

# Periprosthetic proximal bone loss after uncemented hip arthroplasty is related to stem size

## DXA measurements in 138 patients followed for 2–7 years

Olof G Sköldenberg, Henrik S G Bodén, Mats O F Salemyr, Torbjörn E Ahl and Per Y Adolphson

Division of Orthopaedics, Karolinska Institutet at Danderyd Hospital, Stockholm, Sweden

Correspondence OGS: olof.skoldenberg@ds.se

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**Background** Periprosthetic bone loss occurs around uncemented femoral stems and may be influenced by the stem size.

**Patients and methods** We studied 138 consecutive patients, 3 (2–7) years on average after a total hip arthroplasty operation (THA) for unilateral osteoarthritis with the Bi-Metric uncemented femoral stem. We analyzed Harris hip score and bone mineral density.

**Results** The mean Harris hip score was 97 at follow-up. Bone mineral density decreased proximally by 19% in both Gruen zones 1 and 7. Bone loss in zones 1, 2, 6, and 7 was significantly associated with stem size. Distally, a small gain in bone mass was found in zones 3 and 5 for medium femoral sizes.

**Interpretation** We found a marked proximal BMD loss, especially for the larger stems, which may be specific for this particular implant. Long-term studies should reveal whether this proximal bone loss will affect the longevity of the THA.

In recent years, the most common designs with porous-coated femoral components or those with ceramic coating such as hydroxyapatite have shown promising mid-term results (McLaughlin and Lee 1997, McNally et al. 2000). However, a remodeling of the periprosthetic bone of the proximal femur has been noted and gives cause for concern (Dorr et al. 1997, Khalily and Whiteside

1998). A well-fixed stem distally seems to cause stress-shielding, with proximal bone resorption (Engh et al. 1992, Kilgus et al. 1993). Prosthetic designs with only proximal coating (Khalily and Whiteside 1998), iso-elastic materials (Jacobsson et al. 1993, Ang et al. 1997) and short femoral components (Morrey et al. 2000) have all been designed to reduce this remodeling.

One long-standing concern is that asymptomatic bone loss may lead to implant subsidence, aseptic loosening or periprosthetic fractures around the stem. One factor known to influence the periprosthetic BMD is stem size of the femoral implant (Huiskes et al. 1992, Nishii et al. 1997), especially after insertion of a stem with a large diameter (Maloney et al. 1996). To achieve “fit and fill”, uncemented stems are typically larger than cemented stems. From a mechanical standpoint, increased stem size results in increased stiffness and subsequently to greater stress-shielding. We have previously found remodeling and proximal bone loss after uncemented THA with the Bi-Metric femoral stem (Bodén and Adolphson 2004). Changes in periprosthetic BMD after THA can be assessed with high precision by DXA (Cohen and Rushton 1995, Venesmaa et al. 2001). This study was undertaken to investigate the extent of periprosthetic bone loss and its relationship to femoral stem size after implantation of the uncemented Bi-Metric femoral stem.

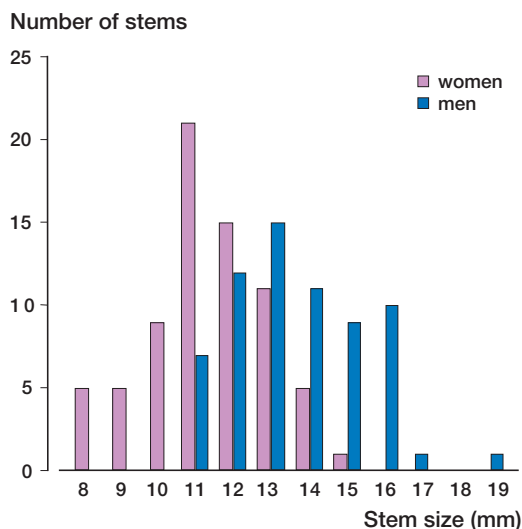


Figure 1. The distribution of femoral stem diameters.

