We performed a histological and histo-
morphometric examination in five cadaver
specimens of the femoral and acetabular components
and the associated tissue which had been recovered
between 3.3 and 6.2 years after primary total hip
arthroplasty (THA) using a proximal hydroxyapatite
(HA)-coated titanium alloy implant. All had
functioned well during the patients' life.

All the stems were fixed in the femur and showed
osseointegration of both the proximal and distal parts.
The amount of residual HA was greatest in the distal
metaphyseal sections, indicating that the rate of bone
remodelling may be the main factor causing loss of
HA. The level of activity of the patient was the only
clinical factor which correlated with loss of coating.
The percentage of bone-implant osseointegration was
almost constant, regardless of the amount of HA
residue, periprosthetic bone density or the time of
implantation. HA debris was seldom observed and if
present did not cause any adverse or inflammatory
reaction. Partial debonding did occur in one case as a
result of a polyethylene-induced inflammatory
reaction.

Bone-implant bonding is regarded as one of the most
important requirements for function, but there is little
histological evidence of sufficient bone ingrowth in
retrieved uncemented porous-coated prostheses.1-6 Bloe-
bbaum et al7 demonstrated that bone had to be within 50 µm
of the porous coating for ingrowth to occur. Hydroxyapatite
(HA) coatings have been shown to achieve a very strong
bond with living bone, in a relatively short period, even
under loaded conditions.8-18 The response of bone to HA
after revision arthroplasty has been well documented.19-24
Few morphological studies have provided histological and
quantitative data from components and surrounding bone
retrieved at post mortem. We have measured this in clini-
cally successful HA-coated femoral stems retrieved at post
mortem from five patients between three and seven years
after insertion.

We tested four hypotheses and three were confirmed. The
first was that osseointegration may be observed in the
uncoated as well as the HA-coated part of the stem. This
view is based on the radiological extension of new endos-
teal or periosteal bone appositions. The second was that the
resorption of the HA coating is cell-mediated and depend-
ent on bone-remodelling processes. Most of the resorption
of HA should therefore take place at the most proximal
level of the metaphysis with less at the more distal sections.
The third was that the percentage of bone contact or
ingrowth into the HA has a positive correlation with the
amount of local periprosthetic bone as indicated by bone
density. This idea was disproved. The last was that polyeth-
ylene (PE) particles should not be seen since the interface is
closed proximally by circumferential osseointegration.

Patients and Methods

The prostheses had been inserted through a Hardinge
approach by the same surgeon (AJT). The femoral stems
(ABG; Howmedica, Staines, UK) were titanium alloy
(Ti6Al4V) with the proximal third coated with HA on a
macro-relief surface.25 The diameter of the cobalt-chrome
(CoCr) head was 28 mm in all cases. The HA coating was
applied by a plasma spray torch under a vacuum on to a
sublayer of titanium to improve adhesion. The coating had
a content of HA of more than 90% with a porosity of less
than 10% and a Ca:P ratio of 10:6. The crystallinity was
100% before coating and more than 75% after.

The grain size was 20 to 50 µm and the strength of the
tensile bond 62 to 65 MPa. A titanium substrate with a
roughness of 3 to 4 µm Ra was used.

Specimen preparation. The prostheses and surrounding bone
were collected at post mortem, immersed in buffered formalin

Received 17 March 1998; Accepted after revision 16 June 1998
for seven days, and then in 70% ethanol for 24 hours.

**Specimen preparation.** Photographs and radiographs of the samples were taken. Five gross sections, approximately 1.0 to 1.5 cm thick, were cut corresponding to the Gruen zones (Fig. 1). Gruen zones 1 to 7 were subdivided into three (1A to 7A, 1B to 7B and 1C to 7B). Each segment was then embedded *en bloc* in a PMMA resin and five 20 µm sections were cut from each zone using the technique of Donath and Breuner. The sections were stained for qualitative histology (paragon staining, a combination of basic fuschin and toluidine blue) and quantitative histomorphometry. A biopsy of the joint pseudocapsule was taken, embedded in paraffin and prepared for light microscopy using haematoxylin and eosin staining.

