HYDROXYAPATITE COATING CONVERTS FIBROUS TISSUE TO BONE AROUND LOADED IMPLANTS

KJELD SØBALLE, EBBE S. HANSEN, HELLE BROCKSTEDT-RASMUSSEN, CODY BÜNGER

From the Orthopaedic Hospital, the Institute of Experimental Clinical Research, and the Institute of Pathology, University Hospital of Aarhus, Denmark

In previous studies, we have demonstrated a fibrocartilaginous membrane around hydroxyapatite-coated implants subjected to micromovement in contrast to the fibrous connective tissue which predominates around similarly loaded titanium alloy implants. In the present study, in mature dogs, we investigated the effect of immobilising titanium (Ti)- or hydroxyapatite (HA)-coated implants already surrounded by a movement-induced fibrous membrane and compared the results with those of similar implants in which continuous micromovement was allowed to continue. The implants were inserted in the medial femoral condyles of 14 dogs and subjected to 150 μm movements during each gait cycle. After four weeks (when a fibrous membrane had developed), half the implants were immobilised to prevent further micromovement. The dogs were killed at 16 weeks and the results were evaluated by push-out tests and histological analysis.

The continuously loaded Ti-coated implants were surrounded by a fibrous membrane, whereas bridges of new bone anchored the HA-coated implants. The immobilised implants were surrounded by bone irrespective of the type of coating. Push-out tests of the continuously loaded implants showed better fixation of those with HA coating (p < 0.001). The immobilised Ti-coated implants had four times stronger fixation than did continuously loaded Ti-coated implants (p < 0.01) but there was no equivalent difference between the two groups of HA-coated implants. The amount of bone ingrowth was greater into immobilised HA-coated implants than into immobilised Ti-coated implants (p < 0.01). Two-thirds of the HA coating had been resorbed after 16 weeks of implantation, but 25% of this resorbed HA had been replaced by bone.

In conclusion, continuous loading of initially unstable Ti implants resulted after 16 weeks in the development of a permanent fibrous membrane, whereas HA coating had the capacity to replace the motion-induced fibrous membrane with bone. The consequence of immobilisation of a motion-induced fibrous anchored implant was replacement of the membrane by bone, irrespective of the type of coating.

Received 23 April 1992; Accepted 14 July 1992

Fibrous tissue interfaces predominate in the majority of retrieved uncemented porous-coated hip and knee prostheses (Cook, Thomas and Haddad 1988; Cook et al 1988a) and fixation by fibrous tissue ingrowth has been regarded as the normal phenomenon of fixation in uncemented knee arthroplasty (Ryd 1986). It has been suggested that the fibrous membrane results from relative movement between the implant and the bone which occurs immediately after implantation (Cameron, Pilliar and Macnab 1973; Ducheyne, De Meester and Aernoudt 1977; Pilliar et al 1981; Heck et al 1986; Eschenroeder, Jones and Hungerford 1988). Such movement has been shown experimentally to be in the range of 100 to 600 μm (Volz et al 1988, Vanderby et al 1989).

In two studies (Søballe et al 1992a,b) we investigated the importance of micromovement of porous-coated implants with and without HA coating. We showed that, four weeks after implantation, a fibrocartilaginous membrane was present around HA-coated implants subjected to micromovement, whereas only fibrous connective tissue was found around Ti implants. In the present study we have followed the development

K. Søballe, MD, Orthopaedic Surgeon
E. S. Hansen, MD, Orthopaedic Surgeon
C. Bünger, MD, PhD, Orthopaedic Surgeon
Biomechanics Laboratory, Orthopaedic Hospital, Randersvej 1, DK-8200, Aarhus, Denmark.

H. Brockstedt-Rasmussen, MD, Registrar
Institute of Pathology, Aarhus Amtssygehus, University of Aarhus, DK-8000 Aarhus, Denmark.

Correspondence should be sent to Dr K. Søballe.

©1993 British Editorial Society of Bone and Joint Surgery
0301-620X/93/2518 $2.00
of the different types of membrane around Ti- and HA-coated implants for longer periods, and have compared the effects of immobilisation and of continued micromovement on implants already anchored by fibrous ingrowth.

