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ORIGINAL PAPER

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The periprosthetic bone remodelling process – signs of vital bone reaction

Abstract Bone remodelling in cementless hip stem replacement occurs as interface and periprosthetic bone remodelling. Results of radiological, histological and bone mineral density (BMD) findings are discussed. Atrophic, hypertrophic and normotrophic bone reactions are described. Osteodensitometry measurements have shown a bone density decrease of 20% within the first 6 months in the region of the proximal femur. Measurements up to 4 years revealed no further loss of BMD.

Introduction

Fifteen years' experience with the BiCONTACT hip stem requires the periprosthetic bone reaction to be analysed. The fact that bone reacts to changes in its functional stress also occurs with endoprosthetic replacement. In accordance to Wolff's law [7], a reduction in bone stress results in a reduction in bone mass, and an increase in bone stress to an increase in bone mass. This adaptation of bone to the physical demands of weight bearing is known as "periprosthetic bone remodelling". Secondary stability and long-term survival of the BiCONTACT stem are determined by the prosthetic implant and the periprosthetic bone quality.

The BiCONTACT stem is designed for proximal fixation and load transfer to bone. According to the implant design and the Plasmapore-coated proximal part the secondary implant stability is achieved by proximal anchoring and cancellous bone ingrowth.

Materials, methods and results

Bone remodelling occurs in the corticocancellous interface and the periprosthetic bone. So we have to consider interface remodelling and periprosthetic remodelling (Fig. 1).

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Interface bone remodelling

Interface remodelling is the interaction between the implant and the bone stock. The contact area between the implant and the bone should be as large as possible and the proximal fit as tight as possible. This can be achieved by the implant design (flat and tapered), the implant material (titanium) and the microporous Plasmapore surface structure. Coating is an important factor influencing the primary stable anchoring of the implant. Porosity and pore size affect the capacity for ongrowth and ingrowth – the main features for secondary stability.

On the other hand well preserved bone – the living material – is serving as a biological stabilising substrate for the implant. Bone quality, load- and stress-bearing capability, anatomical condition of the proximal femur (narrow or wide) and changing bone quality affected by advancing age osteoporosis, all influence the interface interaction.

The interface-related reactive lines have been studied within the BiCONTACT multicentre study of 246 X-ray follow-ups over an average period of 8 years [2] (Fig. 2). In Gruen zones 1 and 7, almost no (0.8%) reactive lines could be observed. In the distal stem, however, according to Gruen zones 3, 4 and 5, up to 33% reactive lines could be detected on X-ray follow-up. These radiological findings explain the proximal force introduction at the implant/bone interface with strong proximal bone ongrowth.

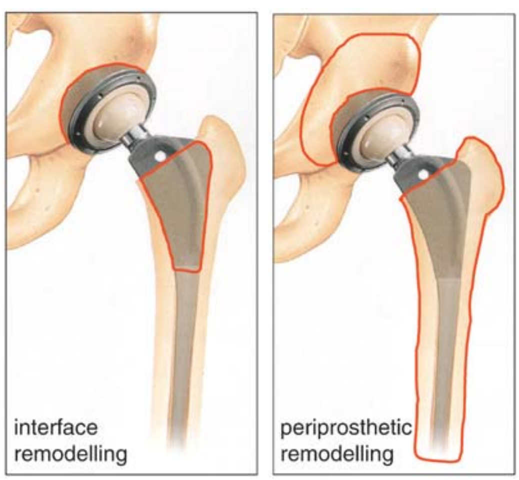


Fig. 1 Interface and periprosthetic bone remodelling around a cementless hip implant

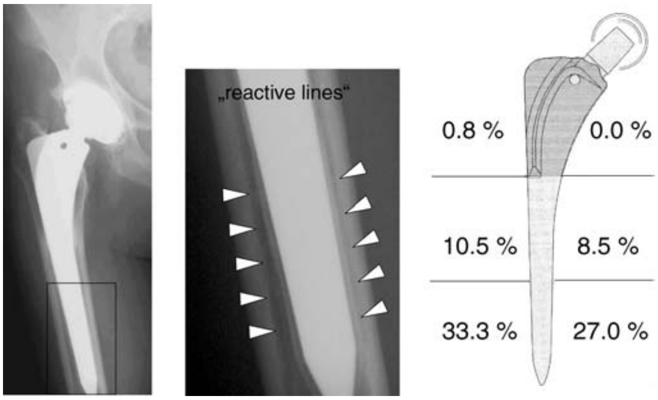


Fig. 2 Interface remodelling with proximal radiolucent lines and distal reactive lines around cementless BiCONTACT stems with an average follow-up of 8 years according to Asmuth et al.

