Original article

Bone mineral density of the proximal femur recovers after metal-on-metal hip resurfacing

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Summary

Bone resorption of the proximal femur is a frequent complication of total hip replacement. As hip resurfacing (HR) may load the bone more physiologically, we measured proximal femur bone mineral density (BMD) in 21 patients with HR. DEXA analysis was performed in the 7 Gruen zones and in the femoral neck pre-operatively and at 3, 9, and 24-months post-operatively. In Gruen zone-2 the BMD ratio decreased to 90±18.8% (p=0.0009) at 3-months and completely restored at 24-months to 100±17.7% (p=0.01). In Gruen zone-7 the BMD ratio decreased to 93±15.3% (p=0.05) by 3 months and surpassed the baseline to 105±14.8% (p=0.01) at 24-months. A positive correlation was observed between valgus positioning of the femoral component and BMD in Gruen zone-2 and 7 respectively. HR preserves the bone-stock of the proximal femur. When the femoral component is implanted in a valgus position BMD is further enhanced, thus potentially reducing the risk of femoral neck fractures.

KEY WORDS: Hip resurfacing, bone mineral density, dual-energy x-ray absorptiometry, valgus, metal-on-metal.

Introduction

Total hip replacement (THR) is one of the most successful orthopaedic procedures. Good long term clinical results and implant survival are reported in literature (1). Nevertheless, bone resorption of the proximal femur caused by stress shielding and wear debris is a possible complication of standard THR. This may lead to thigh pain, implant loosening, periprosthetic fracture and a difficult revision (2-6).
Metal-on-metal hip resurfacing (HR) offers several advantages compared to THR. These include femoral bone stock preservation, optimization of stress transfer to the proximal femur, enhanced joint stability and improved range of motion (7-9). Possible complications of HR included: femoral neck fracture (10), metal ion release (11) and adverse reactions to metal debris (12). HR is indicated for young and active patients affected by osteoarthritis, avascular necrosis, slipped femoral capital epiphysis, congenital hip dysplasia, and rheumatoid arthritis. Several studies show positive results and a low rate of complications at medium term (13-19).
Although bone preservation is a frequently reported advantage of HR there are only few dual-energy X-ray absorptiometry (DEXA) studies evaluating bone mineral density (BMD) of the proximal femur postoperatively. With HR good acetabular component positioning is crucial as increased metal wear is a well-known consequence of a steep cup (20). Furthermore, valgus implantation of the femoral component has been recommended as a tool to reduce the risk of femoral neck fractures. However, an excessive valgus orientation could be detrimental for the risk of femoral neck notching.
Although the position of the femoral component plays an important role in the loading of the proximal femur, few studies have been conducted to evaluate its influence on BMD changes over time (21).
The aim of this study was to evaluate the proximal femur BMD preoperatively and at 3, 9 and 24 months after HR. We also wanted to see whether there was a relationship between the position of the femoral component and BMD changes.

Materials and methods

Between January 2001 and May 2003, a prospective study using DEXA was performed to follow the changes in BMD of the proximal femur after HR with the Birmingham hip resurfacing (BHR) implant (Midland Medical Technologies, Birmingham, UK) (Note BHR is now manufactured by Smith & Nephew, Birmingham UK).

Patients

Twenty-one patients (12 men and 9 women) with an average age of 49.3±12.4 years (range, 24-73 years) affected by primary osteoarthritis of the hip were recruited for this study. Patients with bone metabolic disease or previous surgery of the ipsilateral femur were excluded.

Surgical technique

All the operations were performed by a single surgeon through a postero-lateral approach. A BHR hydroxyapatite-coated cup was fixed without cement while the BHR femoral component was fixed with low-viscosity cement (Surgical Simplex P; Stryker Howmedica, Allendale New Jersey). Cementing around the short stem of the femoral component was avoided.

Rehabilitation protocol

After surgery, the patients were allowed to walk with crutches with

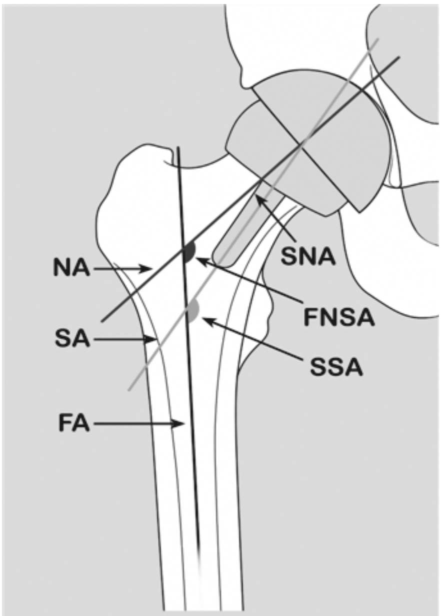

Figure 1 - The femoral neck axis (NA), stem axis (SA), femoral axis (FA), stem-neck angle (SNA), femoral neck-shaft angle (FNSA), and stem-shaft angle (SSA).

