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The bone-cement interface in hip arthroplasty

A histologic and enzyme study of stable components

Thirteen patients were reoperated on because of a nonseptic complication of their cemented hip replacement. In each patient, one of the two components was stable, and biopsies from this bone-cement interface were obtained for histologic and enzyme histochemical studies. Microscopy revealed a spectrum of tissue reactions, ranging from a seemingly direct bone-cement contact to a fibrous membrane, up to 1.5 mm thick. The bone necrosis incurred at the primary operation had been largely resorbed and replaced by viable bone.

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It is generally accepted that after implantation of a cemented joint prosthesis the bone cement rests on a zone of dead bone that after a period of time is usually replaced by a soft-tissue membrane (Lee & Ling 1984). It has been debated why this membrane remains thin and nonprogressive in some patients and widens to the point of prosthetic loosening in others. Moreover, in recent years the existence of a membrane as a general phenomenon has been questioned (Charnley 1979, Linder & Hansson 1983).

The aim of our study was to define the type and viability of the tissue at the interface in stable, cemented total hips using histologic and enzyme histochemical methods.

Patients and methods

Thirteen nonrheumatoid patients had their hip revised because of nonseptic complications following total hip replacement (Table 1). In each patient, one of the prosthetic components was stable, and tissue biopsies were obtained from the bone-cement interface of this component. Prosthetic stability was defined as intraoperative macroscopic stability and the absence of radiographic signs of instability, such as migration or progressive radiolucent lines at the bone-cement or component-cement interfaces.

Laboratory data. Preoperative laboratory tests--including ESR, CRP, electrophoresis, and WBC counts--were within normal limits. The absence of infection was verified by multiple negative aerobic and anaerobic cultures of tissue biopsies obtained intraoperatively according to Kamme & Lindberg (1981).

Radiography and scintigraphy. The acetabular biopsy sites had radiolucent lines ranging from 1 mm (Cases 10 and 13) to 1.5 mm (Case 12). None of the femoral biopsy sites had a radiolucency exceeding 0.5 mm, and 4 cases had no radiolucency. ^{99m}Technetium methyldiphosphonate scintigrams were available except in Cases 1, 7, and 13; in 6 cases there was normal activity at the biopsy site and in 4, a slight increase in activity (Cases 3, 4, 10, and 12).

Biopsies. One to three 0.5-1 cm x 1-2 cm biopsies were taken from either the acetabulum or the femur. The total number of technically acceptable biopsies was 22--five from the acetabulum and 17 from the femur.

In the acetabulum the biopsies were taken after the socket and the cement had been removed; in the femur an anterior or a posterior slot was made between 3 cm and 10 cm below the transection of the femoral neck, and from this site, bone and attached cement were retrieved in one piece. In Case 4, the biopsy was taken at the level of the distal, stable part of the stem.

Each biopsy was immediately transferred to a transport medium (Histocon®, Histo-Lab., Göteborg, Sweden) at 4°C. This medium is specially prepared to preserve tissue for histochemical purposes, permitting a delay in tissue preparation of at least 24 hours at 4°C. Within this time, all the biopsy specimens arrived at the laboratory (Department of Oral Pathology, University of Göteborg, Sweden).

In the laboratory the biopsies were divided into smaller pieces; the bone cement was carefully removed from the femoral biopsies, and the specimens were put into 10 per cent EDTA (pH 6.95) at 4°C for decalcification. After decalcification, the specimens

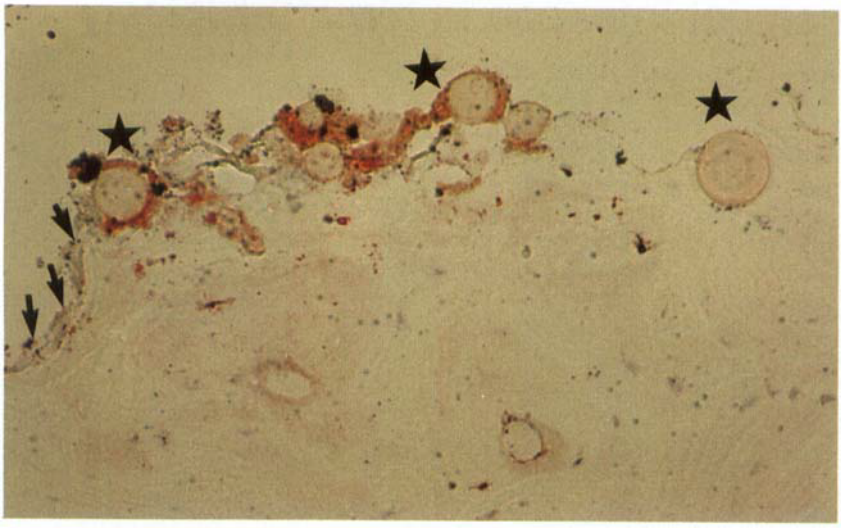

Figure 1. Remnants of bone cement (*) still attached to the bone surface after the main cement was removed. There is no soft tissue between the single sphere and the bone surface. Observe that quite close to this spot there are foreign-body giant cells contacting the cement surface (arrows). (Oil red O × 210).