MATERIALS AND METHODS

Experimental design. We used 14 mature Labrador dogs with a mean age of 19.5 months (13 to 36) and a mean weight of 25.1 kg (20 to 32). They were bred for scientific purposes and handled according to Danish law on animal experimentation. Preoperative radiographs of both knees ensured that all animals were skeletally mature and without osseous abnormalities. The experimental design is shown schematically in Figure 1. Ti- or HA-coated implants, subjected to micromovement of 150 μm, were inserted into the medial femoral condyles of all 14 dogs, alternating randomly between the right and left knees. Four weeks later the implants in seven of the dogs were immobilised to prevent further micromovement; the other seven underwent sham operations allowing the continuation of loading in their implants. The dogs were killed 12 weeks after the second operation and the results were evaluated by push-out tests and histomorphometric analysis.

The dynamic device. The device for producing controlled micromovement has previously been described in detail (Søballe et al 1992a, b). The principle of the system is shown in Figure 2. The range of movement allowed was approximately 150 μm. The dynamic devices were tested before and after implantation with an Instron machine. Before implantation, the stiffness of the springs was adjusted to the desired elasticity (about 15 N/mm)
and preload (approximately 2 N). Both increased significantly during the 16 weeks of implantation from 16.5 N/mm (SEM 0.4) to 23.3 N/mm (3.1) and 2.18 N (0.1) to 3.4 N (0.25), respectively. The mean displacement was 169 μm (3.8) before implantation and 168 μm (7.1) after implantation and was similar for the two types of implant. The implants. The test implants were cylindrical plugs 6 mm in diameter and 10 mm in length. The Ti-coated implants had a solid Ti-6Al-4V alloy core with a coating of Ti-6Al-4V deposited by plasma spraying, with a mean pore size of 300 μm (200 μm at the substrate and 1000 μm at the surface; Fig. 3a). The HA-coated implants had a similar Ti-alloy core and a Ti-alloy porous coating on which a 50 μm layer of synthetic hydroxyapatite (Ca/P ratio 1.67) had been deposited by plasma spraying (Fig. 3b). The substrate titanium for the HA-coated implants was appropriately undersized so that all implant diameters were similar after the coating had been applied. X-ray diffraction analysis showed pure hydroxyapatite with no detectable impurities. The surface roughness of Ti- and HA-coated implants was determined using a roughness meter (Perthen, Germany) as previously described (Søballe et al 1992a) with a stylus tip radius of 3 μm. The Ra (the arithmetical mean of the departures of the roughness profile from the mean line) was 41 μm for HA-coated implants and 47 μm for Ti implants. The profile depth was 445 μm for HA- and 496 μm for Ti-coated implants.

The polyethylene (UHMWPE) plugs (Chirulen, Ruhrchemie Oberhausen, Germany) were manufactured to be 25 μm less than the inner diameter of the centralising ring.

Operative procedures. As has been previously described (Søballe et al 1992a,b) the femoral condyle was exposed under general anaesthesia and the dynamic device inserted under fluoroscopic control into the inferior central part of the condyle, which is in contact with the meniscus or the tibia during the stance phase of the walking cycle (Adrian, Roy and Karpovic 1966). The test implant was surrounded by an initial gap of 0.75 mm to allow it to move freely relative to the surrounding bone. A prophylactic antibiotic (Anhypen, Gist-Brocades, Holland) was administered for three days. Lateral radiographs were taken immediately postoperatively.

The dogs were allowed free activity and unrestricted weight-bearing after surgery. They lived in individual cages 1.5 m × 2.5 m and had outdoor exercise for three hours a day (1.5 × 3.5 m). Gait performance was recorded regularly.

After four weeks the knees were opened through the old scar and in a random sample of seven dogs, the projecting part of the polyethylene plugs was cut off with a knife. In the other seven, sham operations were performed. The knees were opened to expose the plugs and then closed again.

Four weeks after the second operation the dogs were given 15 mg/kg of chlortetracycline intravenously (Dumocyclin: Dumex, Copenhagen, Denmark) (Frost 1983). Five days before terminating the experiment the dogs were further labelled with 8 mg/kg of calcein intravenously (Merck, Darmstadt, Germany).

They were all killed 16 weeks after the first operation. Immediately after death the knees were opened under sterile conditions, and cultures were taken from the implantation site and the synovial fluid. Synovial biopsies were taken for histological examination.