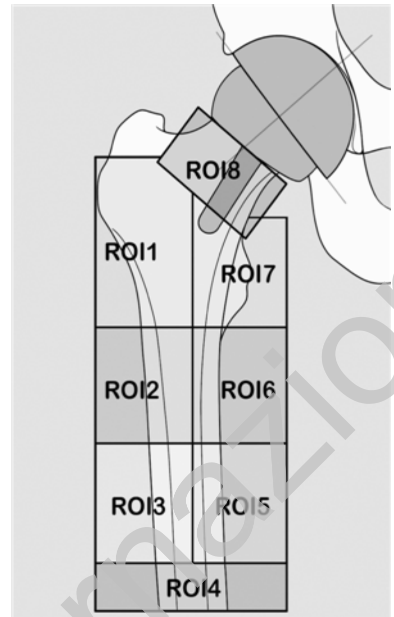

Figure 2 - Regions of interest, measured by dual-energy X-ray absorptiometry. The proximal part of the femur was divided into 7 zones (ROI 1-7) according to Gruen et al. , ROI-8 was located in the femoral neck.

partial weight bearing during the first 4 weeks, and then to progress to full weight bearing over the next month. The majority of the patients returned to a high level of activity 6 months after surgery, and a few patients even returned to impact sports such as tennis or jogging.

Clinical and radiological evaluation

Clinical evaluation, using the Harris Hip Score (22) was performed before surgery, and 3, 9 and 24 months after the operation. At the same time an antero-posterior radiograph of the pelvis was taken; the stem-shaft angle (SSA) and stem neck angle (SNA) were calculated on the X-ray (Figure 1).
At the baseline and at the scheduled follow-up, the BMD of the proximal femur was measured by DEXA (Norland XR 36). The software (Orthopaedic Software, version 1.3.6; Norland) used in our study was designed to measure periprosthetic bone mineral content and density of the proximal femur. The resolution of the scan was 1.0 x 1.0 mm. The mean time for taking a scan was 3,02 minutes and the mean scan dose was 0,39 mrem. The patients were placed supine on the table with standard knee and foot supports so that the femur was in a neutral position.
In total, eight regions of interest (ROIs) in the proximal femur were determined for measuring the BMD. Seven of eight ROIs were defined according to the protocol of Gruen et al. (23) and one ROI was located in femoral neck around the short stem (ROI-8) (Figure 2).

Statistical analysis

All statistical analyses were carried out using the SPSS (Statistical Package of Social Sciences, Chicago, IL, USA) for Windows software program version 13.0. A p value of less than 0.05 was considered statistically significant.
The results are expressed as mean ± SD. The paired Student t-test was used to test for significant differences between baseline and various follow-up measurements.
Linear regression analysis by Pearson's formula was performed to determine correlation coefficients between BMD variations during the study follow-up and varo/valgus positioning of the femoral component.

Results

Twenty-one patients completed the study protocol. No patients showed radiological evidence of aseptic loosening or osteolysis during the follow-up period.

Clinical outcome

The clinical outcome was excellent in all patients. Average preoperative HHS was 54±7 (range: 41-68) points and improved to 89±8 (68-100) at 3 months, 93±7 (79-100) at 9 months and 96±4 (87-100) at 24 months follow-up.

Implant positioning

Average NSA was 135°±10° (range: 112°-156°), average SSA was 141°±6° (range: 132°-158°). The difference between SSA and NSA was defined as the stem-neck angle (SNA) and represents the varus-valgus orientation of the femoral component. Average SNA was 6.2°±7° (range: 21°- -6°). According SNA, 15 patients had a valgus orientation of the femoral component (SNA > 0°), 5 patients had a varus orientation (SNA < 0°) and one patient had a neutral alignment of the femoral component (SNA = 0°).

DEXA analysis

Table 1 shows the changes of BMD ratios (%) and BMD values in proximal femur in each of the ROIs examined.
In ROI-1 the mean BMD ratio decreased during the first 3 months to 93±15.9% (p=0.0006) and increased to 94±15.4% at 9 months

Table 1 - BMD Ratios (%) and BMD values expressed as g/cm^2 in the 8 ROIs pre-operatively and at 3, 9 and 24 months follow-up after hip resurfacing.