were frozen in isopenthane chilled to -140°C with liquid nitrogen. They were then stored at -70°C until serially sectioned at 5 μm in a cryostat kept at -20°C. The sections were mounted on glass slides and stained for histologic studies with hematoxylin-eosin, van Gieson, and Oil red O. Also, the sections were processed for the enzyme histochemical determination of the activity of $NADH_2$-diaphorase, ATPase, and acid and alkaline phosphatases (for details, see Linder et al. 1983).

Wear particles of bone cement, socket plastic, and metal were classified and quantified according to Mirra et al. (1976)

Results

All the acetabular biopsies and the majority of the femoral biopsies revealed a fibrous membrane between the bone and the cement. In Cases 5, 6, and 9, the membrane was extremely thin, and in some of the tissue sections it appeared to be interrupted by bone extending to the cement surface in a manner described earlier by Linder & Hansson (1983). In one case (No. 3) a piece of bone cement, which had broken off when cement was being re-

Table 1. Patient material

Patient no.	Sex	Age at primary surgery	Diagnosis[a]	Duration of service (yrs)	Prosthesis[b]	Reason for revision	Biopsy site[c]
1	F	74	FNF	1	C	Dislocations	F
2	F	55	OA	8	C	Socket migration	F
3	M	58	OA	6	B	Socket loosening	F
4	M	58	OA	11	C	Stem fracture	F
5	M	29	Perthes	6	B	Socket loosening	F
6	M	34	CDH	5	B	Socket loosening	F
7	F	35	OA	13	C	Dislocations	F
8	F	49	CDH	2	Ch	Socket loosening	F
9	F	75	OA	4	L	Unexplained pain	F
10	F	55	OA	3	M	Dislocations	A
11	F	63	OA	5	C	Dislocations	F
12	M	60	OA	3	C	Unexplained pain	A
13	M	54	OA	1	Ch	Femoral fracture	A

[a]FNF, femoral neck fracture; OA, osteoarthrosis; CDH, congenital dislocation of the hip.
[b]B, Brunswik; C, Charnley; Ch, Christiansen; L, Lubinus; M, McKee-Farrar.
[c]F, femur; A, acetabulum.

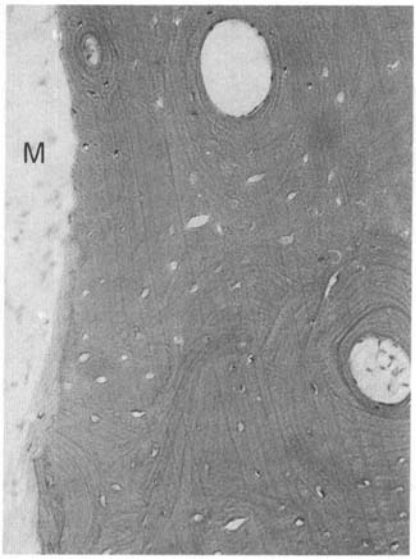

Figure 2

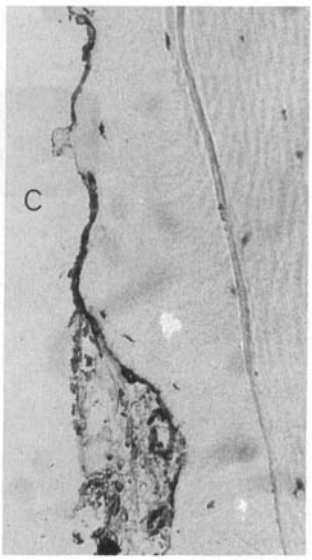

Figure 3

Figure 2. Lamellar bone in the endosteal part of the femur. An area with empty osteocyte lacunae is traversed by new osteons with concentrically arranged lamellae and filled lacunae, indicating revascularization of dead bone. The basal part of the soft-tissue membrane is also seen (M). (Hematoxylin-eosin, × 190).