**Specimen analysis.** We used a Polyvar microscope for qualitative analysis and an Axioskop microscope equipped with a colour-image-analysing system (SAMBA; TITN Alcatel, France) for quantitative analysis. The quantitative morphometric evaluation of the surrounding bone tissue (bone-implant contact and bone density) was performed on seven areas (Fig. 2) for each metaphyseal section and on four for each diaphyseal section. The surfaces of these areas varied from 10 to 12 mm². Sixteen (4×4 fields) microscopic fields were necessary to scan the whole surface of each area. Each pixel of the reduced image represented 61 µm² of the section. Implant, bone and lacunae, including all soft tissues, were successively identified and their respective surfaces and contacts with the implant measured. For each section the total implant perimeter, the percentage of implant covered by bone, the relative bone density in the vicinity of the implant, the total percentage of residual coating and the coating thickness were measured. The means and standard deviations were calculated for each section and side of the stem. We performed statistical analysis using the Spearman (correlations for rank data) and the Mann-Whitney U tests.

**Results**

The results are shown in Table I. The femur was intact in all cases at post mortem. There were no loose particles of any type in the capsule, which showed no blackening. The stems were stable in the bone.

**Radiological findings.** The stem was found to fill the diaphysis completely in three patients (cases 1, 2 and 4) in...
whom modest diaphyseal thickening was noted at the two-year follow-up, with formation of a reactive line at the tip of the stem in cases 2 and 4. This line vanished between the third and fourth years after operation. When the stem did not fill the medullary canal, as in cases 3 and 5, a reactive line was seen at six months in the distal part of the stem extending upwards into Gruen zones 3 and 5. In these cases endosteal bone apposition was marked at Gruen zones 2 and 6, extending later into Gruen zones 3 and 5, as a sign of osseointegration of the distal stem. All patients showed slow but progressive bone resorption in Gruen zones 1 and 7 with rounding of the calcar. In case 3 a small cyst near the calcar was noted at the five-year follow-up, while the femoral head showed asymmetrical tracking with wear of at least 1 mm of the acetabular component. All five stems showed radiological osseointegration of the stem starting proximally and subsequently extending distally (Fig. 1).

**Histological examination.** Four of the implants showed an extensive direct bond between the HA, or the prosthesis, and the bone without a fibrous or inflammatory interface (Fig. 3). In one patient (case 3) progressive histological loosening, due to PE-particle-related osteolysis was seen extending from the proximal metaphyseal Gruen zone 1A to 7A down to Gruen zone 1B to 7A (Fig. 4). This debonding process did not reach zone 1C to 7B. The bone tissue surrounding the mid-part of the stem (zones 2 to 6) was mature trabecular bone, without any active and extensive remodelling but with obvious increased porosity. Bone marrow was observed directly in contact with the metal or coating surface without any fibrous interface, illustrating the quality of the osseointegration and the absence of micromovement. In areas where bone resorption was focally increased the resorption of HA was also increased, and some osteoclasts were seen. When the bone marrow was adjacent to the stem, HA granules were sometimes seen

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<th>Table I. Details of and findings in the five cases</th>
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<td>Distal stem zones 3 to 5</td>
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* HA coating parameter between parentheses
associated with active signs of phagocytosis (cases 1, 2, 4 and 5). HA or titanium particles did not induce a significant change in the adjacent bone marrow or inflammatory infiltrate (Fig. 5). The foreign-body reaction described in the metaphyseal region of case 3 is a classical inflammatory response to PE debris.\(^\text{27}\) (Fig. 6)

Around the distal stem endosteal bone apposition was seen where the stem did not fill the diaphysis (cases 3 and 5). Modest apposition of periosteal bone was the rule when there was full diaphyseal fill from the outset (cases 1, 2 and 4). There was no formation of an intermediate fibrous layer at these zones, except for the most distal 1.5 cm in Gruen zone 3 in case 3.

**Particles.** Three types of particle were observed: metal, PE and HA. PE particles with an associated inflammatory tissue reaction were present in profusion in case 3 at the two proximal mid-stem levels but not at the interface in zones 1C to 7B or in the regions of the distal stem. Case 5 showed a small focus of PE particles at Gruen zones 1C to 7B without surrounding inflammatory tissue.

Metal particles with hardly any inflammatory response were seen in nearly all metaphyseal sections mostly in combination with some HA granules in areas where there was resorption of the HA coating. HA debris, when present, was only seen adjacent to the metaphyseal part of the stem and never distal to the level of the coating. Occasionally, osteoclasts or macrophages were seen phagocytosing the HA granules.

