Changes in bone mineral density in the proximal femur after cementless total hip arthroplasty

A FIVE-YEAR LONGITUDINAL STUDY

W. Brodner, P. Bitzan, F. Lomoschitz, P. Krepler, R. Jankovsky, S. Lehr, F. Kainberger, F. Gottsauner-Wolf

From Vienna General Hospital and the University of Vienna, Austria

We investigated prospectively the bone mineral density (BMD) of the proximal femur after implantation of a tapered rectangular cementless stem in 100 patients with a mean age of 60 years (16 to 87). It was determined using dual energy x-ray absorptiometry, performed one week after surgery and then every six months until the end-point of five years.

The BMD increased significantly in Gruen zones 2, 4 and 5 by 11%, 3% and 11% respectively, and decreased significantly in Gruen zones 1, 6 and 7 by 3%, 6% and 14% respectively, over the five-year period. The net mean BMD did not change over this time period. The changes in the BMD were not confined to the first 12 months after surgery. This investigation revealed no change in the overall periprosthetic BMD, but demonstrated a regional redistribution of bone mass from the proximal to distal zones.

J Bone Joint Surg [Br] 2004;86-B:20-6.

Received 19 May 2003; Accepted after revision 18 July 2003

Mechanical load forces continuously expose bone to remodelling processes according to Wolff's law. Increased load leads to a gain of bone mass, and reduced load results in a

loss. The implantation of a total hip arthroplasty (THA) changes the distribution of mechanical forces around the hip joint.¹ Serial radiographs,² dual-energy x-ray absorptiometry (DEXA),³⁻¹⁹ and quantitative CT^{20,21} have been used and evaluated in understanding changes in bone density. Retrospective densitometric analysis of serial radiographs has been found to be unreliable, because of differences in exposure, intensity of the radiation field, target distance and femoral rotation.²² Also, interobserver consensus on periprosthetic bone loss from radiographs only emerges after 70% of the bone has been lost.²³ DEXA is now widely recognised as the method of choice for assessing changes in bone mass around prostheses.²⁴ It is reliable having a reproducibility of measurement with a precision error of 5% or less.^{9-12,14,15,19,25} Changes in bone mineral density (BMD) due to femoral rotation^{5,26} are controlled by positioning devices.²⁵ Most bony remodelling around femoral stems takes place during the first six to 12 months after implantation,^{8,14,17-19} but subsequent changes have also been observed.^{13,15,27}

Our aim was to describe changes in the periprosthetic BMD of the proximal femur as a function of altered mechanical demands after the implantation of a cementless titanium tapered rectangular stem.

Patients and Methods

We studied 100 consecutive patients prospectively over five years after the implantation of a cementless total hip prosthesis. The selection criteria were unilateral osteoarthritis or avascular necrosis of the femoral head. Patients with rheumatoid arthritis or other joint arthroplasties were excluded. There were 70 women and 30 men with a mean age at the time of surgery of 60 years (16 to 87). The indications for surgery were primary osteoarthritis in 70, avascular necrosis in 16 and secondary osteoarthritis in 14 (12 after developmental dysplasia of the hip, and two after childhood joint infection).

An Alloclassic total hip prosthesis consisting of an SL Ti6Al7Nb tapered rectangular stem, and a CSF commercially pure titanium threaded metal cup (Centerpulse Orthopaedics Ltd, Baar, Switzerland), was implanted in all patients. Half of the patients had an Al₂O₃ ceramic-on-UHMWPE articulation (BioloX, CeramTec AG, Plochingen,

W. Brodner, MD, Consultant Orthopaedic Surgeon
P. Bitzan, MD, Consultant Orthopaedic Surgeon
P. Krepler, MD, Consultant Orthopaedic Surgeon
Department of Orthopaedics
F. Lomoschitz, MD, Radiologist
F. Kainberger, MD, Radiologist
Department of Radiology
Vienna General Hospital and the University of Vienna, Währinger Gürtel 18-20, A-1090 Vienna, Austria.

