ULTRASTRUCTURAL ASPECTS OF THE INTERFACE BETWEEN BONE AND CEMENT IN MAN

REPORT OF THREE CASES

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An extremely strong mechanical bond between cement and bone was observed in three patients with cemented hip protheses who underwent revision operations. The nature of the bone–cement attachment was studied by electron microscopy. The tissue at the interface was found to be made up of viable bone alternating with areas of soft tissue containing macrophages. The important qualitative differences between this reaction and the reaction seen around inert materials such as titanium are discussed.

The nature of the anchorage of cemented implants in bone has been a matter of controversy for almost two decades. It is generally held that the normal response to bone cement is the development of a soft-tissue membrane between the cement and the bone. However, Charnley (1970, 1979) has suggested that in perfectly successful cases the cement may lie in direct contact with what appears to be living bone, even though there is uncertainty whether the tissue represents a transitional form of fibrocartilage and bone.

In the three cases to be presented here there is ultrastructural evidence to support Charnley’s view that the bone cement may indeed border on living bone.

CASE HISTORIES

Case 1. In 1971 a 61-year-old man had a McKee–Farrar hip prosthesis inserted because of osteoarthritis. The functional result was good for eight years, after which time he developed pain. The radiographs then showed that the acetabular socket was surrounded by a two-millimetre radiolucent line and that it had migrated cranially. In the femur there was bone resorption in the calcar region but distally there was no sign of loosening and no radiolucent line. The hip was revised. A slot was made in the anterior cortex to remove the distal femoral cement. The underlying cement was found to be fixed remarkably strongly to the removed piece of bone and to elucidate the nature of such an attachment the entire bone–cement block was prepared for electron microscopy.

Case 2. In 1979 a 70-year-old man received a McKee–Arden hip prosthesis because of osteoarthritis. The course was uneventful for one year but gradually a radiolucent line developed around the acetabular socket. Moreover, the femoral cement fractured so that the stem migrated mediodistally, while the proximal lateral part of the cement mantle remained stable in the trochanteric region without evidence of a radiolucent line. At revision this part of the cement mantle proved impossible to remove from the bone and had to be chiselled out with the surrounding bone attached to it. This specimen was also prepared for electron microscopy.

Case 3. In 1973 a 56-year-old woman was operated on for osteoarthritis of the hip. A Charnley total hip arthroplasty was performed. The result was excellent for seven years, after which time she developed pain. The acetabular socket proved to be loose, and was surrounded by a three-millimetre radiolucent line on the radiographs. The femoral component appeared to be well fixed. At revision the femoral component had to be removed for technical reasons. A window was sawn in the anterior cortex. It was impossible to separate the cement from the bone in this region manually and the removed bone–cement specimen was processed for ultrastructural analysis.

PREPARATION OF SPECIMENS

The bone with attached cement was fixed in three per cent glutaraldehyde in cacodylate buffer and postfixed in osmium tetroxide. Some of the specimens were decalcified in ethylenediamine tetra-acetic acid (EDTA) whereas others were left undecalcified before being embedded in Epon. During the routine embedding procedure the specimens were at one point kept in propylene oxide. This step proved useful as the propylene oxide dissolved the cement more or less completely. As a result we obtained a bone specimen in which the interface had not been distorted by mechanical removal of the cement.
OBSERVATIONS
Under the light microscope the findings were essentially the same as those of Charnley (1979). In some areas there was close contact between the living bone and the cement, although a thin rim of proteoglycans was always interposed. However, between such areas of bony contact were stretches of soft tissue where fibroblasts, macrophages and giant cells were present (Fig. 1).

Under the electron microscope the areas where the cement had not apparently been completely dissolved out had a biphasic appearance, electron-dense areas alternating with electron-lucent ones. This pattern has been described in an experimental study by Pedley, Meachim and Gray (1979). In areas of bony contact the cement was separated from the collagen and calcium deposits of the bone by a layer of uncalcified proteoglycans. This layer was in continuity with the proteoglycans of the ground substance between the collagen filaments. Its thickness varied within a wide range (0.3 to 7 microns), but typically was between 1 and 3 microns (Fig. 2). It seems reasonable to suggest that the "pale-staining material" in Charnley's specimens was the layer of proteoglycans observed here. There were calcium deposits throughout the collagen (Fig. 3). The cells of the bone had the appearance of osteocytes, displaying normal cell organelles.

In areas of contact between soft tissue and cement the macrophages and giant cells were metabolically active, displaying a prominent endoplasmic reticulum, indicating high synthetic activity; there was no, or only a small amount of, phagocytosed material within their lysosomes, which occasionally also contained lipid droplets (Fig. 4). The cells were separated from the cement surface by a layer of proteoglycans of at least 30 to 40 nanometres (300 to 400 ångströms). Multinuclear cells, suggestive of osteoclasts, were occasionally seen at the interface (Fig. 5).

We have not been able to find records of the cement brands used in our patients. However, as the radiopaque of the cement remained undissolved in the
Epon and as such particles were shown by EDAX analysis to contain barium, we drew the conclusion that the cement must have been either CMW or Simplex-P. Information to the discussion on the cause of radiolucent lines often seen around cemented implants. It is accepted that macrophages or macrophage-derived cells are the mediators of bone resorption. A radiolucent line therefore is the result of the action of such cells. According to Freeman, Bradley and Revell (1982) bone cement is an inherently macrophage-attracting material, creating a biologically unstable interface. That macrophages are often seen at the cement surface is also shown in this study, even in cases where micro-instability can be ruled out, at least at the microscopic level.

However, our observations also indicate that the presence of macrophages per se is not necessarily associated with a radiolucent line. In fact, macrophages seem to be able to remain at the surface of the cement with high synthetic activity but with no obvious signs of resorptive activity. Moreover, in the same patient, the cement may be bordered by resorptive macrophages in the acetabulum while there are non-resorptive ones in the femur. This would indicate that an additional trigger mechanism—related or unrelated to the cement—is at work. We believe it is essential to go one step further and investigate if and how the macrophages of the interface are triggered to become destructive cells and also how this activity is regulated. Only then may we be able to predict the behaviour of bone cement on a long-term basis.

**DISCUSSION**

To our knowledge this is the first report of the ultrastructure of the interface between viable bone and cement in man. Our observations support the suggestion of Charnley that bone cement may remain in contact with living bone even after many years of service. This was an incidental finding in three patients out of a number who presented for revision operations and it is possible that in patients with perfect functional results this type of interface may be more common than previously thought.

Considering the remarkable mechanical integrity of the bone–cement junction in these patients the anatomy of the interface differed surprisingly from that of bone and titanium, where a direct bone–metal contact is regularly achieved. In the case of titanium the proteoglycan layer contains calcium deposits and has a thickness of only 20 to 40 nanometres and there are no macrophages at the interface (Linder et al. 1983). The difference probably reflects the inferior biocompatibility of bone cement: the presence of multinuclear cells at the surface of the cement indicates that there is a chronic stimulus causing a reaction at variable, mostly very low, levels.

The observations presented here may add some
ACKNOWLEDGEMENTS

Financial support was given by Riksförbundet mot Reumatism, Greta och Einar Askers Stiftelse and Svenska Läkaresällskapets Forskningsfond.

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