ROI	Pre-Op	3 months	9 months	24 months
ROI-1	100% 0.818	93,2% 0.761	94,5% 0.771	98,5% 0.802
ROI-2	100% 1.219	90% 1.099	96% 1.166	101% 1.220
ROI-3	100% 1.681	96.9% 1.633	98.1% 1.651	99% 1.655
ROI-4	100% 1.749	99% 1.732	99.% 1.732	100.1% 1.766
ROI-5	100% 1.675	97.5% 1.633	97.6% 1.651	99.4% 1.665
ROI-6	100% 1.313	97% 1.277	100.8% 1.325	105.3% 1.381
ROI-7	100% 1.118	93.2% 1.043	99.4% 1.109	105.3% 1.171
ROI-8	100% 0.912	91.9% 0.834	97.8% 0.890	102.2% 0.929

and 98±14.5% at 24 months (p=0.02). An analogous trend was observed in ROIs-2, 6, 7 and 8.

In ROI-2 the BMD ratio decreased to 90±18.8% (p=0.0009) at 3 months follow-up and completely restored at 24 months to 101±17.7% (p=0.01).

At 3 months' follow-up, in ROIs-6, 7 and 8 the BMD ratio decreased to 97±16.9% (p=0.04), 93±15.3% (p=0.05) and 91±16.8% (p=0.002) respectively. At 24 months, the BMD ratio restored surpassed the baseline value to 105±15.7% (p<0.0001), 105±14.8% (p=0.01) and 102 ±18.1% (p<0.0001) in ROIs-6, 7 and 8 respectively.

A different trend was observed for ROIs-3, 4 and 5. BMD ratio decreases slightly at 3 months to 97±15.2% (p=0.002), 99±13.4% (p=0.16) and 97±14.1% (p=0.008) respectively. At 24 months' follow-up, an almost-complete return to the baseline value was detected in ROIs-3, 4 and 5; the BMD ratio was 99±14.6% (p=0.28), 100±13.6% (p=0.12) and 99±13.7% (p=0.08) respectively.

In ROI-2 a positive correlation was found between SNA and BMD ratio at 9 and 24 months follow-up respectively (9 months: r=0.433, p<0.05, 24 months: r=0.417, p<0.05). An analogous correlation was observed in ROI-7 at the same follow-up (9 months: r=0.399, p<0.05, 24 months: r=0.481, p<0.02) (Figure 3).

Discussion

Although THR represents the most effective solution for elderly patients affected by osteoarthritis of the hip, HR has provided a viable alternative to standard THR in young and active patients with good bone quality. The advantages of HR over THR include: the preservation of femoral bone stock, wider range of motion, a lower risk of dislocation and eventually an easier revision surgery. Moreover, resorption of proximal bone around femoral stems is a common phenomenon in stable cementless THA (24-26). This is thought to represent bone atrophy because of mechanical unloading, in accordance with Wolff's Law. Loss of periprosthetic bone may lead to periprosthetic fracture, reduced prosthesis stability, and difficult revision. Maintenance of proximal femoral bone quality is thought to require normal transfer of load to the proximal femur. HR represents a viable solution to overcome this negative aspect.

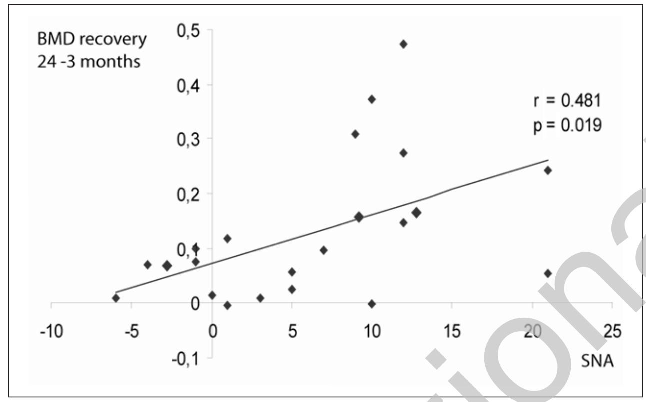

Figure 3 - The positive correlation between SNA and BMD recovery in ROI-7 at 24 months follow-up.

As reported by Harty et al. (27) HR transfers load to the proximal femur in a more physiological manner, prevents stress shielding, and preserves the bone stock of the proximal femur. In their study at 18 months follow-up the BMD of the femoral neck was slightly increased on the prosthetic side as opposed to the contralateral side although this difference did not reach statistical significance.

In another clinical study, Kishida et al. (15) reported that the median BMD loss was 11% in Gruen zone 1 and 17% in Gruen zone 7 at 2 years after THA. Conversely after BHR, the BMD in Gruen zone 1 remained at almost 100% and improved by 11% in Gruen zone 7 at 2 years follow-up.

Our study shows that significant bone loss in the proximal femur occurred during the first 3 months following HR. Although a decrease in BMD was observed in all ROIs, the largest bone loss occurred in ROIs-1, 2, 6, 7 and 8.

In ROIs-3, 4, 5, which are far from the implant and consequently less influenced by its presence, the BMD decreased slightly at 3 months and subsequently recovered almost the baseline value at 9 and 24 months.