R. Jankovsky, MD, Orthopaedic Registrar
Landesklinik für Orthopädie Salzburg, Müllner Hauptstrasse 48, A-5020 Salzburg, Austria.

S. Lehr, MSc, Statistician
Institute of Medical Computer Sciences, University of Vienna, Währinger Gürtel 18-20, A-1090 Vienna, Austria.

F. Gottsauner-Wolf, MS, PhD, Chairman
Department of Orthopaedics, General Hospital Krems, Mitterweg 10, A-3500 Krems an der Donau, Austria.

Correspondence should be sent to Dr W. Brodner.

©2004 British Editorial Society of Bone and Joint Surgery
doi:10.1302/0301-620X.86B1.14637 \$2.00

Table I. Repeatability coefficient (RC) of two DXA scans for each Gruen zone and the entire periprosthetic proximal femur (net mean). Patients were repositioned in between the two scans

BMD zone	RC
1	0.059
2	0.097
3	0.092
4	0.080
5	0.089
6	0.102
7	0.082
BMD net mean	0.062

Germany; Centerpulse Orthopedics Ltd) and the others a Metasul metal-on-metal articulation (Centerpulse Orthopedics Ltd). Full weight-bearing was allowed within six weeks of the operation.

The exclusion criterion during the observation period was revision surgery of the stem. One patient suffered a periprosthetic femoral fracture with the need for open reduction and fixation and was consequently excluded from the trial. Three patients died during the observation period and six refused or were unable to present for follow-up investigations. One patient missed the final DXA scan, but as she had had her final clinical examination and scoring at five years, she was included. One patient was lost to follow-up. One had revision surgery with replacement of the cup because of aseptic loosening and another had revision surgery with debridement and replacement of the liner and femoral head because of deep infection. These two patients were not excluded from the trial because the surgery did not involve the bone around the femoral stem.

The BMD of the proximal femur was measured by DXA using a QDR Hologic scanner (Hologic Inc, Waltham, Massachusetts). We began with the Hologic 2000TM version and upgraded this to the 4500TM model during the course of the study in accordance with current advances in densitometry equipment. Upgrades were performed with documented cross-calibrations between the old and new equipment, following official recommendation by the manufacturer.

The patients were placed in a supine position with the affected leg in slight internal rotation. The foot was attached to a positioning device in order to obtain reproducible rotation in all patients since it has been demonstrated that rotation influences the BMD.^{5,25,26} The periprosthetic BMD was automatically determined using the metal removal mode software. The proximal femur was divided into seven zones according to Gruen, McNeice and Amstutz.²⁸ Zone 4 which is distal to the tip of the stem was adjusted to 35 pixels in height. The first DXA scan was made one week after surgery and served as a baseline for the subsequent scans as recommended by Kröger et al.⁹ Further scans were obtained at intervals of six months during the five-year

period of the study. A template of the distribution of the zones on the baseline scan of each patient was superimposed on subsequent scans to guarantee identical arrangement of the zones.

We performed a precision study on 20 patients. These patients had two DXA scans on the same day. The interval between the scans was 15 to 30 minutes and the patients were repositioned for the second scan. The repeatability coefficient²⁹ was calculated to show the accuracy of measurements of the BMD in our hospital setting. It indicates that, if two repeated measurements were performed, 95% of the observed differences of these measurements would differ by less than this value (Table I).

All collected data were used to calculate the mean BMD for each of the seven zones as well as the overall BMD (net mean BMD) for each investigation. The first DXA scan was regarded as the baseline measurement. In order to describe the relative changes in the BMD, all subsequent values were presented as percentages of the initial values.

We selected four points in time for analysis of changes in the BMD, namely one week after surgery as the baseline value and then six months, one year and five years. At the five-year end-point, the body mass index (BMI), the Harris hip score (HHS),³⁰ and the University of California Los Angeles (UCLA) activity levels³¹ were assessed from 89 patients upon whom the further analysis was based. The patients were divided into four age groups, <45 years, 45 to 59 years, 60 to 74 years and ≥75 years. The BMI was classified according to WHO criteria as normal (<25 kg/m²), overweight (25 to 29.9 kg/m²), and obese (≥30 kg/m²). We categorised clinical success according to the Harris hip score into excellent (91 to 100 points), good (81 to 90) and others (≤80 points). We also classified three groups according to the level of UCLA activity as inactive (1 to 3 points), moderately active (4 to 6), and very active (7 to 10 points). Patients were also categorised according to gender and type of articulation (ceramic-on-polyethylene or metal-on-metal). The BMD values were log-transformed for analysis.