Control implants. To determine the state of the implant interfaces at the time of the second operation, two further dogs with Ti- and HA-coated implants subjected to 150 μm micromovement were killed after four weeks, and the implants were prepared and analysed as described below.
Preparation. The distal femora were prepared as previously described (Søballe et al 1992a,b) and sections were cut at right angles to the long axis of the implant. One 3 mm thick section was used for mechanical testing, and another for histology. One 100 μm thin slice was used for ultraviolet fluorescent microscopy. Following the push-out test the membranes around the continuously loaded Ti-coated implants were separated from the surrounding bone under a dissecting microscope and prepared for light microscopy.

Mechanical testing. The push-out tests were done with an Instron test machine as previously described (Søballe et al 1991a,b). A load of 2 N was used to define the contact position for the start of the push-out test. The implant displacement from 0.2 to 2 N load applied at a speed of 0.5 mm/min was recorded. Load-deformation curves were obtained by an X-Y recorder and used to estimate ultimate shear strength, apparent shear stiffness, and energy absorption (Søballe et al 1990, 1991a,b,c, 1992a,b,c).

Histomorphometry

Bone and fibrous tissue ingrowth. The amount of bone and fibrous tissue was measured on ground sections 50 μm thick as previously described (Søballe et al 1990). They were stained with 0.4% basic fuchsin and counterstained with 2% light green to allow quantitative histological evaluation of fibrous tissue distribution and bone to implant apposition by transmitted light microscopy at 100 × magnification (Gottfredsen, Budtz-Jørgensen and Jensen 1989). The procedure was performed blindly and in random order using the linear intercept technique (Revell 1986). Measurements were made on successive adjacent fields (approximately 200 points) along the entire implant circumference. Bone marrow accounted for the remaining tissue at the implant surface.

Gap healing. In a well-defined area 40 to 220 μm distant from the implant surface, bone volume (BV) was quantified to measure the amount of bone filling the initial gap. BV was estimated blindly by a point counting technique using the central part of the integrating plate with 25 points at 160 × magnification. Measurements were made on successive adjacent fields (approximately 1000 points) along the entire implant circumference.

Fluorescent microscopy. To study the time of new bone formation the 100 μm sections were examined by fluorescent microscopy at 25 and 100 × magnification. The location of the two fluorochromes relative to the implant and to the border of the drill hole was mapped.

Resorption of hydroxyapatite coating. The amount of HA on the implant surface was measured on ground specimens by the linear intercept technique around the entire implant circumference at 100 × magnification, and the percentage of the implant surface with or without HA was calculated. Unused, ground, stained, and embedded HA-coated implants were measured similarly and used as control values to evaluate the amount of HA resorbed during the period of implantation.

Synovium. Specimens of synovium were taken from the knee and stained with Giemsa, haematoxylin and eosin, Van Gieson or iron for histological evaluation of inflammatory changes.

Statistics. From all measurements, the mean values and standard error of the mean (SEM) were calculated. Comparison of the means was performed by paired and unpaired t-tests. A p value of < 0.05 was considered significant.

RESULTS

All dogs walked without a limp within three days of each operation and they remained active throughout the study. At the second operation all the polyethylene plugs were in place and projecting above the articular cartilage surface. At post-mortem increased synovial fluid was seen in all knees. Bacterial cultures from the implantation site and from the synovial fluid grew a few colonies of Staphylococcus albus in several knees; this was ascribed to contamination from the skin. No clinical signs of infection were encountered.

Push-out test. The implants surrounded by a fibrous membrane displaced approximately 80 μm when loaded in the range of 0.2 to 2 N before contact position was reached. The displacement of implants with bone apposition was negligible in this load range. No failures were observed at the HA-Ti alloy substrate interface.

The ultimate shear strength in the continuously loaded implants was greater in those with HA coatings than in those with Ti coatings (p < 0.001) (Table I).

