Massive osteolysis induced by high molecular weight polyethylene wear debris

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Summary. *We investigated the mechanism by which particulate wear debris of polyethylene may induce bone resorption using an in vivo model. Two uncemented total hip prostheses, in which the socket was directly in contact with acetabular bone, were selected because there was massive bone loss around the implant. A thick synovium-like layer was found at the polyethylene-bone interface during revision operations. Samples were examined by transmitted and polarised light microscopy, and by transmission electron microscopy. This study demonstrates that polyethylene wear products alone can cause massive osteolysis by triggering the formation of foreign body granuloma at the bone-implant interface.*

Résumé. *Nous avons étudié le méchanisme par lequel les débris de polyéthylène peuvent produire la résorption de l'os, en utilisant un model particulier in vivo. Deux patients traités par protheses de hanche sans ciment, avec cotyle en polyéthylène en contact direct avec l'os, ont été choisis a cause de la présence d'une large érosion au niveau du cotyle. Une membrane pseudo-synoviale, présente entre l'os et le polyéthylène, a été observée pendant la reprise; des échantillons de ce tissu ont été étudiés par microscopie polarisée et par microscopie éléctronique à transmission. Les résultats de cet étude démontrent que les débris du polyéthylène peuvent eux-même produire une large érosion par formation d'une membrane d'interface.*

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Introduction

Improved surgical techniques and the refinement of biomaterials have diminished the occurrence of mechanical failure such as the breakage of prosthetic components and the incidence of postoperative infections. However, the most common complication of all total joint replacements is aseptic loosening of the components [2, 3, 26]. The causes are multifactorial, but the quality of fixation is very important and is often a decisive factor in short and long term failure [5, 14, 18, 22]. In technically satisfactory operations where the components appear stable in radiographs, the loosening may be due to a biological reaction to particulate wear debris which forms at the implant-bone interface [1, 32]. The finding of particulate polymethylmethacrylate in specimens from focal areas of lysis, as well as uniform linear bone resorption in both stable and unstable prostheses, gave rise to the concept of cement-disease [12]. A proposed advantage of uncemented prostheses was that this complication might be eliminated. However, lysis has been reported associated with both stable and loose uncemented components [10, 11, 16, 30]. Particulate cobalt-chrome, titanium alloy and polyethylene wear debris have been observed with loosening and loss of bone stock in total hip replacements without cement [1, 9, 23, 25]. Macrophages, activated by the phagocytosis of particulate wear debris, are the key cells in this process [27]. These cells release factors which can cause osteoclastic bone resorption [4, 6, 21] and may be responsible for radiolucencies or failure of the implant.

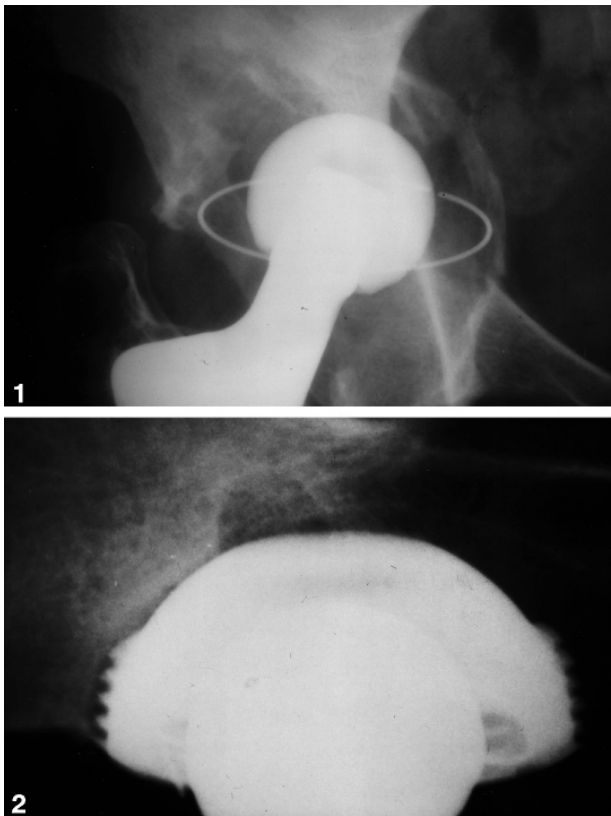This study evaluates the biological host response to a large amount of polyethylene debris in

Fig. 1. *Case 1.* Extensive bone resorption around an uncemented polyethylene acetabular cup

Fig. 2. *Case 2.* Localised osteolysis in the polar zone of the acetabular shell

2 cases of uncemented prostheses where the plastic was in direct contact with acetabular bone.