Statistical analysis. Analysis of variance (ANOVA) with fixed factors and the random patient factor was calculated for each region separately. Subsequently, post hoc comparisons between time points were performed according to Tukey's studentised range test. No further adjustment for multiplicity was performed, the main results being supported by very small p values. A p value <0.05 was considered to indicate statistical significance. Since the data are log-transformed, the antilog of the estimated differences of the least-square means corresponded to geometric means of the ratios. Calculations were performed using the SAS software system V8.2 (SAS Institute Inc, Cary, North Carolina).

Our working hypothesis was that younger, male and more active patients experienced less decrease, or maybe even an increase in BMD. We did not expect that the BMI, type of articulation or HHS would influence the changes in the BMD around the stem.

Fig. 1a

Fig. 1b

Fig. 1c

Fig. 1d

Fig. 1e

Examples of DEXA scans. Figure 1a – A regular DEXA scan with good detection of soft-tissue-bone and bone-metal interfaces. Figures 1b and 1c – Failure to detect the bone-soft-tissue interface with adjacent soft tissue recognised as bone (arrowed) in continuity with the bone (b) or as an island of bone surrounded by soft tissue (c). Figure 1d – Failure to detect the bone-metal and the bone-soft tissue interface (arrowed). Figure 1e – Failure to detect the bone metal interface (arrowed) with part of the metal stem recognised as bone. In figure 1b the BMD in zone 1 was 0.38 g/cm^2 before and 0.49 g/cm^2 after manual correction and that in zone 2 0.44 g/cm^2 before and 0.74 g/cm^2 after manual correction. In figure 1c the BMD in zone 3 was 0.98 g/cm^2 before and 1.60 g/cm^2 after manual correction and in zone 4 1.50 g/cm^2 before and 1.89 g/cm^2 after manual correction. In figure 1d the BMD in zone 2 was 1.31 g/cm^2 before and 1.72 g/cm^2 after manual correction and in zone 3 1.61 g/cm^2 before and 1.52 g/cm^2 after manual correction. In figure 1e the BMD in zone 3 was 2.36 g/cm^2 before and 1.42 g/cm^2 after manual correction, in zone 5 1.83 g/cm^2 before and 1.49 g/cm^2 after manual correction, and in zone 6, 0.98 g/cm^2 before and 0.94 g/cm^2 after manual correction.

Table II. Mean ($\pm$ SD) BMD (g/cm^2) and relative change of BMD (compared with the baseline scan) of 11 post-operative DEXA scans for each Gruen zone and the entire periprosthetic proximal femur (net mean)