### Table I. Results of the push-out tests (mean, SEM) on Ti-coated and HA-coated implants, continuously loaded or immobilised after the fourth week (n = 7)

<table>
<thead>
<tr>
<th>Test</th>
<th>Ti-coated implants</th>
<th>HA-coated implants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loaded</td>
<td>Immobilised</td>
</tr>
<tr>
<td></td>
<td>Loaded</td>
<td>Immobilised</td>
</tr>
<tr>
<td>Ultimate shear strength (MPa)</td>
<td>1.8 (0.8)*</td>
<td>7.8 (1.4)</td>
</tr>
<tr>
<td>Apparent shear stiffness (GPa/m)</td>
<td>6.6 (2.5)*</td>
<td>43 (11)</td>
</tr>
<tr>
<td>Energy to failure (J/m)</td>
<td>6.0 (2.0)*</td>
<td>38.2 (6.8)</td>
</tr>
</tbody>
</table>

* continuously loaded Ti-coated implants were different from immobilised Ti-coated implants (p < 1 x 10^-3); continuously loaded Ti-coated implants were different from continuously loaded HA-coated implants (p < 1 x 10^-3); continuously loaded Ti-coated implants were different from immobilised HA-coated implants (p < 1 x 10^-3)
Fig. 4a
Cross sections of implants subjected to 150 μm movements for four weeks. The HA-coated implant (a) is surrounded by a membrane with thick bundles of collagen fibres radiating in fan shape from the implant surface. The Ti-coated implant (b) is surrounded by a membrane with a more random orientation of thinner collagen fibres (polarising microscopy; light green and basic fuchsin; original magnification × 8). (With permission from Acta Orthop Scand) (Søballe et al 1992.)

Fig. 4b

Fig. 5a

Fig. 5b

After a further 12 weeks of continuous loading, bone (green) has replaced the fibrous membrane around the HA-coated implant (a) shown in Figure 4a but a fibrous membrane (red) is still present around the Ti-coated implant (b). Around the periphery of the fibrous membrane, there is a plate of condensed lamellar bone (b) (light green and basic fuchsin, original magnification × 8).

Immobilisation of the Ti-coated implants resulted in a fourfold increase in the strength of fixation (p < 0.01) but in the HA-coated implants the fixation only improved by 40% (NS). That of immobilised Ti-coated implants was not significantly stronger than that of continuously loaded HA-coated implants. Shear stiffness and energy absorption showed the same tendency as did ultimate shear strength, but shear stiffness was three times greater in immobilised HA implants than in continuously loaded HA implants (p < 0.01) (Table I). This latter tendency was not demonstrated in shear strength values.

**Table II. Percentage (mean, SEM) of bone ingrowth, fibrous tissue ingrowth, and bone gap volume around Ti- and HA-coated implants**

<table>
<thead>
<tr>
<th>Test</th>
<th>Ti-coated implants</th>
<th>HA-coated implants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loaded</td>
<td>Immobilised</td>
</tr>
<tr>
<td>Bone ingrowth</td>
<td>5 (3.7)*</td>
<td>34 (6.4)†</td>
</tr>
<tr>
<td>Fibrous tissue</td>
<td>82 (0.04)*</td>
<td>20 (0.12)</td>
</tr>
<tr>
<td>Bone gap volume</td>
<td>7 (4.1)*</td>
<td>40 (7.3)</td>
</tr>
</tbody>
</table>

* continuously loaded Ti-coated implants were different from immobilised Ti-coated implants (p < 1 × 10⁻³); continuously loaded Ti-coated implants were different from continuously loaded HA-coated implants (p < 1 × 10⁻³); continuously loaded Ti-coated implants were different from immobilised HA-coated implants (p < 1 × 10⁻³)
† immobilised Ti-coated implants were different from immobilised HA-coated implants (p < 1 × 10⁻³)
‡ continuously loaded HA-coated implants were different from immobilised HA-coated implants (p < 2 × 10⁻³)

**Histology**

**Qualitative description.** All implants had been placed centrally in the femoral condyle except one (an immobilised, HA-coated implant) which was close to the lateral cortex, although more than 90% of it was covered by trabecular bone. The fixation of this implant was reduced by one-third compared with the others.

**Control implants.** After four weeks the two control Ti-coated implants were surrounded by fibrous tissue whereas the two HA-coated implants were surrounded by fibrocartilage (Fig. 4), confirming the results of a previous study (Søballe et al 1992a,b).

