Tissue response to the failed Gerard double-cup

Histologic analysis of 40 uncemented hip arthroplasties

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Femoral head remnants, joint capsules and acetabular membranes were retrieved at revision of 40 failed uncemented, Gerard double-cup hip arthroplasties. All femoral heads were covered with a fibrous membrane containing polyethylene and metal particles, macrophages, and giant cells. The same histopathologic features were found in the joint capsules and acetabular membranes. There was a relationship between the amount of polyethylene particles in the fibrous membrane of the femoral head and the presence of osteonecrosis. Resorption of necrotic bone contributed to failure of the arthroplasty, aided by granulomatous reactions to the wear particles that appeared to induce osteolysis. The overall findings indicate that the severity of the foreign body reaction in periprosthetic tissues is related to the amount of wear particles.

Future designs of resurfacing hip arthroplasties should be focused on wear-resistant material combinations.

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A large femoral head size in resurfacing hip arthroplasties causes great friction and wear of the cup (Ma et al. 1983, Livermore et al. 1990). Theoretically, polyethylene wear in the uncemented Gerard bipolar double-cup arthroplasty could be expected to be less than in other types of resurfacing because motion is distributed to 2 different sliding surfaces: the prosthesis allows motion between components and between component and bone (Gerard 1978). Polyethylene wear would occur only during the initial range of hip movements.

We evaluated the histological significance of polyethylene and metal wear in 40 failed Gerard double-cup hips.

Material and methods

From 1978 to 1991, 260 hips were resurfaced with the Gerard double-cup, consisting of a femoral and acetabular component (Figure 1). The acetabular component is fitted exactly to the reamed acetabulum and free to move in all directions. Most of the movements occur during the initial ranges of motion between the inner and outer cup; the acetabular cup moves only during the extremes of range of motion, i.e., the prosthesis is self-centering.

64 arthroplasties have now been revised; the cumulative success rate after 11 years was only 48 percent. The median interval between the double-cup arthroplasty and the revision was 5 (1–11) years. Sex and age had apparently no effect on success or failure of the arthroplasty. Pain was the main reason for revision. In 16 cases there were no radiographic abnormalities. In 11 cases there was evidence of resorption of the femoral head that appeared as sinking down or varus tilting of the femoral component. In 5 cases the cups did not move properly. In 6 cases there was evidence of protrusion of the outer component. In 1 case a femoral neck fracture was the indication for revision, and in another case a severe heterotopic ossification. There were no infections.

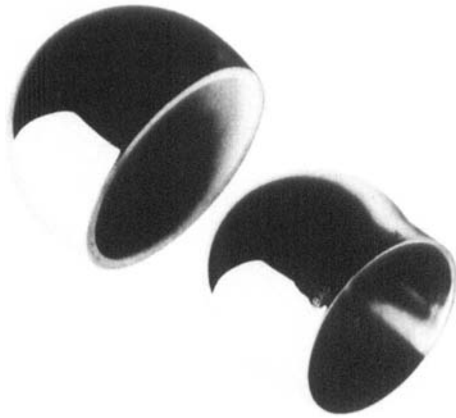

Figure 1. The Gerard double-cup arthroplasty.