### Patients and methods

179 primary unilateral THAs were performed with the uncemented Bi-Metric femoral implant at Danderyd Hospital from 1997 through 2001. 31 patients were excluded from this study (because of rheumatoid arthritis in 15 patients, peroperative or postoperative fractures of the femur in 7, corticosteroid treatment as a result of systemic illness in 6, congenital hip dysplasia with abnormal anatomy of the proximal femur in 2, and peroperative damage to the sciatic nerve in 1). 10 other patients were lost to follow-up (4 died, 2 refused to participate and 4 could not be reached). Thus, 138 patients (66 men) with the following characteristics were included in the study: mean age 58 (37–91) years, mean weight 81 (47–120) kg, and mean height 171 (146–198) cm. The patients were operated on because of primary arthrosis (89%), congenital hip dysplasia (4%), posttraumatic arthritis (2%), and other diseases (5%). The distribution of stem sizes in the patients is shown in Figure 1.

All patients were operated on through a standard posterior approach. A 28-mm cobalt-chrome head was used for all patients. On the acetabular side, the patients received either an uncemented hydroxyapatite-coated cup with a cylindrical polyethylene liner (74 patients) or a cemented polyethylene cup (64 patients). After surgery, the patients were mobilized on the day after the operation. Postoperative

weight bearing was individualized according to the surgeon's wishes. No protocol regarding weight bearing or use of crutches was used.

Within 6 weeks of surgery, 16 non-fatal complications (7 superficial wound infections that required antibiotics, 4 deep venous thromboses, 3 pulmonary emboli, and 2 myocardial infarctions) were diagnosed. All patients were studied after a mean of 41 (24–80) months after surgery, which included clinical examination, radiographical assessment and DXA measurement.

We recorded Harris hip score. Standard antero-posterior and lateral radiographs were taken immediately after surgery and at the time of survey. All radiographs were examined for prosthetic migration and remodeling changes (Engh et al. 1990).

The BMD of the periprosthetic femur was measured in the coronal plane by DXA (DPX-L, Lunar Co., Madison, WI). Avoiding interference from the femoral implant, the software detected the interface between the bony part and the prosthesis stem on the basis of density changes and simulated the stem in the form of a prosthesis mask, which was superimposed on the healthy side. The healthy hip was scanned at the corresponding level and BMD in 7 regions of interest, based on Gruen zones, was analyzed. The values were expressed as areal BMD in  $g/cm^2$ . The differences in BMD were compared with stem size and correlated to sex, age, weight, height, body mass index, implant time, initial BMD—expressed as BMD on the healthy femur—and Harris hip score.

To estimate the precision error of the DXA method, we had previously made double measurements in 10 patients with complete repositioning of the patients and the scanner. The precision error was found to be 2.3% in Gruen zone 1, 1.0% in zone 2, 2.0% in zone 3, 3.5% in zone 4, 4.2% in zone 5, 1.3% in zone 6, and 3.7% in zone 7 (Bodén and Adolphson 2004). This precision is of the same order as reported by Kilgus et al. (1993) and Nishii et al. (1997).

The investigation was approved by the ethics committee of Karolinska Hospital (D.nr approval no. 04-011/3). The patients also gave their informed consent before inclusion into the study.

### Statistics

The mean values (SD) were calculated for absolute

BMD in the 7 Gruen zones for all stem sizes. Mean values (SD)

Gruen zone	Operated side (g/cm <sup>2</sup> )	Unoperated side (g/cm <sup>2</sup> )	Change (%)
1	0.85 (0.16)	1.05 (0.17)	-19 (11)
2	1.81 (0.28)	1.85 (0.26)	-2 (10)
3	2.00 (0.25)	1.92 (0.25)	+5 (8)
4	1.91 (0.29)	1.95 (0.26)	-2 (9)
5	2.09 (0.23)	1.99 (0.23)	+5 (7)
6	1.78 (0.28)	1.87 (0.23)	-5 (10)
7	1.09 (0.29)	1.35 (0.24)	-19 (15)

change and percentage change in BMD. Student's t-test was used to analyze the difference between the legs (paired observations) and also the differences between stem sizes in the different Gruen zones (unpaired observations). To investigate factors that may influence bone remodeling, we used the Pearson's product moment correlation coefficient to analyze the relationship between BMD and sex, age, weight, height, body mass index, implant time, initial BMD—expressed as BMD on the healthy femur—and Harris hip score. The statistical analyses were performed with the statistical package JMP (SAS Institute Inc., Cary, NC). Dif-

ferences were considered significant at p-values of less than 0.05.

**Results**

At follow-up, the mean Harris hip score was 97 (63–100) points with only 6 patients having slight thigh pain. There were no signs of stem loosening.