Patients and methods

Case 1

A woman teacher, 57 years of age, was 168 cm tall and weighed 70 kg. A total hip replacement was carried out for primary osteoarthrosis of the right hip in 1991. The socket was an all polyethylene cup positioned directly in the bony bed of the acetabulum; the femoral stem was of cobalt-chrome with a 32 mm diameter head and was fixed without cement (Fig. 1). She was seen 3 years later with progressive pain on weight-bearing and at rest in the hip.

Case 2

A retired man, 62 years of age, was 175 cm tall and weighed 81 kg. An uncemented total hip replacement was carried out in 1989 for severe osteoarthrosis of the right hip. The socket was a titanium shell in which a large polar hole allowed direct contact of the polyethylene liner with bone. The femoral stem was titanium with a 32 mm diameter head (Fig. 2). He was seen in 1993 because of progressive loss of function and pain on weightbearing in the right hip.

Radiographs in both cases showed severe loss of acetabular bone, but no evidence of femoral loosening. At revision in each case, a cemented acetabular socket was inserted supplemented by reconstruction with autologous grafts. The postoperative course was smooth in both patients and the functional results were satisfactory.

At the operations, we found a thick membrane (5 mm in one, 2 mm in the other) at the polyethylene-bone interface, and this was removed. Specimens of this tissue were fixed in 10% formalin, embedded in paraffin, cut in 3 μ to 5 μ sections and stained with haematoxylin-eosin, Masson trichromic and oil red O [24]. They were examined by plain and polarised light microscopy. Other samples were fixed in 2% glutaraldehyde, postfixed in osmium tetroxide, dehydrated in ethanol, Epon embedded and stained with uranile acetate and lead citrate for examination with transmission electron microscopy (TEM).

The removed sockets, after ultrasonographic washing, were coated with colloidal gold, stuck onto a metal support with electroconductive silver paste and were examined by scanning electron microscopy (SEM) to analyse the polyethylene surface where it had fretted against bone.

Results

Histological examination of the membrane obtained from the polyethylene-bone interface showed a synovium-like appearance (Fig. 3) [7]. The membrane formed, towards the polyethylene surface, large papillary folds which were divided into 3 distinct zones: a layer of giant cells lining the external surface (Fig. 4a); a sheet of mononuclear histiocyte-like cells in the middle substance, and bi- and trinuclear cells in the midportion (Fig. 5a). Several polyethylene fragments were identified by polarised light microscopy in the cytoplasm of macrophages and the stroma. The fragments showed a wide variation in size, from less than 1 μm to more than 100 μm, and shape. The largest fragments of polyethylene debris were found in the interstitial part of the external membrane and were surrounded by giant cells forming body granuloma (Fig. 4b), while large but phagocytable fragments were seen in the cytoplasm of single polynuclear cells in the same surface zone. The underlying oligonuclear histiocytes contained multiple refractive particles. Diffuse birefringence was seen with polarised light microscopy in the cytoplasm of polygonal mononuclear cells in the middle zone (Fig. 5b). The cytoplasm of these histiocytes appeared intensely red when stained with oil-red-O, but the reason for the specificity of the stain for polyethylene activated histiocytes is not clear [24].

Analysis of selected sections by TEM confirmed the presence of polyethylene debris of less than 1 mm in length lying within the histiocytes (Fig. 6). The polyethylene particles phagocytosed