BMD zone	1 wk (n = 97)	6 mths (n = 88)	1 yr (n = 87)	1.5 yrs (n = 76)	2 yrs (n = 75)	2.5 yrs (n = 77)	3 yrs (n = 74)	3.5 yrs (n = 79)	4 yrs (n = 81)	4.5 yrs (n = 85)	5 yrs (n = 88)
1	0.68 $\pm$ 0.15 (1.00)	0.64 $\pm$ 0.18 (0.95)	0.65 $\pm$ 0.18 (0.97)	0.64 $\pm$ 0.18 (0.97)	0.67 $\pm$ 0.18 (0.99)	0.66 $\pm$ 0.18 (0.98)	0.66 $\pm$ 0.17 (0.97)	0.65 $\pm$ 0.16 (0.96)	0.66 $\pm$ 0.16 (0.97)	0.64 $\pm$ 0.17 (0.97)	0.66 $\pm$ 0.18 (0.97)
2	1.09 $\pm$ 0.26 (1.00)	1.08 $\pm$ 0.28 (1.01)	1.10 $\pm$ 0.31 (1.01)	1.12 $\pm$ 0.31 (1.03)	1.13 $\pm$ 0.30 (1.07)	1.16 $\pm$ 0.30 (1.09)	1.15 $\pm$ 0.29 (1.10)	1.18 $\pm$ 0.31 (1.08)	1.19 $\pm$ 0.29 (1.10)	1.17 $\pm$ 0.31 (1.09)	1.18 $\pm$ 0.31 (1.11)
3	1.46 $\pm$ 0.22 (1.00)	1.38 $\pm$ 0.22 (0.95)	1.39 $\pm$ 0.22 (0.96)	1.42 $\pm$ 0.23 (0.98)	1.42 $\pm$ 0.21 (0.99)	1.44 $\pm$ 0.24 (1.00)	1.45 $\pm$ 0.24 (1.02)	1.46 $\pm$ 0.24 (1.01)	1.48 $\pm$ 0.22 (1.02)	1.47 $\pm$ 0.24 (1.01)	1.47 $\pm$ 0.23 (1.01)
4	1.65 $\pm$ 0.30 (1.00)	1.61 $\pm$ 0.31 (0.98)	1.61 $\pm$ 0.29 (0.99)	1.63 $\pm$ 0.28 (1.00)	1.65 $\pm$ 0.27 (1.02)	1.66 $\pm$ 0.27 (1.01)	1.64 $\pm$ 0.27 (1.02)	1.66 $\pm$ 0.26 (1.02)	1.69 $\pm$ 0.25 (1.02)	1.66 $\pm$ 0.27 (1.02)	1.69 $\pm$ 0.27 (1.03)
5	1.45 $\pm$ 0.21 (1.00)	1.49 $\pm$ 0.20 (1.03)	1.52 $\pm$ 0.21 (1.05)	1.53 $\pm$ 0.21 (1.06)	1.56 $\pm$ 0.21 (1.09)	1.54 $\pm$ 0.20 (1.08)	1.56 $\pm$ 0.22 (1.09)	1.58 $\pm$ 0.20 (1.10)	1.60 $\pm$ 0.20 (1.11)	1.59 $\pm$ 0.20 (1.10)	1.60 $\pm$ 0.20 (1.11)
6	1.18 $\pm$ 0.25 (1.00)	1.06 $\pm$ 0.30 (0.90)	1.07 $\pm$ 0.30 (0.91)	1.08 $\pm$ 0.32 (0.92)	1.09 $\pm$ 0.32 (0.93)	1.11 $\pm$ 0.31 (0.95)	1.10 $\pm$ 0.31 (0.94)	1.11 $\pm$ 0.32 (0.96)	1.12 $\pm$ 0.31 (0.96)	1.10 $\pm$ 0.33 (0.93)	1.11 $\pm$ 0.33 (0.94)
7	0.94 $\pm$ 0.23 (1.00)	0.80 $\pm$ 0.26 (0.85)	0.82 $\pm$ 0.28 (0.88)	0.81 $\pm$ 0.25 (0.87)	0.81 $\pm$ 0.25 (0.88)	0.82 $\pm$ 0.25 (0.88)	0.81 $\pm$ 0.26 (0.87)	0.82 $\pm$ 0.27 (0.88)	0.82 $\pm$ 0.27 (0.86)	0.80 $\pm$ 0.27 (0.85)	0.81 $\pm$ 0.27 (0.86)
BMD	1.23 $\pm$ 0.19	1.17 $\pm$ 0.20	1.18 $\pm$ 0.19	1.19 $\pm$ 0.19	1.21 $\pm$ 0.18	1.22 $\pm$ 0.19	1.22 $\pm$ 0.19	1.22 $\pm$ 0.19	1.24 $\pm$ 0.18	1.22 $\pm$ 0.19	1.23 $\pm$ 0.19
Net mean	(1.00)	(0.96)	(0.97)	(0.98)	(1.00)	(1.00)	(1.01)	(1.01)	(1.01)	(1.00)	(1.01)