Table 1. Observations in 40 failed Gerard double cup arthroplasties

Hip	Interval (months)	Characteristics of femoral head remnants							Histopathology: Capsule				Histopathology: Acetabulum			
		A	B	C	D	E	F	G	D	E	F	G	D	E	F	G
1	17	2	2	3	1	2	1	2	0	1	1	2	0	2	2	2
2	17	2	2	2	2	3	3	2	1	3	3	2	1	3	2	2
3	19	1	2	3	1	2	1	1	1	1	0	1	1	1	1	2
4	30	3	2	3	0	2	1	1	0	0	0	1	1	1	0	1
5	32	1	1	1	1	1	2	2	2	2	3	2	2	2	2	2
6	32	2	1	2	0	2	0	0	0	0	0	0	0	0	0	0
7	33	2	1	1	0	1	0	1	0	0	0	1	1	1	0	1
8	34	1	2	1	1	1	1	1	1	1	1	1	1	2	1	2
9	35	3	2	1	1	2	0	1	1	0	0	1	1	0	0	2
10	37	1	1	1	3	0	0	3	2	1	1	2	1	1	0	1
11	40	3	2	2	0	2	0	0	0	0	0	0	0	0	0	0
12	44	1	2	1	2	1	2	2	1	2	3	3	1	2	2	1
13	45	2	2	2	1	2	1	1	0	1	0	1	1	1	1	1
14	50	1	2	2	0	1	0	0	0	1	0	1	1	2	1	2
15	53	3	2	1	1	2	2	2	1	2	2	3	1	2	2	2
16	58	1	2	1	0	1	0	0	2	2	2	3	2	3	3	2
17	60	3	2	2	0	2	1	0	0	0	0	0	0	0	0	0
18	60	3	1	2	2	3	3	1	2	2	3	2	1	3	3	1
19	61	2	2	2	1	2	2	3	0	1	1	2	1	2	2	2
20	62	2	2	2	1	2	2	2	1	2	2	2	1	2	1	2
21	67	2	2	1	0	2	0	0	0	0	1	1	0	0	1	1
22	68	3	2	2	1	2	1	1	1	2	1	2	1	2	2	2
23	68	2	2	2	2	3	1	3	0	2	0	2	1	2	0	3
24	71	1	2	1	0	0	1	1	1	3	1	3	0	0	0	1
25	73	1	1	2	3	3	2	3	2	2	1	2	2	3	2	3
26	81	3	2	1	0	0	1	1	0	0	1	1	0	0	1	1
27	82	2	2	2	1	3	0	3	1	2	0	2	1	2	1	2
28	83	2	2	2	2	3	2	3	1	1	0	1	1	1	0	1
29	84	1	2	2	1	2	1	2	1	3	2	3	1	2	2	3
30	85	1	2	3	1	1	1	1	1	1	0	1	1	1	0	1
31	89	2	2	2	2	3	2	3	1	2	1	3	1	2	2	3
32	90	1	1	2	1	2	1	3	1	1	0	3	1	1	1	2
33	92	2	2	2	1	2	2	2	1	2	1	2	1	3	2	3
34	95	1	2	1	2	1	0	2	0	1	1	1	0	1	0	1
35	96	3	2	1	1	3	2	2	2	3	3	2	2	2	2	2
36	96	2	2	2	1	3	2	2	1	2	1	2	1	2	1	2
37	101	1	1	1	1	1	1	1	1	2	2	2	1	2	1	2
38	108	1	2	2	2	2	1	2	1	2	1	2	1	2	2	2
39	119	1	2	1	3	2	2	3	2	2	2	2	3	2	2	2
40	121	3	2	2	0	3	2	3	1	3	2	2	1	3	2	2

A Macroscopy of femoral head remnant
- 1 Cylindrical
- 2 Conical
- 3 Stump

B Amount of collagen membrane covering femoral head remnant
- 1 Fully
- 2 Largely

C Osteonecrosis in femoral head remnant
- 1 No or not significant
- 2 Moderate
- 3 Extensive

D Metal particles in high power field (×400; field diameter 0.7 mm)
- 0 No particles observed
- 1 1–25 particles
- 2 26–100 metal particles
- 3 101 or more particles

E Polyethylene particles at high power (×400)
- 0 Absent
- 1 1–15 extracellular particles and/or 1–5 macrophages containing one or more particles per cell
- 2 16–25 extracellular particles and/or 16–25 macrophages containing one or more particles per cell
- 3 26 or more extracellular particles and/or 26 or more macrophages containing one or more particles per cell

F Giant cells in medium power field (×200; field diameter 1.3 mm)
- 0 No giant cells
- 1 1–4 giant cells
- 2 5–10 giant cells
- 3 11 or more giant cells

G Macrophages in high power field
- 0 Absent
- 1 1–10 cells
- 2 11–60 cells
- 3 61 or more cells

During revision, roughening and loss of polyethylene at the edge of the acetabular component were observed. The wear appeared to be caused by impingement of the lengthened cylindrical part of the femoral component on the cup edge. A histopathologic evaluation of specimens retrieved at revision was performed in 40 cases, including 15 cases previously reported (Willems et al. 1988). The form of the femoral head and the amount of the collagen membrane developed at its surface were recorded. The resorption of the femoral head was graded on a 1 to 3 scale (Table 1).

The femoral head remnants were fixed in 4% formaldehyde, sectioned in the coronal plane in 5 mm slices and demineralized in formic acid. After embedding in paraplast, sections were cut and stained with Hematoxylin and Eosin. Specimens of the joint capsule and the connective tissue membrane found in the acetabular cavity after component removal were fixed in 4% formaldehyde and embedded in paraplast without demineralization. Sections 5–7 micrometers thick were also stained with Hematoxylin and Eosin. In some cases an additional biopsy was taken from cavitary lesions of the acetabulum that were filled with granulomatous tissue.

The amounts of polyethylene and metal particles, and the number of giant cells and macrophages were graded in a 0 to 3+ semiquantitative scale according to the number of particles or cells per high-power field up to 400× with a field diameter of 0.7 millimeters (Dorr et al. 1990). Counts were averaged over 5 fields per section. Especially those areas with large concentrations of macrophages, giant cells, polyethylene and metal debris were recorded. The relation between the macroscopic or histologic appearance and the number of polyethylene or metal particles in the tissues around the prosthetic joint was recorded.