The mean BMD values and the percentage change for all implants in the different Gruen zones are summarized in the table. BMD loss most pronounced in zones 1 and 7 (Figure 2). All stem sizes caused significant bone loss in zone 1 (Figure 3). There was a decrease of 2% in zone 2. The 15-mm and 16-mm stems lost 8% and 9%, respectively, and these were the only stems that gave statistically significant losses ( $r^2 = 0.091$ ,  $p < 0.001$ ). The BMD in zone 3 showed a gain of 5%. Stem sizes of 10 mm (7%), 12 mm (7%), 13 mm (5%), 14 mm (5%) and 15 mm (5%) were significantly increased. No correlation between stem size and BMD gain was found. In zone 4, a BMD loss of 2% was found. Stem size 11 mm decreased by 5% and was the only size that showed significant change. We found

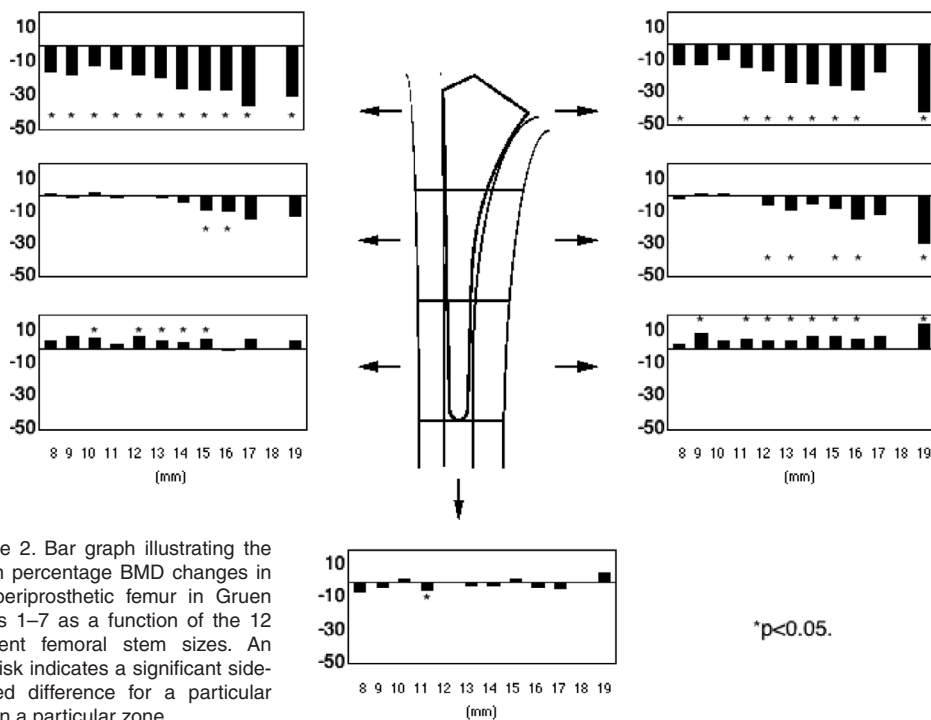


Figure 2. Bar graph illustrating the mean percentage BMD changes in the periprosthetic femur in Gruen zones 1–7 as a function of the 12 different femoral stem sizes. An asterisk indicates a significant side-related difference for a particular size in a particular zone.

\*p<0.05.

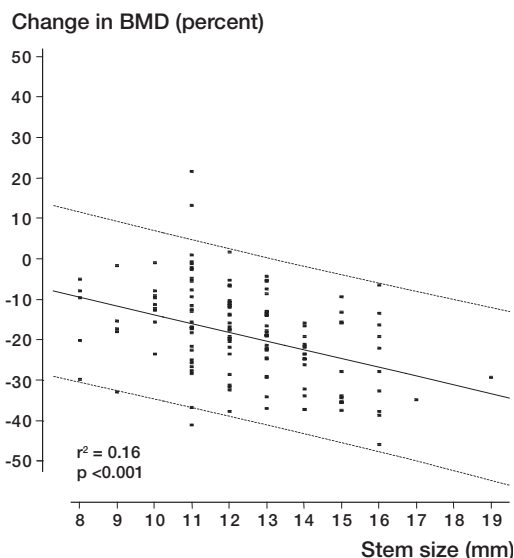


Figure 3. Correlation between stem size and BMD ratio (percentage of the contralateral value) in Gruen zone 1. Regression line and 95% confidence intervals are given.