**Continuously loaded implants.** The continuously loaded Ti-coated implants were surrounded by a fibrous membrane with occasional bone within the gap (Table II).
One Ti implant was surrounded by more bone. All but one of the HA-coated implants had bone ingrowth with bridges of bone making direct contact with the HA surface (Fig. 5). The one implant without bone ingrowth was completely surrounded by a fibrous membrane. The membranes surrounding the continuously loaded Ti-coated implants consisted predominantly of fibrous connective tissue with sporadic presence of islands of fibrocartilage.

**Immobilised implants.** The initial gaps surrounding the immobilised implants contained some woven and lamellar bone irrespective of the type of coating (Fig. 6). Two Ti-coated implants were surrounded by a relatively thick fibrous membrane with only a single bridge of bone crossing the gap, whereas all the HA-coated implants were covered by bone without any membrane formation. The cancellous host bone around the implant was continuous with the newly formed ingrown bone. No inflammatory reaction was seen around the implants.

**Histomorphometry**

**Bone ingrowth.** Six of the seven immobilised HA-coated implants were totally covered by bone; a small amount of fibrous tissue was present on one implant.

Bone ingrowth was seven times greater in the continuously loaded HA-coated implants than in the continuously loaded Ti-coated implants (p < 0.01) (Table II). Immobilisation of both types of implant gave increased bone ingrowth (p < 0.02). Immobilised HA-coated implants had more bone ingrowth than did immobilised Ti-coated implants (p < 0.01) (Fig. 7).

**Fibrous tissue ingrowth.** The greatest amount of fibrous tissue was found around continuously loaded Ti-coated implants which was significantly more than on similarly loaded HA implants (p < 0.01) (Table II). The amount of fibrous tissue around continuously loaded HA-coated implants was about the same as around immobilised Ti-coated implants. Immobilisation decreased the amount of fibrous tissue around both types of implant, and the least fibrous tissue was found around immobilised HA-coated implants.

**Gap bone volume.** The BV filling the initial gap of 0.75 mm around the continuously loaded HA-coated implants was five times more than that surrounding continuously loaded Ti-coated implants (p < 0.01). Immobilisation of Ti-coated implants increased the BV fivefold (p < 0.001) but no such improvement resulted from immobilisation of HA-coated implants. No difference in BV was found between immobilised HA-coated and Ti-coated implants (Table II).

**Fluorescent microscopy.** For continuously loaded implants, mapping of the two fluorochromes showed absence of tetracycline-labelled tissue (labelled eight weeks after implantation) in a circular zone around the implants. This zone, however, was labelled with calcein, indicating that all the new bone was formed after the
eighth week of the experiment (Fig. 8). One HA-coated implant was surrounded by a mixture of tetracycline and calcein-labelled bone.

Around immobilised implants, the gaps were filled with a mixture of tetracycline and calcein-labelled bone, indicating that the gaps were filled with newly formed bone during the first eight weeks after implantation. Resorption of hydroxyapatite. A mean 66% of the HA coating was resorbed after 16 weeks of implantation. For comparison, 91% of the surface of the unused implants was covered by HA. Continuously loaded implants had significantly more resorption of HA (77%) than did immobilised implants (56%).

The previous 4-week study had also shown differences between the movement-induced membranes around the two types of implant. Around HA-coated implants there was more collagen in thick bundles, amorphous precipitates of calcium phosphate and a small proportion (7%) of the surface was covered by bone. These findings suggested that the mechanical strength of the membrane would provide better fixation and a more steady mechanical environment around the HA-coated implants (Søballe et al 1992a,b) and thereby allow the process of endochondral ossification to progress. This seems to be confirmed by the present study.

As suggested previously (Søballe et al 1992b), the main reason for differences in tissue response between HA- and Ti-coated implants may be that some of the hydroxyapatite surface is dissolved (van Blitterswijk et al 1985; Beight et al 1989), releasing calcium and phosphate ions which are taken up by the fibroblasts. The resulting increase in intracellular calcium level may be responsible for the morphological changes in the fibroblasts, and for the increased cell proliferation and DNA and protein synthesis which have been found in cell cultures to which HA particles have been added (Gregoire et al 1987).