Table III. Significance (p value) of changes in BMD for each Gruen zone and the entire periprosthetic proximal femur (net mean) in the four analysed time periods

BMD zone	1 wk to 6 mths	6 mths to 1 yr	1 yr to 5 yrs	1 wk to 5 yrs
1	0.001	NS	NS	0.02
2	NS	NS	<0.001	0.001
3	<0.001	NS	<0.001	NS
4	0.05	NS	<0.001	0.01
5	0.02	NS	<0.001	<0.001
6	<0.001	NS	NS	<0.001
7	<0.001	NS	NS	<0.001
BMD net mean	<0.001	NS	<0.001	NS

Results

All stems were classified as radiographically stable on the latest radiographs. We reviewed the entire series of 909 DEXA scans and detected three different types of failure of the automatic metal removal software (Fig. 1). The first was failure to detect the bone-soft-tissue interface with soft-tissue recognised as bone (Figs 1b and 1c), the second, failure to detect the bone-metal interface with bone recognised as metal (Fig. 1d); and the third, failure to detect the bone-metal interface with metal recognised as bone (Fig. 1e). The first mode of failure usually detected the same amount of bone mineral content, but in a larger area, thus decreasing the BMD. The second decreased the area of the specific Gruen zone and often decreased the BMD, although this was not a consistent finding and the third increased the BMD since the metal of the prosthesis is denser than the adjacent bone. Twenty-one per cent of all performed DEXA scans (194 scans in 94 patients) were manually corrected to avoid these modes of failure.

In Gruen zone 1 there was bone loss of 5% in the first six months after surgery ($p = 0.001$). Later changes in the BMD were not significant. At five years the loss was 3% compared with the baseline value, which was still significant ($p = 0.02$; Tables II and III; Fig. 2).

There was a progressive increase in the BMD in Gruen zone 2 until a plateau was reached at three years after surgery. This increase was not significant during the first six months or from six months to one year, but it was significant from one year to five years ($p < 0.001$). The final increase in the BMD was 11% compared with the baseline value ($p = 0.001$; Tables II and III; Fig. 2).

The BMD in Gruen zone 3 initially decreased by 5% ($p < 0.001$) in the first six months, but this loss was regained at 2.5 years after surgery. The final BMD (a 1% increase) was not statistically different from the baseline value (Tables II and III; Fig. 2). In Gruen zone 4, there was an initial loss of BMD, but it was regained after 1.5 years. A slight, gradual increase was noted between six months and five years. The final BMD was 3% greater than the baseline value ($p = 0.01$; Tables II and III; Fig. 2). In Gruen zone 5, there was a constant increase in BMD until a plateau was reached at two years. The gain in the first six months (3%) was significant ($p = 0.02$). The final BMD was 11% higher than the baseline value ($p < 0.001$; Tables II and III; Fig. 2).

In Gruen zone 6, 10% of the BMD was lost during the first six months ($p < 0.001$). In spite of a partial restoration, the final figure remained 6% less than the initial value ($p < 0.001$; Tables II and III; Fig. 2). In Gruen zone 7, 15% of the BMD was lost in the first six months ($p < 0.001$), and

Fig. 2

Relative changes in BMD of the seven Gruen zones and the entire periprosthetic proximal femur (net mean). The first DEXA scan one week after surgery is considered to be the baseline scan. All subsequent BMD values are presented as a percentage of the baseline value.

thereafter there was no significant change. The five-year scan indicated a loss of 14% compared with the baseline value ($p < 0.001$; Tables II and III; Fig. 2).

The net mean BMD decreased significantly in the first six months (4%; $p < 0.001$) but returned to the initial value by two years. Thereafter no further changes were observed. The final BMD after five years was 1% higher than the immediate post-surgical value (Tables II and III; Fig. 2).