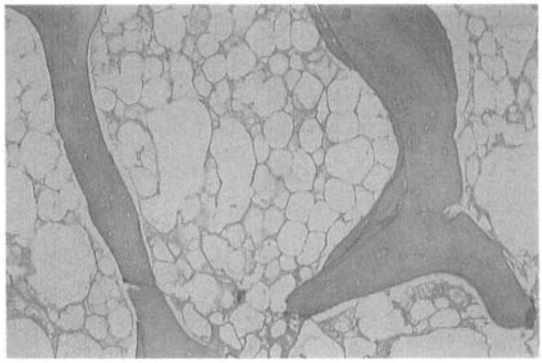

Figure 2. Margin of an area of femoral head osteonecrosis showing necrotic bone and bone marrow necrosis. HE, ×400.

Results

In only 2 cases was the femoral component attached to the femoral head at revision; the other 38 femoral heads rotated easily inside the cup. The gross appearances varied widely from cylindrical heads fitting tightly in the cups to only small nubbles of bone. Only 16 heads had retained a cylindrical shape. The time interval between the primary operation and revision, was not correlated to the amount of bone resorption. All femoral heads, including those with a non-rotating cup, were completely or partially covered by a layer of fibrous tissue with collagen fibers oriented parallel to the surface. This parallel fiber orientation was less marked on femoral heads with major bone loss.

Polyethylene wear products were identified microscopically by their double refraction in polarized light. They were usually surrounded by macrophages and giant cells. Metal appeared as fine, brown-black granules, mostly inside the cytoplasm of macrophages. Metal particles were smaller than polyethylene particles. 37 of the 40 femoral head membranes contained polyethylene and 29 contained metal particles (Table 1). The mean polyethylene score of the collagen membrane on femoral heads that had remained cylindrical was 1.3, that on conical ones 2.4, and on stumps 2.1. For metal particle scores, these averages were 1.4 (cylindrical), 1.1 (conical) and 0.6 (stumps). If no macrophages were found in the membrane of the femoral head, metal particles were also absent. Furthermore, a linear relationship between giant cell formation and presence of metal particles was found. The number of giant cells was also dependent on the size of the polyethylene particles. Small particles were mostly found in the cytoplasm of macrophages. Of the 40 femoral heads, 25 showed osteonecrosis characterized by absence of osteocyte nuclei in large bone areas, often combined with bone marrow necrosis (Figure 2). In 4 cases, the osteonecrosis was massive. This osteonecrosis was often present at the apex of the femoral head, where sclerotic bone was not covered by cartilage or collagen membrane. In some cases with moderate or extensive osteonecrosis, a layer of fibrous tissue separated the necrotic bone marrow from the viable marrow. There was no correlation between the shape of the femoral head remnant and the severity of osteonecrosis. However, the amount of polyethylene particles in the fibrous femoral membrane appeared to be related to the presence of osteonecrosis. In 23 of 25 femoral head remnants with a moderate or extensive osteonecrosis, the amount of polyethylene particles in the membranes was graded 2 or 3+.

All acetabular cups were separated from the acetabular cavity by a smooth membrane which was loosely

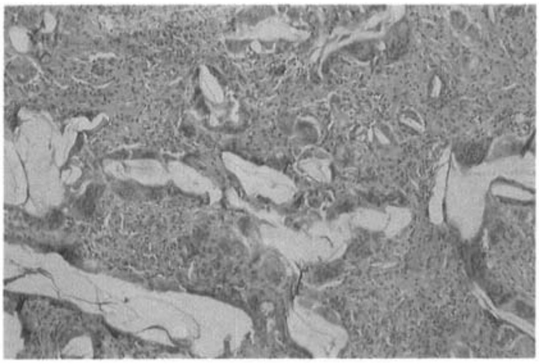

Figure 3. A. Foreign body granuloma in the acetabular membrane. HE, ×400.

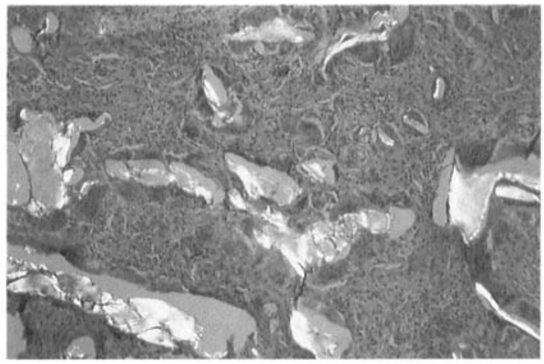

Figure 3. B. Idem under polarized light. There are masses of polyethylene particles visible.

