A comparison of bone remodelling around hydroxyapatite-coated, porous-coated and grit-blasted hip replacements retrieved at post-mortem

M. J. Coathup, G. W. Blunn, N. Flynn, C. Williams, N. P. Thomas
From the Royal National Orthopaedic Hospital, Stanmore and Basingstoke General Hospital, England

We investigated the implant-bone interface around one design of femoral stem, proximally coated with either a plasma-sprayed porous coating (plain porous) or a hydroxyapatite porous coating (porous HA), or which had been grit-blasted (Interlok). Of 165 patients implanted with a Bimetric hip hemiarthroplasty (Biomet, Bridgend, UK) specimens were retrieved from 58 at post-mortem.

We estimated ingrowth and attachment of bone to the surface of the implant in 21 of these, eight plain porous, seven porous HA and six Interlok, using image analysis and light morphometric techniques. The amount of HA coating was also quantified.

There was significantly more ingrowth (p = 0.012) and attachment of bone (p < 0.05) to the porous HA surface (mean bone ingrowth 29.093 ± 2.019%; mean bone attachment 37.287 ± 2.489%) than to the plain porous surface (mean bone ingrowth 21.762 ± 2.068%; mean bone attachment 18.941 ± 1.971%). There was no significant difference in attachment between the plain porous and Interlok surfaces. Bone grew more evenly over the surface of the HA coating whereas on the porous surface, bone ingrowth and attachment occurred more on the distal and medial parts of the coated surface. No significant differences in the volume of HA were found with the passage of time.

This study shows that HA coating increases the amount of ingrowth and attachment of bone and leads to a more even distribution of bone over the surface of the implant. This may have implications in reducing stress shielding and limiting osteolysis induced by wear particles.

Received 24 March 1999; Accepted after revision 21 September 1999

The use of hydroxyapatite (HA) coating has been advocated in order to increase the attachment of bone to metal implants. Many animal as well as clinical studies have demonstrated the osseoconductive properties of HA and the results at six to eight years are excellent.\(^1,2\) Bone apposition appears to be well advanced as early as three weeks,\(^3\) and some studies have shown it to be greater than 90% at 96 weeks.\(^4\) Although there is concern that HA resorbs with time and that the release of HA debris may have adverse effects,\(^5\) the clinical results reported so far for HA-coated components suggest that at present this is not a significant problem.

Several reports of the outcome after the insertion of porous-coated uncemented implants have shown good results.\(^6-8\) Most studies found some degree of bone ingrowth into the pores\(^9-12\) with the mean extent reported to be in the range of 5%\(^9,12\) to 39.2%\(^13\) of the available pore volume.

An HA coating has been advocated in order to reduce the effects of debonding and to encourage bone ingrowth and attachment to a porous surface. Several studies have examined the use of an HA surface coating on porous-coated implants. Some have reported that there is no clinical advantage\(^14\) while others have demonstrated a significant increase in bone ingrowth.\(^15,16\) We have investigated bone ingrowth and attachment to an HA-coated porous titanium surface, a plain porous titanium surface and a roughened titanium (Interlok) surface finish in one femoral design from specimens obtained at post-mortem.