The membranes around the unstable Ti-coated implants in the previous study (Søballe et al 1992b) showed a more random orientation of thin collagen fibre with little mineralisation, and no bone was found on the Ti-implant surfaces. This membrane has now been shown to persist after a further 12 weeks' observation. With time the collagen fibres did become better organised which may explain their better fixation at 16 weeks than at 4 weeks.

We suggest that the initial fibrocartilaginous tissue around an HA-coated implant prepares the gap around the implant, both mechanically and biologically, for later bone ingrowth by endochondral ossification. According to the interfragmentary strain theory (Perren 1979), the initial presence of fibrous tissue during fracture healing may serve to reduce the strain between the fracture fragments to a level at which cartilage can be formed. The presence of fibrocartilage may then further reduce this strain to allow the formation of bone.

DISCUSSION

Our experiment is the first to demonstrate that an HA coating can cause a movement-induced fibrocartilaginous membrane to convert to bone despite continued loading. This conclusion is based on the assumption that the HA-coated implants were initially surrounded by a fibrous membrane. This was evidenced by fluorescent microscopy which showed no tetracycline-labelled tissue around the implant at 8 weeks but did show that mineralisation occurred between 8 and 16 weeks, as indicated by the calcein-labelled tissue (Fig. 8). Evidence from the control implants, and from a previous study (Søballe et al 1992b), also suggested that both the HA- and Ti-coated implants were regularly surrounded by a fibrous membrane after four weeks of similar micro-movement.

Synovium. The sections showed a synovial reaction in all knees with plasma cells, lymphocytes and some proliferation of synovial cells. All specimens stained positively for iron but no fibrin was present and there was no necrosis. Macrophage infiltration was seen in two specimens, both from Ti-coated implants.

Comparing the continuously loaded implants in the present study with those in previous studies with 500 or 150 μm micromovement (Søballe et al 1992a,b) it appears that a decrease in the amount of movement results in a two to threefold increase in the strength of the fibrous anchorage for both types of surface coating. During the longer observation period from 4 to 16 weeks further increases in the strength of the membrane occurred (Table III).

The ultimate shear strength of the continuously loaded Ti-implants in the present study after 16 weeks (1.8 MPa) was the same as that for the similarly-loaded HA-coated implants at four weeks (1.85 MPa) (Søballe et al 1992b), indicating that fibrous anchorage of HA-
coated implants is obtained in one-quarter of the time required for the same degree of fixation of implants without HA coating (Table III).

Most studies on HA coating have been performed on stable unloaded implants (Ducheyne et al 1980; Berry et al 1986; Thomas et al 1987; Cook and Thomas 1988; Cook et al 1988b; Rivero et al 1988; Søballe et al 1990, 1991a,c, 1992c; Sumner, Kienapfel and Galante 1992). Some have failed to show any benefit from HA (Berry et al 1986; Cook and Thomas 1988) and others have indicated only a temporary effect. Ducheyne et al (1980) demonstrated a significant stimulation of bone ingrowth in dogs initially, but by 12 weeks the implants did not differ from those without HA coating.

Our study suggests that under loaded conditions the osteoconductive effect of the HA coating is prolonged. There was seven times more bone ingrowth into the HA-coated implants 16 weeks after implantation. Similar results have been demonstrated in other loaded models (Geesink, de Groot and Klein 1987; Manley et al 1987; Thomas et al 1989; Poder et al 1992). Thus, HA coating seems to be efficacious also in the clinically relevant situation when the implant is subjected to loaded conditions during the entire observation period. We confirmed this in a recent clinical study using roentgen stereophotogrammetric analysis on total hip arthropasties with or without HA coating (Søballe et al 1992d). This study indicated that HA coating enhanced the secondary fixation of the femoral component as compared with Ti porous coating because HA coating stabilised the femoral components at three months.

The other interesting finding in the present study was that the movement-induced fibrous membrane around the porous-coated implants was replaced by bone when they were subsequently immobilised. This result is in agreement with that of Uthoff and Germain (1977) who found that the "beginning of loosening around screws can be reversed by addition of simple external immobilisation". Significantly more bone ingrowth was demonstrated on the immobilised HA-coated implants than on the Ti-coated implants but this difference was not reflected in the push-out test.