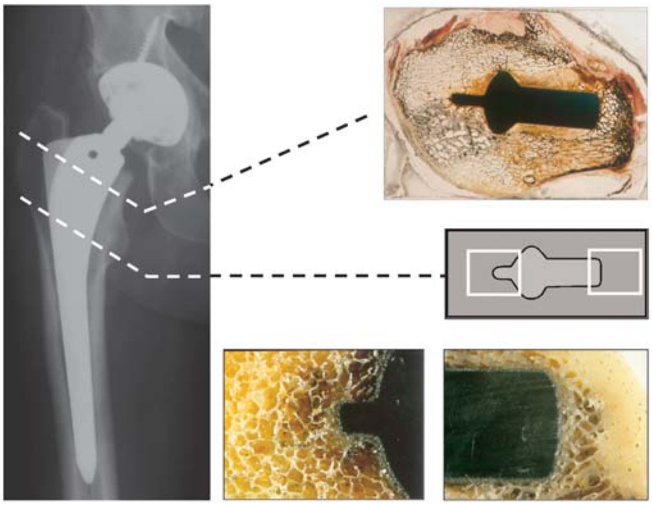


Fig. 3 Interface findings in a 3 months post-operation retrieval of a cementless BiCONTACT stem

Micromotion in the distal implant area due to the relation of stiff implant condition and vital cortical bone interaction leads to reactive lines, which are, however, no sign of implant loosening. These reactive lines in combination with well-fixed proximal interface conditions are characteristic for the BiCONTACT-related bone remodelling process. Reviewing a retrieval stem implant, it was possible to demonstrate how impressive bone ingrowth occurs around the prosthesis as early as 3 month after implantation. The histological analysis of a retrieval interface confirm that – in accordance with the BiCONTACT design – direct contact between the Plasmapore-coated stem and cancellous bone occurs in the medial proximal area and supportively in the region of the lateral and antirotation wings. In the medial proximal area, the contact between implant and bone amounts to approximately one fifth of the medial prosthesis surface. The bone grows onto and into the Plasmapore coating in this contact area. The thickness of the trabeculae are approximately 0.3 mm. Less bone contact is present on the lateral wing, and the trabeculae are arranged perpendicular to the prosthesis surface. Isolated bone contact occurs on the posterolateral wings (Fig. 3). A very strong medial bone structure was noted in the distal part of the Plasmapore-coated area, with gradual transition from trabecular to cortical bone. No implant/bone contact was present in the distal uncoated stem. The load is therefore transmitted to the bone mainly through the medial or upper mid-level interface of the prosthesis.

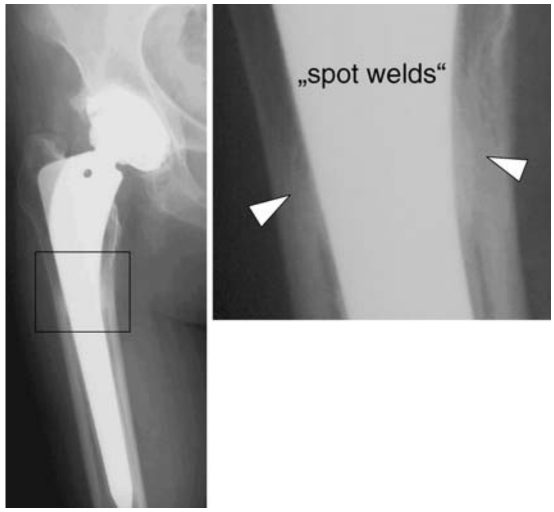


Fig. 4 Internal bone remodelling with bone condensation/spot welds at the distal part of the Plasmapore-coated implant area

Periprosthetic bone remodelling

Periprosthetic bone remodelling is the interaction between the interface stress and the periprosthetic bone stock. This can be shown on X-ray follow-up or dual energy X-ray absorption (DEXA) bone mass density (BMD) measurements. Bone remodelling is mainly influenced by implant design and anatomical condition. Load and stress to the proximal femur can be metaphyseal, diaphyseal or metaphyseal and diaphyseal. Under these loading conditions, the bone reacts with normotrophy, atrophy or hypertrophy. As a result of force introduction, periprosthetic bone remodelling at the implant interface and the periprosthetic bone can be observed as (1) internal bone remodelling, and (2) external bone remodelling.

