Is early bone resorption around non-cemented THA cups related to stress shielding?

IS EARLY BONE RESORPTION AROUND NON-CEMENTED THA CUPS RELATED TO STRESS SHIELDING?

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Introduction Bone resorption behind acetabular cups in non-cemented total hip arthroplasty (THA) is frequently reported. This is usually attributed to wear-particle related osteolysis. However, some studies reported bone resorption behind the cup in early stages after surgery, without any signs of focal osteolysis [1,2]. This may possibly be related to stress shielding of peri-prosthetic bone after placement of the acetabular cup. As bone density is maintained by mechanical stimuli in a biological regulatory process, bone density and strength will be adjusted locally if these mechanical stimuli are absent due to stress shielding. Although bone resorption related to stress shielding was studied extensively for the femoral side of THA reconstructions, this phenomenon was scientifically overlooked for the acetabular side. It is not obvious that stress shielding also takes place on the acetabular side, as a cup can be considered a surface replacement, lacking the ‘stress bypass’ phenomenon seen on the femoral side. The aim of the current study was to investigate the nature of the peri-acetabular bone-adaptation process and whether the adaptations can be explained by changes in mechanical loading of the bone after cup placement.

Methods *Radiographic study:* On informed consent, three patients were followed-up after primary non-cemented THA. All were treated with a press-fit HA-coated titanium cup (Stryker Howmedica Osteonics, Allendale, NJ, USA). Peri-acetabular bone density measurements were taken 0, 6, 12 and 25 weeks post-operatively using dual X-ray absorptiometry (DEXA) techniques. DEXA scans were taken in the anteroposterior direction (Fig. 1). Bone mineral density (BMD) was determined for the three Charnley DeLee zones [3] individually (Fig. 1). BMD values were expressed as a percentage of the BMD value directly post-operative.

Computer simulation study: Post-operative bone density adaptation around the cup was simulated by applying a strain-adaptive bone remodeling theory [4] to a finite element (FE) model of a human pelvis. The theory assumes that the peri-prosthetic bone reacts to a change in strain energy density (SED) relative to the pre-operative situation by locally adapting its density. Use was made of an extensively validated FE model of the intact human pelvis [5], adapted to include a non-cemented acetabular cup similar to the ones used in the radiographic study (Fig. 2). A variable Young’s modulus was assigned to all trabecular bone elements, based on the local bone apparent density as determined from CT-scans. The titanium cup was assumed to be completely bonded to the peri-prosthetic bone, simulating full bony ingrowth. Eight load cases were applied to the model repeatedly, representing eight phases out of the gait cycle. A total of 21 muscle forces were included in addition to the hip joint contact force. The latter was applied through a freely rotating titanium head. Bone density, hence also bone Young’s modulus, was adapted iteratively each time the eight load cases had been simulated. A DEXA simulation program was used to produce density scans of the FE model, thus allowing the predicted bone density adaptations to be compared to the patient measurements.

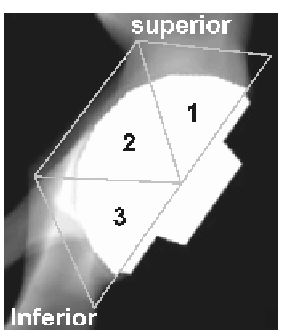

Fig. 1: DEXA scan of the acetabulum with definition of the three Charnley-DeLee zones.

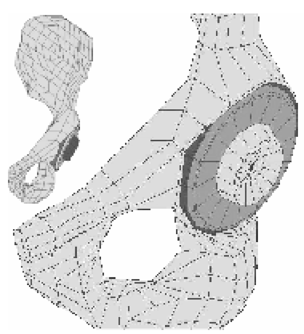

Fig. 2: Left half of the FE model with enlarged view on the reconstructed acetabulum.

Results Although the patterns of bone density development showed some variation between the patients in zone 1 and 3, a clear pattern of bone resorption was observed around the dome of the cup in zone 2 (Fig. 3). Bone resorption in that zone was generally preceded by bone apposition in zone 1. In two of the patients bone adaptation developed in a non-monotonous way in zone 1 starting with bone apposition, which was later reversed to bone resorption. In these two patients bone density changes in zone 3 were small. In the third patient bone density changes in zone 1 were small, whereas bone resorption was found in zone 3.

The computer simulation also predicted a non-monotonous development of bone density (Fig. 4). The bone adaptation process started with bone apposition superior to the cup in zone 1. Bone densification in this zone caused the SED-values around the dome of the cup in zone 2 to drop over time. This triggered considerable bone resorption in zone 2, and slight bone densification in zone 3. Just before the bone adaptation process reached a steady state, bone apposition was reversed to resorption in zones 1 and 3.

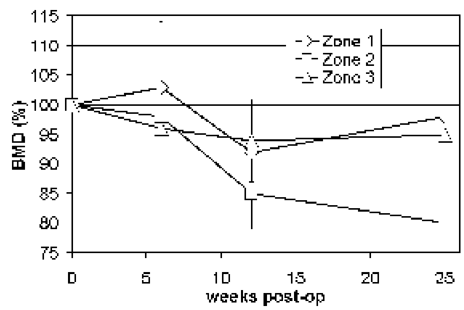

Fig. 3: Relative BMD changes as measured from the three patients

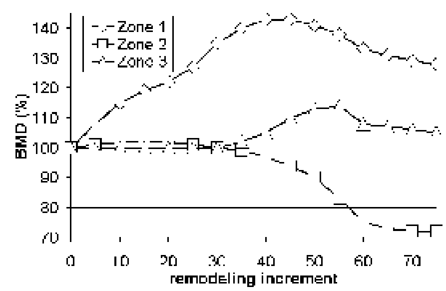

Fig. 4: Relative BMD changes as predicted by the FEA simulation

Discussion Although the relative BMD changes as predicted by the simulation did not correspond closely to the patient data in a quantitative sense, some remarkable qualitative similarities were found in the measured and predicted patterns of bone adaptation. The most striking similarity is considerable resorption in zone 2 around the dome of the cup. This is also the location for which bone resorption is often reported in the literature. Both the computer and patient data showed that bone resorption in zone 2 was preceded by bone apposition in zone 1. A third similarity is that both the computer predictions and patient data showed a non-monotonous development of bone density superior to the cup in zone 1. This is in contrast with the pattern of bone adaptation on the femoral side, where bone density decreases or increases monotonously.

In conclusion, the qualitative similarities between the computer predictions and the patient data indicate that the computer simulation is able to predict the nature of the bone adaptation process. This supports the hypothesis that bone density changes around the cup as observed in patients are caused by mechanical disuse.

References [1] Geesink et al, JBJS-Br. 4, 1995; [2] Wright et al, JBJS-Am. 83, 2001; [3] Charnley et al, CORR 121, 1976; [4] Huiskes et al, J Biomech 20, 1987; [5] Dalstra et al, J Biomech 117, 1995.

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