Figure 3. Bone surface, possibly covered by an extremely thin membrane, showing overt $NADH_2$-diaphorase activity. Cement (C). (× 500).

moved, remained attached to the bone surface without interposed soft tissue (Figure 1). There was no apparent correlation between degree of tissue reaction and length of observation time.

Particles of socket polyethylene or polyacetal were identified by their birefringence in polarized light. They were all of the small particle size (<100 μm). They were seen in 2 of 13 cases (both Christiansen prostheses) and only rarely were there more than five particles per high power field. Cement flakes were easily detected; they were present in 5 of 13 cases and the amount was rated +. Metallic granules were seen inside macrophages in 6 of 13 cases – 4 of which were rated + and 2, ++.

Bone histology. In the acetabulum the trabeculae were thickened adjacent to the membrane at the cement surface, often creating a continuous lamella of bone. In the femur the bone appeared to be porotic in the interface region. In the femoral cortex there were areas with empty osteocyte lacunae within the lamellar bone, but such areas were always traversed by newly formed osteons (Figure 2). These areas are indicative of revascularization of necrotic bone. In the cancellous bone of the acetabulum, areas of residual necrosis were rarely found.

Enzyme histochemistry of bone. The enzyme pattern parallelled the histologic appearance. Thus, in the cases where the histology showed empty osteocyte lacunae, there was no $NADH_2$-diaphorase activity – an enzyme used to assess aerobic metabolism. In general, however, most of the bone had marked $NADH_2$-diaphorase activity. This was also true of the bone closest to the cement surface, even in those cases where the membrane appeared to be absent (Figure 3). Thus, there was no indication that the absence of a membrane implied that the cement rested on necrotic bone.

Both ATPase activity and alkaline phosphatase activity were present in the marrow spaces, indicating osteoblastic activity. Acid phosphatase activity – a marker of macrophages, foreign-body giant cells, and osteoclasts – was observed in the marrow spaces closest to the interface region, but the activity was not pronounced. The activity also decreased with increasing distance from the cement.

Histology of the soft-tissue membrane. In the acetabulum the membranes were thicker than in the femur. In both instances the greater part of the membranes consisted of dense fibrous tissue without much cell infiltration. This type of tissue was usually found in the middle part of the membranes. Towards the cement surface, there was an increasing number of macrophages and foreign-body giant cells; and towards the bone, there was unspecific

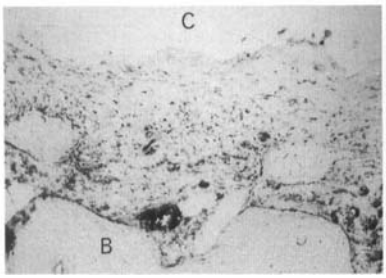

Figure 4

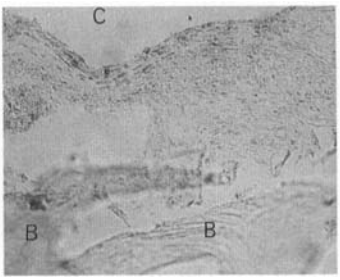

Figure 5

Figure 4. Soft-tissue membrane showing $NADH_2$-diaphorase activity throughout, but also a relatively mild cellular infiltration. Bone (B) Cement (C). (× 90).

Figure 5. The membrane from the same case as in Figure 4, showing acid phosphatase activity predominantly in scattered cells at the cement surface. Occasional cells in the basal part of the membrane also show acid phosphatase activity. Bone (B). Cement (C). (× 225).

granulation tissue with increased cellularity (fibroblasts, macrophages, and round cells) and vascularity. At the border of bone and soft tissue, bone formation and bone resorption occurred simultaneously.

Enzyme histochemistry of the soft-tissue membrane. No necrotic areas were seen; all the membranes displayed overt $NADH_2$-diaphorase activity and ATPase activity, but no alkaline phosphatase activity (Figure 4). Acid phosphatase activity was weak, but present in the superficial and basal parts of the membranes and absent in the areas with dense fibrous tissue (Figure 5). Even in the cases where the membrane was extremely thin or appeared to be absent, acid phosphatase activity was observed in the soft tissue adjacent to the points of intimate bone-cement contact (Figure 6).

Discussion

Enzyme histochemistry is considered superior to histology in assessing tissue viability (Eriksson et al. 1984) and has been used by us in a previous study of loosened cemented prostheses (Linder et al. 1983). In that study, we used $NADH_2$-diaphorase activity to verify oxidative enzyme activity, ATPase to depict endothelial cell activity, alkaline phosphatase to show osteoblastic activity, and acid phosphatase to demonstrate macrophages, foreign-body giant cells, and osteoclasts.