no correlation between stem size and bone loss in this zone. A gain of 5% was found in zone 5. Sizes 9 mm, 11–16 mm, and 19 mm were all significantly increased with a gain of 4–15%. However, we found no correlation between stem size and change in BMD. In zone 6, there was a BMD loss of 5%. Stem sizes 12 mm (–5%), 13 mm (–7%), 15 mm (–7%), 16 mm (–14%), and 19 mm (–29%) were significantly reduced. The correlation analysis indicated a strong relationship between stem size and bone loss ( $r^2 = 0.16$ ,  $p < 0.001$ ). Finally, in zone 7, the mean BMD loss was 19%. The correlation analysis yielded  $r^2 = 0.14$ ,  $p < 0.001$  (Figure 4).

Multiple regression analysis with stem size as the control variable showed no correlation between bone loss of the operated femur in any zone and sex, age, weight, height, body mass index, implant time, initial BMD—expressed as BMD on the healthy femur—or Harris hip score. In addition, we did not find any difference in BMD loss in any zone between the patients who received an uncemented hydroxyapatite-coated cup and those who received a cemented polyethylene cup.

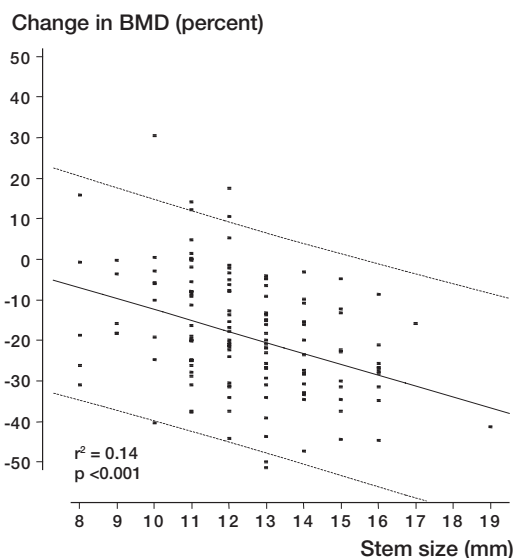


Figure 4. Correlation between stem size and BMD ratio (percentage of the contralateral value) in Gruen zone 7. Regression line and 95% confidence intervals are given.

## Discussion

The clinical outcomes in our study are similar to those of other studies with the Bi-Metric stem and other uncemented porous-coated THAs from a mid-term standpoint (Robertsen et al. 1996, Meding et al. 2004). Most patients had an excellent clinical outcome, with only 6 patients (4%) complaining of slight thigh pain, and there was no loosening of any stem. We did, however, find pronounced bone resorption of the proximal femur. There is concern that bone loss may lead to osteolysis, with loosening of the stem or a periprosthetic fracture. Although there is no evidence that bone resorption causes clinical symptoms or complications, a large amount of—or continuous—femoral bone resorption may reduce the stability of the stem.

Retrospective studies using contralateral comparisons have shown a 40% decrease in proximal femoral BMD after 7–14 years (McCarthy et al. 1991). Kilgus et al. (1993) noted largest BMD loss (35%) in the most proximal 1 cm of the medial femoral cortex. Longitudinal studies have also been performed (Trevisan et al. 1997, Venesmaa et al. 2001), confirming the results of cross-sectional studies.

There was a significant correlation between stem size and periprosthetic change in BMD in zones

1, 2, 6 and 7. Stress-shielding and disuse atrophy are considered to be the main factors contributing to BMD loss after THA (Engh and Bobyn 1988, Bryan et al. 1996). Engh et al. (1987) noted that stems equal to or greater than 13.5 mm showed 5 times the amount of resorption of those 12 mm or less. The concept of stems that mimic the elasticity of the normal femur, i.e. isoelastic stems, was introduced to reduce stress-shielding and subsequent bone loss (Morscher and Mathys 1974, Butel and Robb 1988). Earlier isoelastic stems have suffered from early loosening and a high revision rate (Nistor et al. 1991, Jacobsson et al. 1993, Niinimäki et al. 1994). However, Glassman et al. (2001) and Kärrholm et al. (2002) presented good results with the Epoch isoelastic stem.