**Histomorphometry.** The predominant areas of bone contact and bone density seemed to move from the anterior side in
Fig. 5
Case 2. Detail of anterior side of zone 1C to 7B. The HA coating remained mainly in areas covered with bone and showed a thickness close to the initial value of 60 µm. Metallic particles (arrows) and HA debris (arrows) showed hardly any inflammatory reaction (×20).

Fig. 6
Case 3. Area 2 of section 1A to 7A of Figure 4 under polarised light. Granulomata (G) induced by polyethylene particles are actively debonding the osseointegration between the bone (B) and the stem (S) (×8).

Fig. 7
Case 1. Detail of the anterior side of zone 1A to 7A. The HA coating is thicker and more regular in areas covered with trabecular bone (TB) than in areas in contact with bone marrow (BM). The mature trabecular bone is spread on the implant (S) surface (×20).
the metaphysis to the medial side at Gruen zones 2 to 6 and to the lateral side in Gruen zones 3 to 5. Except for case 3, the overall bone-implant contact in the metaphysis had a constant ratio of approximately 50% of the total surface.

**HA coating.** The appearance of the coating was non-uniform. In areas covered by bone it was thick and regular but in those covered by bone marrow it was thin, fully absorbed or irregular (Fig. 7). An intermediate stage (50% of HA loss or 50% of the original thickness) was seldom observed. The resorption of the HA coating was usually more advanced on the posterior and lateral sides whereas bone contact was lower compared with the medial and anterior aspects. The amount of HA residue did not correlate with the time of implantation but was related to the level of the section in each patient (except for case 3 in which extensive PE-induced osteolysis was seen). The coating was thickest in two patients (cases 1 and 4) who had the lowest levels of activity. In case 5, in which the HA had almost completely disappeared, bone was growing directly against the metal stem.

**Discussion**

**Role of osseointegration.** All five cases showed good medium-term fixation by osseointegration. The almost complete loss of HA as seen in case 5 did not seem to jeopardise fixation or osseointegration. The amount of bone-implant contact in this case did not change substantially in the proximal-stem region and was similar to the other prostheses. This confirmed the observation by Overgaard et al that resorption of HA was partly replaced by bone in direct contact with the metal implant. There was no clear correlation between the amount of osseointegration and the density of the periprosthetic bone, as was also seen in the experiments of Eckhoff, Turner and Aberman. Their study in sheep showed that generalised age-related involution of bone did not effect the quality or quantity of the osseointegration of the implant in the distal femur. This finding supports our earlier radiological observations in rheumatoid patients that the amount of periprosthetic bone is not a decisive factor in determining the quality of bone-implant osseointegration. Nevertheless, the nearly complete loss of HA in case 5 does point to the importance of the surface texture of the metal, especially in the light of long-term fixation.

**Load transfer and stress shielding.** The observations of bone-density and bone-implant contact confirmed the remodelling patterns predicted by a finite-element study of a well-fixed proximally coated titanium stem. Mechanisms of coating loss. Recent studies have disputed the mechanisms of loss of the HA coating and it has been suggested that cell-mediated degradation by macrophages or by osteoclastic resorption is the most important reason for the loss of coating. Other means such as delamination or dissolution have also been reported. In our series the lack of delamination may be attributed to the excellent homogeneity and bonding strength of the coating obtained by vacuum plasma spraying. Time-related studies on histological specimens have shown that osteoclastic resorption of the HA is a definite phenomenon in bone remodelling and experiments in dogs have shown that loading of HA-coated implants accelerated the resorption of the HA coating significantly compared with immobilisation.

**Conclusions.** We have confirmed the ability of HA to provide a sound stem-bone interface with a bone-implant bonding of greater than 43% at the proximally HA-coated shaft in four patients. This is significantly higher than the degree of bone ingrowth found with porous-coated implants. Apart from the expected osseointegration of the proximal stem, we also observed this at the distal stems. This biomaterial appears to enhance implant-bone fixation without interfering with the normal processes of bone remodelling.

The authors want to thank Dr B. Davies for correcting the English. The histology and histomorphometry were done at Biomatch SA, Z. I. de l'Islon Rue Pasteur, 38670 Chasse sur Rhone, France.

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**References**