Radiological signs of internal bone remodelling and osteointegration of a cementless stem is the endosteal presence of bone condensation – so-called “spot welds”. This essential feature of bony integration in cementless stems was described and published by Engh et al. [3] (Fig. 4).

This area of bone condensation is found in BiCONTACT stems in the distal metaphyseal coating at the isthmus of the femur, where the endosteal surface of the cortex and the implant are in close contact. This radiological sign is not, however, detectable in all cases with successful bony integration. In a series of 50 BiCONTACT stems, the radiologically visible endosteal zone of bone condensation (in the distal Plasmapore-coated surface) was observed 1 year after implantation in only 30.6% of cases [5, 6]. In case of bone condensation in the distal part of the metaphyseal load transfer area, internal bone remodelling of the calcar with rounding and slight atrophy could be seen on X-ray follow up. This happened as normal bone reaction due to the stress distribution and is no sign of implant loosening.

External bone remodelling is often observed in narrow proximal femoral diaphysis due to dysplastic hip and related bone conditions. High distal load transmission with a narrow femoral canal results in reactive increase in the peripheral cortical bone mass. So local cortical hypertrophy or hyperostosis is a result of constant load bearing due to strong implant/bone contact, mainly in the distal uncoated BiCONTACT stem (Fig. 5).

Different to bone hypertrophy and atrophy, normotrophic bone and its mineral density changes are difficult to determine on normal X-ray follow-up. A quantitative method to measure periprosthetic bone density allows a more detailed analysis of implant interaction on the surrounding bone. DEXA bone density measurement allows plantar analysis of bone mineral content (BMC) (grams) in the area of interest (centimetres squared) (Fig. 6).