During the first 3 months, patients underwent a transition from partial to full weight bearing, and the effects of immobilization and incomplete weight-bearing might explain the bone loss occurring during this period, especially in the ROIs nearest to the prosthesis. At 9 months, the bone remodelling appeared to be still in progress and an almost complete recovery of BMD was observed in ROIs-2, 6, 7 and 8 by this time, with a further improvement at 24 months. The recovery of BMD observed in ROI-1, although present, proceeded slightly compared to the nearby ROIs. At 9 and 24 months, the BMD ratio reached 94.5% and 98.5% of the baseline respectively. ROI-1 was probably an area with a lower speed of bone remodelling; a similar result was observed by Kishida et al. (15) and Hayaishi et al. (28).

A possible limitation of our study was that the femoral neck was evaluated as a single ROI (ROI-8). In other similar studies (7, 29) the measurement of the BMD of the femoral neck was performed in 6 different locations around the short stem (proximal-lateral, midlateral, distal-lateral, proximal-medial, mid-medial, distal-medial). Considering that no significant difference was reported in the variation of BMD over time between these locations, we hypothesized that the femoral neck should be evaluated as a single ROI.

In the present study, the BMD changes in the femoral neck were similar to those observed in the nearby ROIs with a BMD ratio that

surpassed the baseline value at 24 months. This result is in accordance with those reported by other authors (15, 21).
Although HR has been proved to be the most direct way to maintain load on the proximal femur, with the force acting on the hip being transmitted by the femoral neck, little is known about the influence of the position of the femoral component on BMD.
A recent study carried out by Anglin et al. (29) reported that valgus positioning of the femoral component increases the fracture load by an average of 28% over neutral for specimens with normal bone mineral density. Nevertheless, component placement greater than 10 degrees valgus is probably undesirable because this can lead to an increase in component size and a greater likelihood of notching which has been described as a cause of femoral neck fracture (30).
In this study a significant positive correlation was found between SNA and BMD recovery in ROIs-2 and 7 both at 9 and 24 months. This result suggests that the BMD in the proximal femur would increase significantly, when the valgus positioning of femoral component was performed during HR. The fact that this correlation reached the level of significance only in ROIs-2 and 7 might be explained by the orientation of the small stem of the prosthesis, which could transfer most of the load in these two particular ROIs.
In a similar study Lian et al. (21) reported that implanting the femoral component with a stem-shaft angle of at least 5° greater than femoral neck-shaft angle, the BMD in the femoral neck was restored to 100% by 6 months and increased more significantly by 24 months. On the contrary, the BMD did not restore to 100% until 12 months in femoral neck after BHR, when the femoral component was implanted with a stem-shaft angle that was not more than 5° over the neck-shaft angle.
Although our study supports the positive effect of valgus positioning of the femoral component, differing from that of Lian et al., we did not observe an effect of implant orientation on BMD recovery in the femoral neck. This apparently controversial result is due to the fact that Lian et al. split the femoral neck into two different ROIs; one medial and one lateral, with two different trends. Only the medial ROI was influenced by the implant positioning.
Another possible limitation of this study is the small number of patients with varus orientation of the femoral component. Davis et al. studied the effect of the alignment of the femoral component in a cadaveric study showing how varus orientation significantly reduce femoral neck strength (31). Varus alignment should be avoided hence is difficult to obtain a wide control group in order to better evaluate its influence on BMD.
Another important issue is that wear debris can also cause resorption of bone and there have been reports of high rates of failure for HR (32).
Watanabe et al. in a finite element analysis study observed stress shielding in the anterosuperior regions of the cancellous bone cross sections near the femoral component rim, nevertheless on the cortical bone stress distribution was not influenced by the presence of the implant (33). Although is difficult to compare a finite element analysis study with a clinical study, we believe that Watanabe et al. did not consider the real shape of the femoral head after reaming. The region in which stress shielding is supposed to be preset is actually removed by femoral head preparation. We believe that our in vivo study in which bone remodelling and implant orientation play as crucial elements should lead to more reliable results and might explain this difference.
The BHR uses an as-cast cobalt-chromium metal-on-metal bearing to eliminate aggressive wear and osteolysis. As a result, we presume that wear debris had a negligible effect on the BMD in our study.
Our results show that HR transfers load to the proximal femur in a more physiological manner, prevents stress shielding and preserves the bone stock of the proximal femur. The valgus positioning of the femoral component, plus avoiding femoral neck notching, can increase compressive stress in proximal femur and enhance the stability of the femoral component. Good bone quality is mandatory for HR survival over time. Maintaining a high mineral density of the proximal femur may reduce the risk of femoral neck fractures.
Although these promising positive results, this study evaluated a small patients' population at short follow-up and caution still needs to be exercised until longer term results are available.

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