Materials and Methods

We treated 165 patients with a mean age of 84.8 years (79 to 92) for fracture of the neck of the femur using a Bimetric hip hemiarthroplasty (Biomet, Bridgend, UK) at the Basingstoke General Hospital, Hampshire. Each patient randomly received a femoral component with either a plain porous, a porous HA or an Interlok surface on the proximal region of the femoral stem. The porous titanium surfaces were applied to the surface of the implant using a plasma spray process. The HA coatings were applied by the same process and had a mean crystallinity value of >85% and a mean thickness of 50 μm. The Interlok surface was grit-blasted titanium with an Ra value of 6 μm. Before surgery,
permission was sought from the patients and their next of kin to retrieve the implants at the time of death. These and the associated femora were collected at postmortem. Overall, 58 specimens were retrieved: 15 Interlok (mean duration 2.5 years; range 4 to 938 days), 24 porous-coated (mean duration 4.5 years; range 2 to 1572 days) and 19 HA-coated (mean duration 2.8 years; range 2 to 1057 days). Because of the high number of implants retrieved and taking into consideration the cost, the lengthy processing of the specimens and the preparation necessary to produce histological thin sections, eight plain porous-coated specimens, seven porous HA-coated specimens and six Interlok specimens were analysed. The duration of the implants was as far as possible matched by selection into one of three groups according to their length of time in vivo: 0 to 1 year (3 porous HA, 173, 261 and 345 days; 2 plain porous, 109 and 243 days; 3 Interlok, 38, 72 and 123 days); 1 to 2 years (2 porous HA, 442 and 660 days; 3 plain porous, 452, 573 and 650 days; 1 Interlok, 607 days); and 2 years and over (2 porous HA, 941 and 1057 days; 3 plain porous, 908, 1094 and 1572 days; 2 Interlok, 864 and 928 days).

On retrieval, the specimens were fixed in 10% formaldehyde solution and excess soft tissue was removed. The proximal region of each femoral component (i.e., the coated area being investigated) was cut using an Exotom cut-off machine (Struers), into a proximal region (F1), a mid region (F2) and a distal region (F3) (Fig. 1). These specimens were then prepared for hard-tissue processing. Thin sections (<50 μm) were prepared through each of the F1, F2 and F3 regions. An Isomet 2000 diamond saw (Buehler Krautkramer) was used to cut the sections and a Motopol grinding and polishing machine (Buehler Krautkramer) for thin sectioning and final polishing. Toluidine Blue and Paragon were used to stain the soft tissue and bone, respectively. After staining, bone ingrowth and the quantity of the HA coating within the void volume of the porous structure were measured by image analysis. Images from the microscope were captured on to a computer using Neotech Image grabber software (HE Electronics, Reading, UK). Image-analysis software using colour thresholding techniques (Optilab; ME Electronics) was used to determine regions of interest. These were the total pore area within the field of view and HA and bone within the porous structure. All measurements were made through ×10 magnification on the microscope. The regions of interest were converted into binary images and the number of particles quantified. Bone ingrowth and HA areas were quantified over the entire porous surface of each implant and also separately at the proximal, middle and distal regions of the coated area. Bone ingrowth was also measured and compared in the medial, lateral, anterior and posterior planes. Attachment of bone to the outer surface of the implant was measured under light microscopy using a line intercept method and Merz graticule. That to the implant was compared over its entire surface and at the F1, F2 and F3 levels.

Statistical analysis. Student’s t-test was used and p values of less than 0.05 were classified as significant. Values for the standard error were calculated and are presented. To determine the effect which the variable duration of the post-mortem specimens had on the results obtained, and to take into account the relatively small sample numbers, we performed the Mann-Whitney U test. The results showed no significant differences in each of the groups and we concluded that the variable duration times of the specimens investigated had little effect on the results and that it was appropriate to compare mean bone ingrowth and attachment in each of the groups.

Results

Radiographs and sections of retrieved femora showed trabeculae streaming up to most of the porous-coated (Fig. 2) and HA-coated implants but not to the Interlok prostheses. Only one specimen had radiolucent lines between the implant and the bone. Sections through all of the plain porous implants taken earlier than six months showed how bone debris remaining from surgery formed a scaffold on to which new bone had grown and invaded the porous structure (Fig. 3). Sections prepared from the femora of patients in which the trabeculae and cortices appeared to be very thin indicating poor osseopotential showed an abundance of bone ingrowth and attachment to the surface of the implant (Fig. 4).

The appearance of the interface showed growth of bone into both plain porous and HA-coated implants (Figs 5 and 6). Overall, it appeared that more bone was attached to the surface of the HA-coated implants than to the plain porous implants. The interface adjacent to the Interlok implants did show some formation of bone but usually this was separated from the surface of the alloy by a thin layer of well-aligned soft tissue composed of fibroblasts (Fig. 7). In some
Fig. 2
Photomicrograph through a plain porous-coated specimen showing how bone has streamed from the cortex to the surface of the implant.