3a

3b

4a

4b

5a

5b

6

7
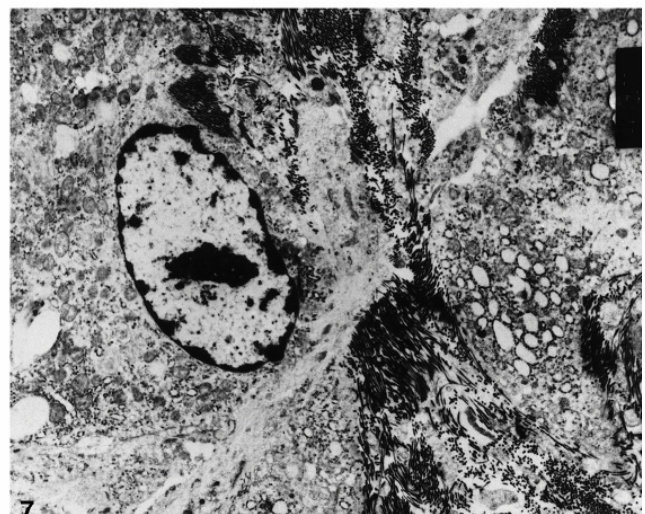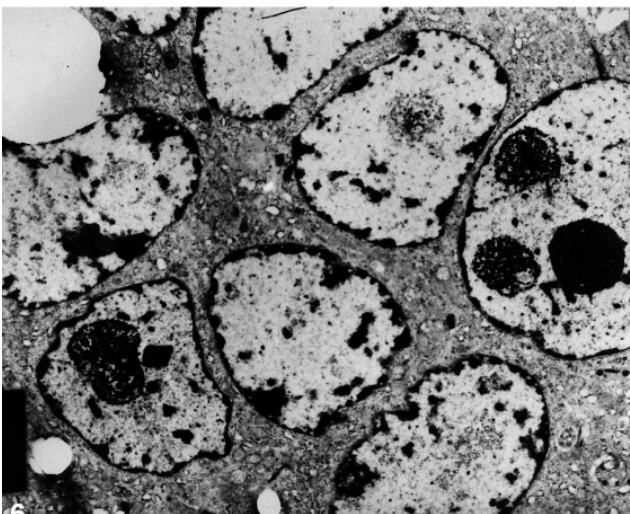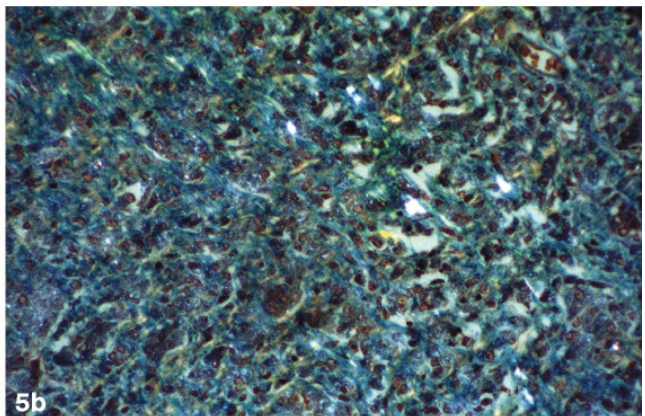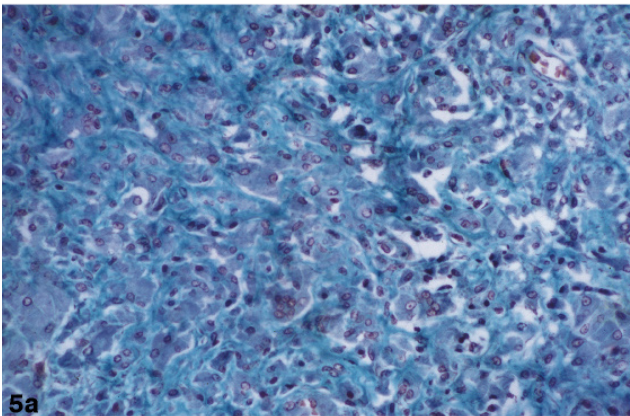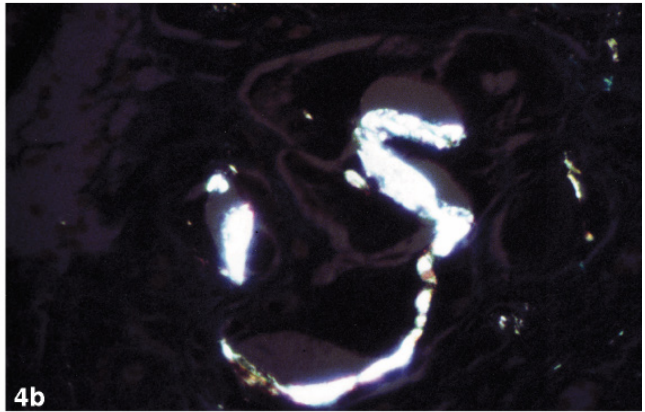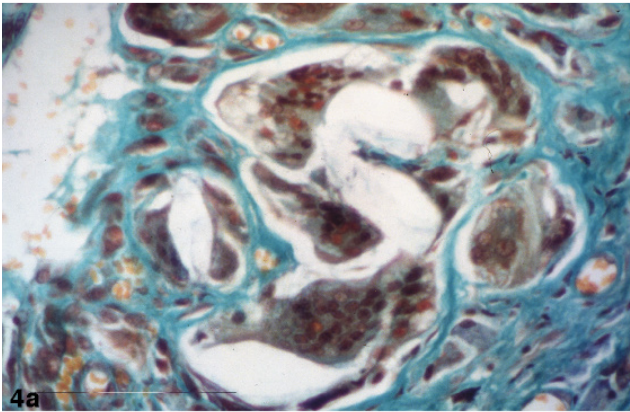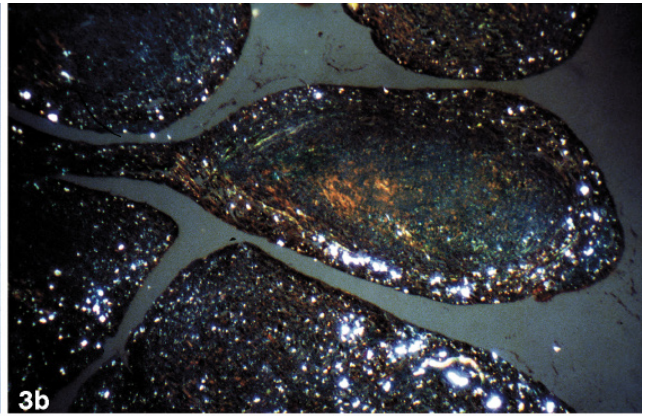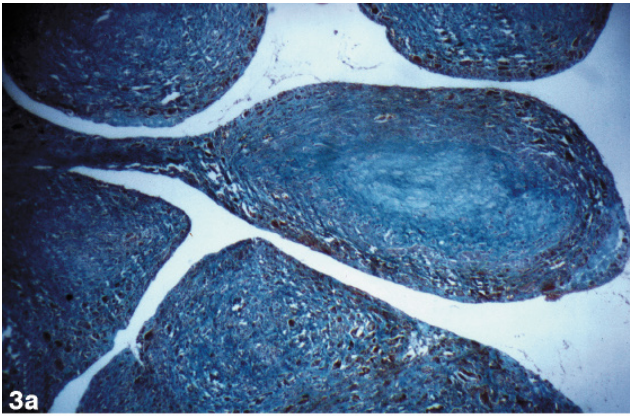
by macrophages appeared like intracytoplasmic, oval, granular, electron-lucent zones (Fig. 7).