attached to the subchondral bone. The acetabular membrane had a synovial lining along the inner surface of the cup. The underlying layers had various amounts of collagen fibers, giant cells and macrophages. In some cases, the inner zone showed abundant foreign body granulomas, with aggregates of polyethylene particles (Figure 3). These granulomas extended into the marrow spaces of the pelvic bone, where cavitary lesions were filled with sheets of macrophages within a matrix of fibrous tissue and necrotic debris. More or less identical histopathologic features were observed in the joint capsule. Less metal and polyethylene particles were present in the joint capsule and the acetabular membrane than in the fibrous membrane that covered the femoral head. Only 1 case had no polyethylene particles in either the femoral head membrane or joint capsule and acetabular membrane, whereas in 5 specimens no metal particles were found. The mean scores for polyethylene particles in the femoral membrane, joint capsule and acetabular membrane were respectively, 1.9, 1.5 and 1.6. For metal particles these numbers were, respectively, 18 and 19, for macrophages 16 and 18 and for giant cells 10 and

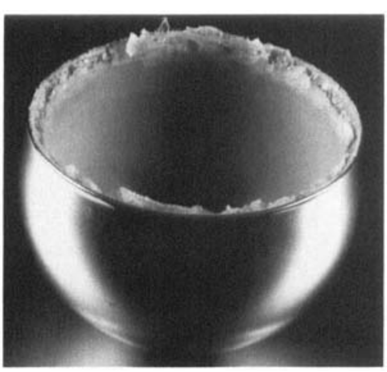

Figure 4. Raised-edge wear of the polyethylene rim of the acetabular component.

28. In 27 of 40 retrieved acetabular components, fragmentation of polyethylene was visible at the edge of the cup (Figure 4). In all of these, polyethylene fragments were present in the femoral and acetabular membranes.

Discussion

There is evidence that release of polyethylene particles may lead to prosthetic failure in the long run (Willert et al. 1990). Although the Gerard prosthesis could be expected to be associated with less wear, polyethylene particles were found in all but one of the 40 failed cases and metal debris in all but 5. Polyethylene and metal particles occurred in all the periprosthetic tissues. The origin of the metal particles could be abrasion of the articulation surface of the outer cup by irregular acetabular bone. That polyethylene particles were found in the collagen membrane on the cylindrical femoral head illustrates that synovial fluid containing polyethylene particles circulated underneath the cup. The presence of macrophages and giant cells in articular connective tissue and bone was related to metal wear particles. In our study, osteonecrosis of the femoral head was related to the amount of polyethylene particles in the femoral membrane. The cause of this association is not clear. In several cases, osteonecrosis was associated with bone resorption causing loosening and failure of prostheses; it might explain the excessive wear of polyethylene and failure of resurfacing hip arthroplasties found in other studies (Bell et al. 1985, Howie et al. 1990, 1991). Bone resorption at the bone prosthesis interface appeared to be caused by foreign-body granulomas at that site. This was particularly suggestive in the acetabular bone. The collagen membrane contained more polyethylene particles in femoral head remnants with massive bone loss than in those with a cylindrical form.

This, however, is inconclusive evidence for the hypothesis that polyethylene particles may cause osteolysis, since these large particles may reach the collagen membrane more easily after bone resorption has made space for larger amounts of synovial fluid. Moreover, a greater amount of small metal particles was found on cylindrical heads than on those with bone loss. The exact effect of these metal particles, most of which were incorporated by macrophages, remains unclear. Little is known about the effect of macrophages around particles. Recent in vitro investigations have shown that abundant particles induce bone resorption by the release of osteolytic mediators (Murray and Rushton 1990). Moreover, metal particles may release toxic metal ions. In this way metal particles could also contribute to osteonecrosis and bone resorption.

Osteonecrosis of the femoral head might also be caused by damage to the lateral epiphyseal vessels at operation. However, in the arthrotic or rheumatoid femoral head, the major route of the blood supply for the bone of the head is derived from the metaphysis or the epiphysis via the intraosseous route.

The large diameter of the femoral component was not the only factor related to polyethylene wear; impingement of the lengthened cylindrical base of the femoral component on the polyethylene edge may be another cause of excessive polyethylene wear. In 92 of 109 retrieved Wagner resurfacing acetabular components, peripheral cup wear caused by impingement of the femoral neck was found (Wiadrowski et al. 1991). The further from the component edge, the less the polyethylene wall thickness was observed. It was suggested that, in future resurfacing, the acetabular components should have less than a hemispheric form to prevent polyethylene wear by impingement. We agree with this view, but a large femoral cup diameter in all types of resurfacing will remain an important factor promoting excessive polyethylene wear. By the use of alternative implant materials with better wear characteristics, a reduction of wear would be expected. Future designs of resurfacing hip arthroplasties should be focused on wear-resistant material combinations.

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