Fig. 3
Photomicrograph through a plain porous-coated specimen showing how bone chips remaining from surgery provided a scaffold for the formation of new bone.

Fig. 4
Photomicrograph through an osteoporotic porous HA specimen showing attachment and ingrowth of bone to the surface of the implant. The cortical bone is thin and bone has condensed around the porous coating.

Fig. 5
Photomicrograph showing ingrowth of bone to a plain porous coating. Bone is found deep within the porous coating (×195).

Fig. 6
Photomicrograph showing bone at the porous HA-implant interface. Bone is growing over the surface of the HA (×195).

Fig. 7
Photomicrograph showing bone at the Interlok implant interface. Most of the interface in this figure is composed of fibrous tissue, but in some regions, bone is remodelling and forming adjacent to the surface of the implant (×195).
instances, bone was observed to be attached to the Interlok surface.

When considering the intervals of time the results showed that there was significantly more bone ingrowth into the porous HA structure (29.093 ± 2.019%) than into the plain porous surface (21.762 ± 2.068%) (mean difference = 25.428%; p = 0.012). A mean of approximately 30% of the void volume of the porous HA structure was occupied by bone compared with 21% for the plain porous implants.

There was an uneven distribution of bone ingrowth into the surface of the plain porous implants with significantly more bone found in the distal region (30.475 ± 3.113%) of the coating than in the proximal (19.490 ± 4.419%) (mean difference = 24.983%; p = 0.012). A mean of approximately 30% of the void volume of the porous HA structure was occupied by bone compared with 21% for the plain porous implants.

A comparison of bone ingrowth into the plain porous surface and the porous HA surface was made in the medial and lateral planes. The results showed that with both surfaces, most bone ingrowth was seen in the medial region and no significant differences were found in bone ingrowth at the three levels (F1, 34.224% and F2, 31.173%, p = 0.618; F1 and F3, 31.729%, p = 0.711; F2 and F3, p = 0.934) (Fig. 8).

Figures 9 to 11 are sections through the proximal region of plain porous, Interlok and HA-coated porous implants which had been matched for their duration in situ. They show how bone forms and grows into porous HA over the entire coated surface but in the section for the plain porous implant at this level there are large regions of fibrous tissue interface. Most of the Interlok specimens have a soft-tissue interface.

A comparison of bone ingrowth into the plain porous surface and the porous HA surface was made in the medial and lateral planes. The results showed that with both surfaces, most bone ingrowth was seen in the medial plane. Increased amounts of bone in this region were also apparent in the Interlok specimens. There were no significant differences in bone ingrowth at the three levels (F1, 34.224% and F2, 31.173%, p = 0.618; F1 and F3, 31.729%, p = 0.711; F2 and F3, p = 0.934) (Fig. 8).

Figures 9 to 11 are sections through the proximal region of plain porous, Interlok and HA-coated porous implants which had been matched for their duration in situ. They show how bone forms and grows into porous HA over the entire coated surface but in the section for the plain porous implant at this level there are large regions of fibrous tissue interface. Most of the Interlok specimens have a soft-tissue interface.
differences in bone ingrowth between the two porous types in this plane.

The findings of the relationship between bone ingrowth and the duration of the implant in situ were not conclusive. Although there appeared to be an increased bone ingrowth with longer implant duration, the results were not significant.

Attachment of bone on to the surface of the implants when taken over all time periods showed that significantly more had occurred with the porous HA-coated surface (37.287 ± 2.489%) when compared with both the plain porous (18.941% ± 1.971%; mean difference = 28.114%; p = <0.05) and the Interlok surfaces (22.600 ± 3.73%; mean difference = 29.944%; p = <0.05). There was, however, no significant difference in the attachment of bone between Interlok and the plain porous-coated implants (p = 0.70).

