Abstract

The success of bone ingrowth into porous coated implants depends on several factors which can be separated into five main groups

- *implant related factors,* such as design of implant, surface structure and pore characteristics.
- *status of host bone bed,* such as underlying disease (rheumatoid arthritis, osteoporosis), available bone stock, use of drugs and surgical technique.
- *mechanical stabilization and loading conditions* applied on the implant.
- *adjuvant therapies* such as bone grafting and HA coating which might enhance the amount of bone ingrowth.
- *remodeling of periprosthetic bone.* Once bone ingrowth has occurred, maintenance of bony anchorage depends on bone remodeling at the interface.

The present series of studies were performed in order to investigate the effect of some of these factors on bone ingrowth in relation to hydroxyapatite (HA) and titanium alloy (Ti) coating when subjected to pathological and mechanical conditions mimicking the clinical situation.

HA- and Ti-coated implants were inserted into the femoral condyles of mature dogs. The observation period ranged from 4 to 16 weeks, and the results were evaluated by mechanical push-out testing, histomorphometric analysis, polarized light microscopy, UV fluorescence microscopy, collagen analysis and transmission electron microscopy (microanalysis). There were no complications related to the operative procedures and all dogs were terminated according to the original time schedule.

Host bone related factors were studied in the initial experiments. First, the effect of a gap between bone and implant was studied and compared with press-fit insertion. The HA-coating yielded superior effect on bone ingrowth compared to Ti in situations where the implant was surrounded by a gap and also where the implants were inserted in press-fit. Gaps of 1 mm and 2 mm around the implant were bridged by bone around HA implants whereas significantly less amounts of bone filled the gap around Ti implants. The gap-healing capacity of bone was increased even at a relatively great distance (400 μm) from the HA surface. This finding indicates that the osteoconductive effect of HA is not limited to the bone forming capacity on the surface of the implant. A positive gradient of newly formed bone was found towards the HA-coating, this gradient not being found towards the Ti-coating.

In order to investigate the significance of arthritic bone changes (osteopenia) on fixation of porous coated implants we adopted the Carragheenin-induced gonarthritis model resulting in substantial bone loss as determined by CT-scanning. In osteopenic bone, the anchorage of Ti implants was weakened compared with control bone whereas HA-coated implants were not affected by the osteopenic condition in the bone bed. However, the fixation of Ti-coated implants was superior to that of HA-coated implants in normal bone. HA-coating was shown to accelerate the rate of bone ingrowth in the presence of an initial gap between bone and implant even in the presence of osteopenic host bone bed.

To study the effect of adjuvant therapies, a model was developed to investigate incorporation of bone graft material into Ti- and HA-coated implants. Allogeneic bone graft packed around the implant enhanced the anchorage of Ti implants by 900%, but HA-coating alone without bone graft offered almost the same improvement in anchorage in 2 mm defects. Only minor additional improvement was obtained when bone graft was used together with HA. Arthritic bone changes did not influence incorporation of allogenic bone graft.

The last three experiments focused on the significance of mechanical stabilization and loading conditions of the implant immediately after surgery. Micromovements between bone and implant prevented bony ingrowth and resulted in development of a fibrous membrane. HA-coating was shown to modify this fibrous membrane as evidenced by the presence of fibrocartilage, higher collagen concentration, radiating orientation of collagen fibers, and a thinner membrane as compared with Ti-coated implants. In a longer-term study (16 weeks), the membrane around HA-implants became replaced by bone even when subjected to continuous load, whereas the membrane around Ti implants persisted after 16 weeks.

A great amount of bone ingrowth into loaded but stable HA-coated implants was demonstrated even in the presence of an initial gap around the implant. Moreover, dynamic load was even shown to increase

the amount of bone ingrowth into HA-coated implants, this being three-fold greater compared with completely unloaded implants. This positive effect of dynamic load was not evident for Ti implants. The best anchorage and greatest amount of bone ingrowth was obtained in the loaded stable situation when the implant was coated with HA.

An increased fibrous fixation was obtained with decreased range of motion (from 500 μm to 150 μm) by both HA and Ti implants, and a further increase in fixation was obtained when the observation period was extended from 4 weeks to 16 weeks. From these studies it could also be demonstrated that the fixation of fibrous anchored HA implants was obtained in 1/4 of the time required for the equal fixation of implants without HA-coating.

The consequence of immobilization of a motion-induced fibrous anchored implant was a complete replacement of the membrane by bone, irrespective of type of coating. A greater amount of bone ingrowth was obtained with immobilized HA-coated implants compared with immobilized Ti implants.

From the results presented here it can be concluded that HA-coating has a positive effect on bone- implant fixation in various situations, i.e. under stable unloaded conditions, under stable loaded conditions, and under unstable mechanical conditions. The most striking effect of HA was the capability to enhance bone to grow across a gap around the implant both during stable and unstable mechanical conditions, and even be capable of converting a motion-induced fibrous membrane to bony anchorage.

This supplement is based on the following studies, which will be referred to in the text by their Roman numerals (I–VIII).

I. Søballe K, Hansen ES, B-Rasmussen H, Pedersen CM, Bünger C. Hydroxyapatite coating enhances fixation of porous coated implants. A comparison in dogs between press fit and non-interference fit. Acta Orthop Scand 61(4):299-306, 1990.

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III. Søballe K, Hansen ES, B-Rasmussen H, Hjortdal VE, Juhl GI, Pedersen CM, Hvid I, Bünger C. Fixation of titanium- and hydroxyapatite coated implants in arthritic osteopenic bone. J Arthroplasty 6(4):307-316; 1991.

IV. Søballe K, Hansen ES, B-Rasmussen H, Hjortdal VE, Juhl GI, Pedersen CM, Hvid I, Bünger C. Gap healing enhanced by hydroxyapatite coating in dogs. Clin Orthop 272:300-307; 1991.

V. Søballe K, Hansen ES, B-Rasmussen H, Pedersen CM, Bünger C. Bone graft incorporation around titanium-alloy- and hydroxyapatite coated implants in dogs. Clin Orthop, 274:282- 293; 1992.

VI. Søballe K, Hansen ES, B-Rasmussen H, Jørgensen PH, Bünger C. Tissue ingrowth into titanium- and hydroxyapatite coated implants during stable and unstable mechanical conditions. J Orthop Res 10:285-299, 1992.

VII. Søballe K, B-Rasmussen H, Hansen ES, Bünger C. Hydroxyapatite coating modifies implant membrane formation. Controlled micromotion studied in dogs. Acta Orthop Scand, 63(2):128-140; 1992.

VIII. Søballe K, Hansen ES, B-Rasmussen H, Bünger C. Hydroxyapatite coating converts fibrous tissue to bone around loaded implants. J Bone Joint Surg, 75(B):270-278; 1993.

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