Thus, in the first six months after surgery, the BMD decreased significantly in five Gruen zones (1, 3, 4, 6 and 7), was the same in one zone (2) and increased in one zone (5). No significant changes were observed between six months and a year. Significant increases in the BMD were seen in four zones (2, 3, 4 and 5) between one and five years, but no significant changes were seen in the remaining three zones (1, 6 and 7). If losses of the BMD were significant, they were observed only during the first six months after surgery. At five years after surgery, compared with the baseline value, three zones had significantly less BMD (1, 6 and 7), three had significantly more BMD (2, 4 and 5), and one (3) had an increase which was not statistically significant. The net mean BMD was slightly higher (1%), but this was not significant (Table III).

When testing for factors which could possibly influence the BMD, gender was significant for zones 2, 3, 4, 5 and 6 (p values 0.003, <0.001 , <0.001 , <0.001 , and 0.04, respectively), but not for the area of the greater or lesser trochanter (zones 1 and 7). Age contributed significantly to the BMD in zones 1 and 4 (p values 0.03 and 0.04), but not in other zones; the BMI only contributed in zone 3 ($p = 0.01$). When assessing the net mean BMD, gender was the only significantly influencing parameter ($p = 0.004$), with a greater bone mass in men than in women (Fig. 3a). The more active

patients had higher values of the BMD than less active patients. This was also observed in patients with a higher HHS, a higher BMI and patients with metal-on-metal joints, compared with patients with ceramic-on-polyethylene bearings. However, none of these differences was significant (Figs 3b to 3f).

Discussion

We are not aware of reports of failures of the automatic metal subtraction software and were surprised by the high number (21%) of DEXA scans which had to be corrected manually. Without recognising the described types of failure and correcting the scans manually, false results would lead to incorrect interpretations of changes in the BMD around total hip arthroplasties.

Cross-sectional^{4,6,7} and longitudinal^{8,10,11,13-15,17,19} DEXA studies after cemented and uncemented total hip arthroplasties have been reported. In cross-sectional studies periprosthetic BMD values have to be compared with those of the opposite side. This is prone to error because of differences in bone mass between the two sides. It has been shown that the BMD of the affected femur is usually lower even before surgery when compared with the contralateral side.^{8,16,32} Therefore, longitudinal studies clearly give more accurate information about bone remodelling processes in the proximal femur.⁹

The Alloclassic SL stem is a cementless rectangular tapered titanium-alloy stem with a grid-blasted surface whose roughness is between 4 and 6 μm . Its clinical success has been demonstrated with a probability of survival of 99% at ten years.³³ In our study we confirmed that this stem allows transmission of mechanical forces mainly to the distal third but also to the lateral intermediate third. The mean bone loss at the calcar (14%) and the greater trochanter (3%) was less than those in several other longitudinal reports using designs of stem which were assumed to favour more proximal fixation.^{11,14,17-19,27} Also medially, at the intermediate third of the stem, the mean bone loss was less (6%) than that reported by some investigators.^{14,17,19}

In contrast to most previous reports,^{8,10,11,14,17,19} we observed an actual increase in the BMD on the final scan compared with the baseline value in Gruen zones 2, 3, 4, and 5. These results require comparisons with those of Sabo et al,¹⁵ Wixson et al²⁷ and Yamaguchi et al.¹⁸

Korovessis et al¹³ carried out a prospective study on the bony remodelling in the proximal femur using the same type of stem as we used. In contrast to our data, they found a higher bone mineral content at the greater and lesser trochanter four years after surgery when compared with the baseline value. Remodelling of the proximal femur was not limited to the first year after THA^{13,15,27} which is confirmed by our observations.

Our working hypothesis predicted higher values for the BMD in younger, male and more active patients. This hypothesis proved to be correct only for certain aspects.

Fig. 3a

Fig. 3b

Fig. 3c

Fig. 3d

Fig. 3e

Fig. 3f

Net mean BMD (g/m^2) of the entire periprosthetic proximal femur. Figure 3a – Net mean BMD (g/cm^2) for women and men. It is significantly higher in male than in female patients ($p = 0.004$). Figure 3b – Net mean BMD (g/cm^2) for patients of four different age groups (see text). The differences were not significant ($p = 0.55$). Figure 3c – Net mean BMD (g/cm^2) for the groups with three different BMIs (see text). The differences were not significant ($p = 0.06$). Figure 3d – Net mean BMD (g/cm^2) for three groups with different clinical success, according to their HHSs (see text). The differences were not statistically significant ($p = 0.65$). Figure 3e – Net mean BMD (g/cm^2) for three groups, with different levels of activity (see text). The differences were not significant ($p = 0.29$). Figure 3f – Net mean BMD (g/cm^2) for patients with metal-on-metal and for patients with Al_2O_3 ceramic-on-UHMWPE articulations. The mean difference was not significant ($p = 0.78$).