The attachment of bone on to plain porous and Interlok surfaces was unevenly distributed and most attachment occurred in the middle and distal regions of these implants. By comparison, attachment of bone on to the porous HA coating was more evenly distributed over the entire length of the coated area with no significant difference in attachment at the F1 (34.277%), F2 (36.797%) and F3 (40.787%) levels (F1 and F2, p = 0.671; F1 and F3, p = 0.376; F2 and F3, p = 0.538) (Fig. 12). No significant differences were noted when investigating the relationship between the attachment of bone and the length of duration of the implant in situ.

Histological examination at the interface showed that attachment and ingrowth of bone occurred by different mechanisms on the porous and HA-coated implants. On the plain porous implants, pegs of bone grew into the porous structure. These originated from a ring of bone surrounding the implant. On HA-coated implants, the formation of bone was directed along the surface of the coating (Figs 5 and 6). There was little quantitative evidence of degradation of the HA coating and no significant differences were found in the volume of HA when measured over time. In some specimens it was observed that the HA coating had broken up. Particles of HA were seen at localised areas around the interface and although these resulted in an inflammatory reaction, this appeared to have no effect on the formation of new bone or the attachment of bone to the implant.

**Discussion**

Our study indicated that in man an HA coating significantly enhanced attachment and ingrowth of bone into a porous surface. It has been shown in both human and animal studies that bone ingrowth does occur on to a plain porous surface, but our study has demonstrated that the osseoductive nature of HA significantly encouraged more bone to grow into and along the surface of the implant. Even in osteopenic bone new bone formed along the surface in both the HA and plain porous implants. Our study also demonstrated that bone fragments left at the implant interface after surgery provided a scaffold for the formation of new bone.

Quantification of the bone around the plain porous and Interlok surfaces showed that our findings compared favourably with reports of ingrowth into other porous-coated systems. We investigated the response of bone in patients who had received the same design of femoral component. The results showed that the formation of bone was unevenly distributed in the proximal, middle and distal regions in the plain porous and Interlok implants. More ingrowth and attachment of bone had occurred in the distal region of the coatings and also on the medial and lateral surfaces when compared with the anterior and posterior surfaces of the implant. The distribution of bone around the HA porous-coated implant, however, was more uniform with no significant differences between the different levels or on any of the aspects of the stem.

When the relationship between the ingrowth and attachment of bone on to the surface of the implant was examined over time it was evident that the responses to the HA coating appeared to be variable. In one case, attachment of bone accounted for approximately 43% of the implant surface compared with 12% of an implant in situ for a few months longer. This could be due to many factors such as
the ability of the patient to form bone. Nevertheless, however variable the response was to the HA coating, overall significantly more bone had grown into and attached to this surface when compared with the plain porous surfaces. HA is thought to resorb over time exposing the metal surface beneath. In our study, the percentage of HA present in the porous structure was quantified. It was found that these beneath. In our study, the percentage of HA present in the interface of the implant. A separate study performed by as occurs with polyethylene or cement particles at the during their effect on bone growth in a rabbit model. They concluded that HA particles did not have the effect of inciting the formation of granulomata or inflammation such as occurs with polyethylene or cement particles at the interface of the implant. A separate study performed by Bauer et al. studied HA-coated femoral stems which had been in situ for a mean of 12 months and were retrieved at post-mortem. They reported that bone had formed a uniform coating over the HA on each stem and that there was extensive direct bone apposition. There was no evidence of fragmentation of HA resulting in an inflammatory reaction. Several other studies have also investigated HA-coated components retrieved at post-mortem and all have reported early deposition and extensive formation of bone on to the HA coating. A clinical study was reported by Karrholm et al. in which 60 hips of the same type were fixed with either cement or an HA coating or a porous coating applied to the proximal one-third of the surface. After two years the clinical results did not differ between the three types but the HA-coated stems showed less subsidence and rotation. Our findings agree with these studies and suggest that an HA coating enhances the early fixation of the femoral component and has a positive effect in femoral remodelling and in the achievement of biological fixation between the surface of the bone and implant, with no adverse effects.

The authors would like to thank Biomet UK for their funding. We would also like to thank Mary Wait for her technical assistance.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References