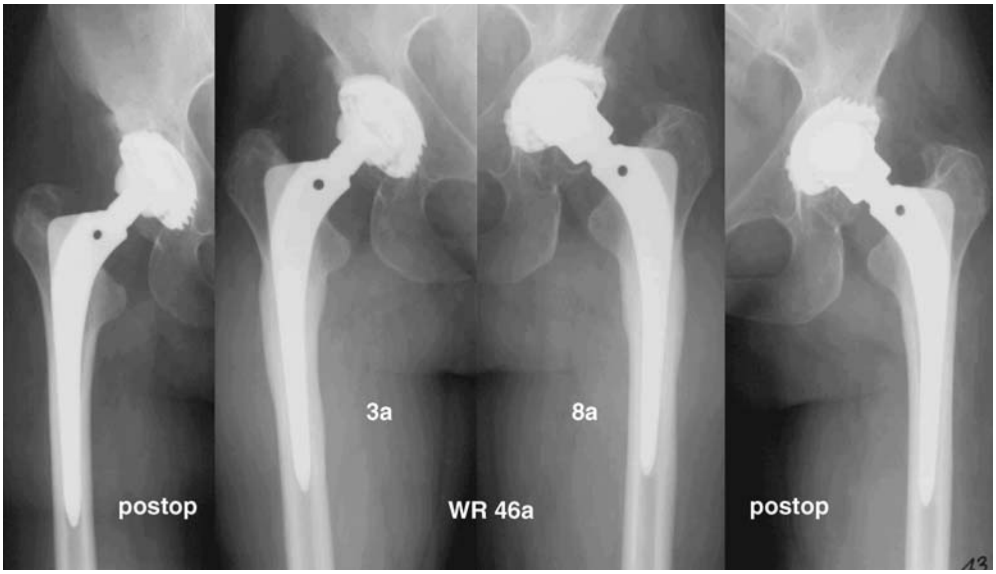


Fig. 5 External bone remodelling in a case of narrow femoral bone conditions

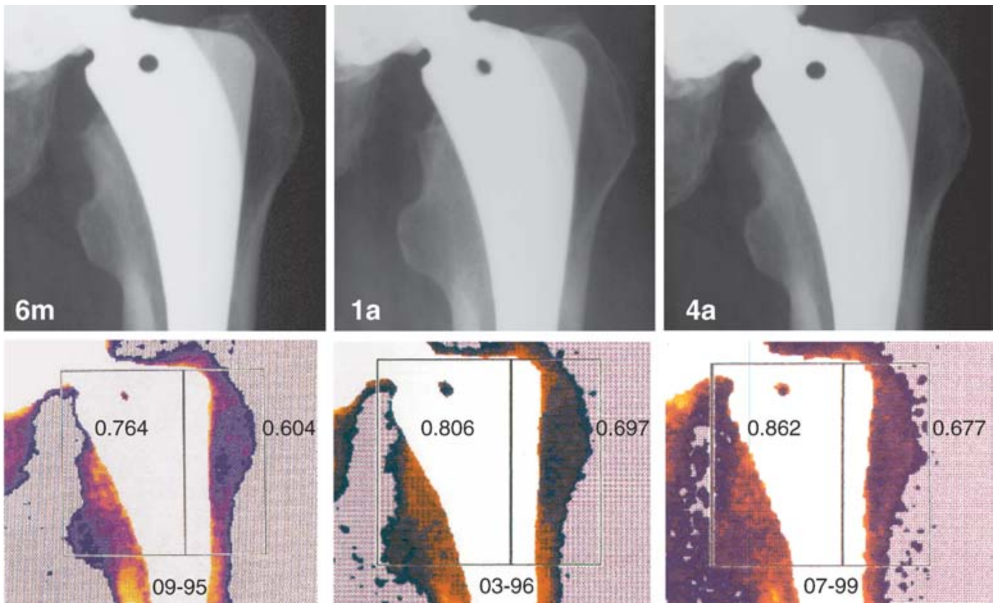


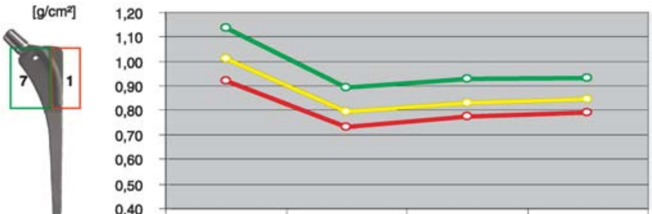
Fig. 6 DEXA osteodensitometry measurements of the proximal femoral bone region around the BiCONTACT hip stem

DEXA osteodensitometry measurements

In 1995, a consecutive series of 36 patients with unilateral BiCONTACT primary cementless metaphyseal fixed stem were serially assessed by DEXA-osteodensitometry. Two weeks after surgery, an X-ray of the hip joint was taken at two levels and osteodensitometry was carried out. Furthermore, density measurements were made the following day, and after 6 months, 1 year and 4 years. The bone density measurements were made using a DEXA XR bone densitometer. The position of the leg to be examined was controlled by a custom-made antirotation brace, which guarantees a rotationally stable and reversible position of the leg. The measurements were performed in Gruen zones 1 (proximal lateral third of the stem) and 7 (proximal medial third of the stem). The overall region "0" is composed of both regions.

In the global region "0", bone density showed an average percentage decrease in the first 6 month of 19.97% followed by a slight increase in the second 6 months. Qualitatively identical results were obtained for regions 1 and 7. In region 1, reduction of bone density in the first 6 months was 19.33% compared with 20.72% in region 7. During the second 6 months, bone density increased by 3.46% in region 1 and 2.33% in region 7. During the period up to 4 years, bone density increased by 5.3% in region 1 and 2.97% in region 7. Reduction in periprosthetic bone density in the proximal third of the BiCONTACT stem in plantar analysis was significant ($p<0.01$) in the first 6 months. However, further measurements at 1 and 4 years revealed that this remained static ($p>0.05$), and there was no further bone loss (normotrophic mineral density) (Fig. 7).

The fact that the stiffness of implants influences the extent of bone remodelling was demonstrated by Engh et al. [4] and Ang et al. [1]. The stress shielding for stem prostheses with large stem diameter appeared to be greater and was related to the increased rigidity of these prostheses. The average periprosthetic reduction in the proximal femur in BMD with BiCONTACT stems larger than size 15 was 31.81% after 4 years. In contrast with stem sizes below 15, the reduction was only 11.74% after 4 years. This supports the above observations that stem size and rigidity also influence bone remodelling.



	2 weeks	6 months	1 year	4 years
Region 7	1,14	0,90	0,93	0,93
Region 0	1,01	0,80	0,83	0,85
Region 1	0,92	0,74	0,77	0,79

Fig. 7 Change of metaphyseal bone mineral density after 6 months, 1 year and 4 years post-operation

Conclusion

The fate of a hip joint implant ultimately depends on implant/bone-interaction. Based on 15 years' experience with the BiCONTACT hip prosthesis, the system provides all criteria for a "state of the art" total hip replacement. Histological and radiological results indicate that the greatest bony integration of the prosthesis is to be found in the distal half of the Plasmapore coating. The reduction in periprosthetic bone density in the proximal third of the prosthesis was significant in the first 6 months. However, further measurements up to 4 years revealed that there was now further bone loss.

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