The chemical stability of HA in the biological environment is still controversial. One study reported resorption of HA (van Blitterswijk et al 1985) while others concluded that biodegradation does not occur (Klein 1983). There now seems to be general agreement that some of the HA coating is resorbed during the process of bone formation around it (Geesink et al 1987; de Groot 1988) and our experiments suggest that HA resorption is less in immobile implants than in continuously loaded implants.

It should be emphasised that most studies on resorption of HA have been performed on stable, unloaded implants. During unstable mechanical conditions, however, 65% of the 50 µm thick HA coating was shown by light microscopy to be completely resorbed during the 16 weeks implantation period (van Blitterswijk et al 1985). This difference may be explained by the presence of micromovements in the present study.

Cook et al (1988b) measured the thickness of HA coating up to 32 weeks after implantation and found no reduction in thickness during the implantation period. The HA characteristics were like those used in the present study but the loading conditions were different. Cook et al used an unloaded transcortical model whereas our implants were loaded and subjected to micromovements. Resorption of HA has also been demonstrated in dogs by Bagambisa, Joos and Schilli (1989) who observed osteoclastic resorption of the hydroxyapatite surface evidenced by Howship-like lacunae in the HA surface after six months. Recently, fluorapatite-coated implants have been studied in trabecular bone in goats, and compared with HA-coated implants (Dhert et al 1991). Both were covered by bone without the presence of fibrous tissue. Degradation of HA was demonstrated after 12 weeks whereas no degradation of fluorapatite could be demonstrated. Whether the HA coating will be completely resorbed from loaded implants in the longer term is still unknown and the clinical effects of HA resorption have still to be elucidated.

In conclusion, our study has indicated that continuous loading of initially unstable Ti implants results in the development of a permanent fibrous membrane after 16 weeks, whereas HA coating seems to have the capacity to replace motion-induced fibrous membrane with bone. The consequence of immobilisation of a movement-induced, fibrous-anchored implant was replacement of the membrane by bone, irrespective of coating.

The authors wish to acknowledge Professor Flemming Melsen, MD, PhD, University Institute of Pathology, Aarhus University, Denmark, for his valuable advice in histomorphometric analysis. They also wish to thank Kaj Josefsson, DDS, Department of Oral Anatomy, Dental Pathology and Operative Dentistry, Royal Dental College, Aarhus, Denmark, for performing scanning electron microscopy of the implants. Our grateful thanks to Jane Pauli and Anette Milton (Royal Dental College, Aarhus) for technical assistance with the grinding procedure. Biomet Inc, USA kindly provided the implants.

This study was supported by the Danish Rheumatism Association, Danish Medical Research Council, Institute of Experimental Clinical Research, University of Aarhus, Aarhus University Research Foundation, Danish Foundation for the Advancement of Medical Science, Biomet, Direkter Madsen og hustru Olga Madsens Fond, Svend Faeltings Fond, Ferd. og Ellen Hindsgaufs Fond and Kong Kristian Den Tiendes Fond.

Although none of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article, benefits have been or will be received but are directed solely to a research fund, foundation, educational institution, or other non-profit institution with which one or more of the authors is associated.

Table III. Ultimate shear strength (MPa) (mean, sem) of Ti-coated and HA-coated implants with various ranges of movement (ROM) at various intervals after implantation. Comparison between previous studies and present study

<table>
<thead>
<tr>
<th>Implant</th>
<th>Interval = 4 weeks ROM = 500 µm*</th>
<th>Interval = 4 weeks ROM = 150 µm</th>
<th>Interval = 16 weeks ROM = 150 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-coated</td>
<td>0.12 (0.01)</td>
<td>0.26 (0.07)</td>
<td>1.8 (0.8)</td>
</tr>
<tr>
<td>HA-coated</td>
<td>0.6 (0.1)</td>
<td>1.85 (0.4)</td>
<td>4.6 (1.0)</td>
</tr>
</tbody>
</table>

* data: Søballe et al 1992a † data: Søballe et al 1992b ‡ data: present study

VOL. 75-B, No. 2, MARCH 1993
REFERENCES


Eschenroeder HC, Jones LC, Hungerford DS. Biological ingrowth into a porous metal surface following established fibrous reaction. Trans 34th Annual Meeting of the Orthopaedic Research Society, 1988; 13:333.


THE JOURNAL OF BONE AND JOINT SURGERY