In the present study the location of the various kinds of enzyme activity was similar to that found around loosened prostheses. Thus, the bone and the soft-tissue membrane were viable. Acid phosphatase activity was found in all the membranes, indicating the presence of macrophages or foreign-body giant cells, although the activity was clearly less prominent than in prosthetic loosening.

It is evident that what is considered clinically as prosthetic stability is, in fact, represented histologically by a spectrum of tissue reactions, ranging from a seemingly direct bone-cement contact to a membrane that is up to 1–1.5 mm thick. These demonstrable tissue reactions, then, actually reflect varying degrees of microinstability. Whether such microinstability also entails a risk of progressive insta-

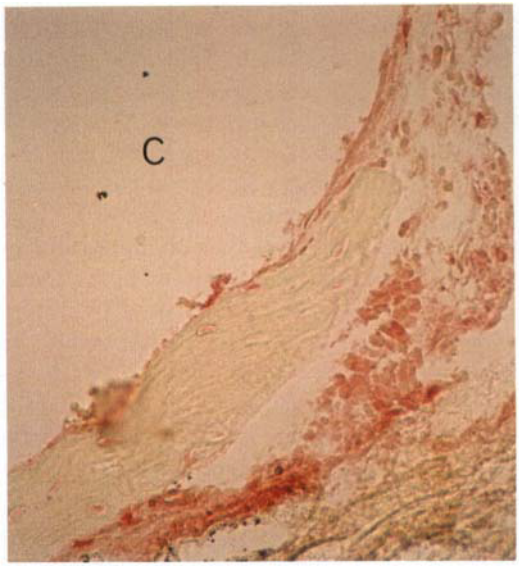

Figure 6. A case of very intimate bone-cement contact, indicating a very high degree of prosthetic stability even at this level of resolution. There is normal background activity of acid phosphatase; but in the soft tissue adjacent to the cement (C), there are scattered cells with high acid phosphatase activity (× 250).

bility is not known yet. According to Delling et al. (1984), no systematic changes in the histologic appearance can be seen with the passage of time, and the present limited material would support this view.

It should be emphasized that our material in some respects differed from present-day conditions: components were clinically stable, whereas the interfaces were not all radiographically perfect. All the primary operations were performed before 1980, a period during which the current cementing techniques – such as using lavage, intramedullary plugging or retrograde cement filling – were not practiced. It is possible that in our material the membranes had formed because of suboptimal primary mechanical stability, and that with current cementing techniques membrane formation can more often be avoided, as suggested by animal experiments (O'Carrol et al. 1985, Paul & Bargar 1985). We cannot exclude this possibility, because there was no evidence that the bone cement itself inhibited bone formation at the interface.

The basic mechanism behind the formation of a membrane is not fully understood. One prevalent hypothesis is that the membrane is due to resorption of bone, necrotized at the operation, notably by the heat of the polymerizing cement (Freeman et al. 1982, Mjöberg et al. 1984). Our present study does not support the view that the membrane forms merely because the bone has been necrotized during surgery, for we had cases in which new bone regenerated directly on the surface of the cement. More truly, the finding of necrotic islands of bone within the femoral cortex suggests that the bone necrosis caused during primary surgery (not necessarily by the polymerization heat alone) was gradually replaced by new bone. This would accord with findings in animal investigations (Harms et al. 1974).

The presence of macrophages at the interface has always been considered an ominous sign with regard to long-term prosthetic anchorage, and it has been suggested by Freeman et al. (1982) that the bone cement itself attracts macrophages. In our present study, as well as in our previous study (Linder & Hansson 1983), macrophages were found on the cement surface even in cases where there was direct bone-cement contact in some areas along the interface. A possible explanation of this is that the macrophages are in some way associated with the physicochemical characteristics of the cement surface and that the presence of macrophages per se does not lead to bone resorption and membrane formation unless the macrophages are activated by some other factor or factors.

Debris of cement, metal, and socket plastic was present in only limited amounts in the membranes. Another noteworthy finding was that no socket wear particles were observed in the prostheses with the longest follow-up times. It is possible that prosthetic stability represents a biologic barrier to the spread of particulate wear from the joint cavity.

The occasional finding of direct bone-cement contact and the absence of an obvious acceleration of the tissue reaction with time are positive features in our material. These findings offer hope for the future of cement fixation, but also emphasize the importance of a standardized and unbiased histologic comparison of the tissue differentiation around cemented and uncemented prostheses using optimal techniques. Such studies would greatly improve our understanding of the long-term behaviour of artificial joints.

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