of loosening, followed by dislocation of the articular components. Nearly all our cases with severe ceramic wear had large amounts of bone cement particles. It is not yet known whether bone cement wear induces the generation of ceramic wear. Since the ceramic components are much harder than polymethylmethacrylate and zirconium oxide, it is not known whether bone cement particles may act as third bodies and damage the ceramic surface.

Comparison of the histologic changes in autopsy specimens with prostheses having different wear couples showed that the ceramic-ceramic combinations were best. The thickness of the synovial layer in the autopsied cases, the villous transformation of the synovial surface, caused by reactive inflammatory changes, as well as the number of macrophages and the extent of the necroses were markedly reduced around prostheses with ceramic-ceramic couples. We ascribe this to the absence of polyethylene wear, which mainly consists of larger particles causing a more extensive foreign body reaction. In uncemented prostheses, polyethylene debris limits the longevity of implants since it causes osteolysis, thereby accelerating the loosening of prostheses.

The metal-polyethylene couples, which generated more than twice as many polyethylene wear particles as did the ceramic-polyethylene combinations, showed the most marked reactive inflammatory changes in the periprosthetic tissues. These findings correlate well with results of simulator tests, where much less polyethylene wear was also produced by polyethylene sockets articulating against ceramic heads. However, the variations were very great—i.e., ranging between 20 times less (Semlitsch et al. 1977) and only 25% less polyethylene wear particles (Wright and Scales 1980).

When the volumetric wear produced during simulator tests is related to the amount of wear particles in histologic sections of the periprosthetic tissue, it should be noted that some wear particles are transported via lymph vessels to regional lymph nodes, which we also found. It seems likely that the minimal ceramic wear determined with abrasion measurements in 2 autopsy cases could not be detected histologically for this reason. The smaller granular wear particles of ceramic and bone cement are removed by the lymphatics in considerable amounts, but large polyethylene fragments can not enter these vessels (Bos et al. 1990b).

An additional advantage of aluminum oxide ceramic is its high corrosion resistance which, unlike metal alloys, prevents the release of metal ions. Therefore no toxic effects should be expected. In contrast, toxic effects presumably arise from bone cement wear, since it contains toxic residual monomers (Löer et al. 1983), catalysator components (Bösch et al. 1982, 1987) and contrast medium particles (Hopf et al. 1989).

It is noteworthy that the one revision case with an uncemented implanted prosthesis with high-grade ceramic wear showed neither degenerative changes of macrophages nor necroses. This finding may indicate that these changes are caused by phagocytosed bone cement wear particles, while ceramic wear particles have no toxic effects on cells.

In conclusion, prostheses with ceramic-ceramic couples can function in vivo almost without abrasion for 7–9 years. In our cases, far fewer reactive inflammatory changes were seen in the periprosthetic tissue than in combinations with polyethylene sockets.

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