The extensive wear of the sockets by abrasion at the polyethylene-bone interface was evaluated by SEM.

Discussion

An important cause of prosthetic loosening is bone resorption resulting from the interaction of particulate debris of polymethylmethacrylate, polyethylene or metal with bone around implant surfaces [1, 5, 14, 15].

The loosening in our 2 cases was due to primary acetabular bone-polyethylene socket contact in the absence of cement. This caused fretting at the interface producing a high rate of release of polyethylene debris. Massive osteolysis was seen after a short period with the formation of a synovium-like membrane at the interface which is the expression of a severe inflammatory reaction to the wear debris causing local necrosis and granulomatosis [17]. An immunological host response to the debris is shown by the disposition of typical zonal cells with a different macrophage reaction to the presence of polyethylene debris of varying size and shape [27].

Very small particles were phagocytosed by mononuclear cells, while larger particles induced a granulomatous reaction with giant pluri-nuclear cells which are unable to remove the polyethylene fragments; they therefore induce bone resorption by different molecular mediators which are able to increase osteoclastic differentiation and activity by the production of prostaglandin E_2, interleukin 1,

interleukin 6 and tumour necrosis factor α [4, 6, 31].

We have demonstrated that massive osteolysis around prosthetic components can be induced by an immunological host response to polyethylene wear debris at the component-bone interface. Macrophage differentiation and activity is related to the rate of debris formation and the size of the particles [19, 28]. A high rate of wear can induce a host response forming an appearance like a tumour [26, 29].

Polyethylene debris plays a crucial role in producing bone loss which varies from radiolucent lines to massive osteolysis [28, 32]. The extent of osteolysis is correlated with a high rate of wear, age, gender, weight, activity and the thickness of the polyethylene are not relevant [22]. In our cases wear was related to abnormal contact between polyethylene and a rough bony surface, although other factors may be responsible [2]. Failure of the replacement, age, weight and activity can influence when this phenomenon develops. An individual's sensitivity to polyethylene may also play a role.

Fig. 3. a The appearance of the interface membrane is similar to synovium. **b** Polyethylene debris are shown by polarised light

Fig. 4. a Giant plurinuclear cells are frequently found in the superficial layer. **b** They form foreign body granuloma around the largest polyethylene debris

Fig. 5. a A large number of mono- or oligonuclear histiocytic cells are seen in the more central zone of the villi. **b** Polarised light shows small fragments of polyethylene

Fig. 6. Electrolucent areas of varying size are seen among the giant cell nuclei corresponding to the voids left by the polyethylene particles removed when the specimen was prepared (TEM)

Fig. 7. TEM shows a large number of polyethylene particles, smaller than 1 μm, in intraplasmic organelles in the periphery of mononuclear histiocytes

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