DXA is an accurate and reproducible method for measurement of bone remodeling (Kalender 1992). It is possible to measure the quantity of bone near a metallic implant accurately (Kiratli et al. 1996, Kröger et al. 1996, 1997). The accuracy error of DXA in the femur is less than 3% (Barden and Mazess 1989). The precision error of the method is also low: 1.1–5.3% (Cohen and Rushton 1995, Kröger et al. 1996). We have previously found a precision error of the same order (Bodén and Adolphson 2004).

A large degree of bone loss of the proximal femur has been identified in longitudinal studies as early as 3–6 months after implantation of an uncemented stem; thereafter, the BMD stabilizes during the first postoperative year (Marchetti et al. 1996, Nishii et al. 1997, Wixson et al. 1997, Kröger et al. 1998). None of our patients were measured until 2 years after surgery. We could not find any correlation between implant time and bone loss in any zone, and we therefore conclude that one can use varying follow-up time beyond 2 years.

Factors that could influence periprosthetic bone remodeling after THA include sex, age, weight, density of bone, activity level, diagnosis, disease state, medications, duration of implantation, and stem stiffness. Different researchers have found conflicting results regarding the effect of anthropometrical factors on bone remodeling. Thus, Brodner et al. (2004) found a correlation between gender and BMD in most Gruen zones, and between age and BMD in Gruen zones 1 and 7. However, Korovessis et al. (1997) did not find any

correlation between age and BMD changes; only body mass index correlated with BMD in zone 3 in their study. Kärrholm et al. (2002) evaluated possible confounding factors (sex, age, weight, diagnosis, BMD and stem size) immediately after the operation, and found that periprosthetic BMD was influenced only by stem design. Kiratli et al. (1996) reported that weight was the only variable that affected bone remodeling. Maloney et al. (1996) found that patients with low weight lost more bone distally. We could not find any correlation between anthropometrical factors and BMD loss.

There is controversy as to whether preoperative BMD predicts the rate of bone loss after THA. Some authors have found that the lower the BMD is before the THA, the larger the BMD loss becomes after the THA (Nishii et al. 1997). However, Aldinger et al. (2003) did not find any correlation between initial BMD and degree of periprosthetic bone loss. Using multiple regression analysis with stem size as control variable, we could not find any correlation between BMD loss on the operated side and initial BMD (expressed as BMD on the unoperated side) in any zone.

Bone atrophy depends on stem elasticity (Ang et al. 1997): the stiffer the stem, the greater the atrophy (Bobyn et al. 1992). Also, femoral stem size and amount of hydroxyapatite coating may influence BMD (Bobyn et al. 1992). Some authors have found a correlation between femoral stem size and proximal bone loss (Engh and Bobyn 1988, Nishii et al. 1997), while other investigators have found no such correlation (Petersen et al. 1995, Yamaguchi et al. 2000, Sychterz et al. 2001). Petersen et al. (1995) concluded that the Taperloc prosthesis design transferred the load in a way that made the stem size of minor importance. However, these authors used a prosthesis with sizes ranging from 7.5 to 15 mm and studied only 22 patients, so the number of hips of any specific size was probably too low. Thus, it is doubtful whether their study had sufficient power to indicate whether size is associated with bone loss with this prosthesis.

Our investigation has some limitations. It is a cross-sectional study in which periprosthetic BMD is compared to the value of the healthy side. This could be a cause of error because of a possible side-related difference in bone mass preoperatively. Some authors have found a lower BMD on the

arthrosis side before operation (Kiratli et al. 1996, Martini et al. 1999). Thus, the BMD difference found in cross-sectional studies could be overestimated, and only a longitudinal study would give more accurate information about the remodeling process. In a cross-sectional study, it is important to perform the investigation after the changes have stabilized. We found no correlation between duration of implantation and BMD changes in any zone; thus, we conclude that a longer implant time would not have affected the results. Also, Hughes et al. (1995) considered that approximately 3 years—after which time most remodeling was complete—is an optimum time to assess atrophy of the proximal femur.

In conclusion, we found that this uncemented femoral prosthesis induced a large degree of bone loss in proximal periprosthetic zones. Intervention with antiresorptive drugs should be considered to inhibit this bone loss. Long-term studies will reveal whether this proximal bone loss is a negative factor for the longevity of this uncemented THA.

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#### *Contributions of authors*

OS examined all patients, collected the data and prepared the manuscript. HB and MS performed the clinical investigations and wrote manuscript. The senior authors, TA and PA, designed the study and supervised the statistical analyses.

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