Male patients had a significantly greater BMD in zones 2, 3, 4, 5, and 6, but in the more proximal regions, the calcar and the greater trochanter, the difference in the BMD between male and female patients was not significant. We suspect that the design and the material of this cementless, tapered stem are probably the most important factors for the pattern of bony remodelling in the proximal femur.

In conclusion two facts should be emphasised. First, the results of DEXA scans should be evaluated for possible failures of recognition of either the soft-tissue-bone or the bone-metal interface and secondly, the overall periprosthetic BMD after the implantation of this tapered rectangular uncemented stem, remained unchanged for five years. However, there was redistribution of bone mass from the proximal to more distal zones around the stem. From our results, proximal stress shielding after implantation of the Alloclassic SL stem is much less marked than was anticipated.

DEXA scanning provides valuable information about bony remodelling after total joint arthroplasty. Optimistically, it may influence modifications in the design of a prosthetic stem. Therefore, different types of stems should be compared in prospective trials under identical study conditions.

We wish to thank Mrs Ingrid März for invaluable technical assistance in performing the DEXA scans and for support in the collection of data, and Dr Richard Eyb for inspiring us to start this investigation.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. Bobyn JD, Mortimer ES, Glassman AH, et al. Producing and avoiding stress shielding: laboratory and clinical observations of non-cemented total hip arthroplasty. *Clin Orthop* 1992;274:79-96.
2. Engh CA, McGovern TF, Bobyn JD, Harris WH. A quantitative evaluation of periprosthetic bone remodelling after cementless total hip arthroplasty. *J Bone Joint Surg [Am]* 1992;74-A:1009-20.
3. Markel MD, Gottsauner-Wolf F, Bogdanske JJ, Wahner HW, Chao EY. Dual energy x-ray absorptiometry of implanted femora after cemented and press-fit total hip arthroplasty in a canine model. *J Orthop Res* 1993;11:452-6.
4. Trevisan C, Bigoni M, Cherubini R, et al. Dual x-ray absorptiometry for the evaluation of bone density from the proximal femur after total hip arthroplasty: analysis protocols and reproducibility. *Calcif Tissue Int* 1993;53:158-61.
5. Cohen B, Rishton N. Accuracy of DEXA measurement of bone mineral density after total hip arthroplasty. *J Bone Joint Surg [Br]* 1995;77-B:479-83.
6. Niinimäki T, Jalovaara P. Bone loss from the proximal femur after arthroplasty with an isoelastic femoral stem: BMD measurements in 25 patients after 9 years. *Acta Orthop Scand* 1995;66:347-51.
7. Peterson MB, Jolthoff N, Eiken P. Bone mineral density around femoral stems: DXA measurements in 22 porous-coated implants after 5 years. *Acta Orthop Scand* 1995;66:432-4.
8. Kiratli BJ, Checovich MM, McBeath AA, Wilson MA, Heiner JP. Measurement of bone mineral density by dual energy x-ray absorptiometry in patients with the Wisconsin hip, an uncemented femoral stem. *J Arthroplasty* 1996;11:184-93.
9. Kröger H, Miettinen H, Arnala I, et al. Evaluation of periprosthetic bone using dual-energy x-ray absorptiometry: precision of the method and effect of operation on bone mineral density. *J Bone Miner Res* 1996;11:1526-30.
10. Marchetti ME, Steinberg GG, Greene JM, Jenis LG, Boran DT. A prospective study of proximal femur bone mass following cemented and uncemented hip arthroplasty. *J Bone Miner Res* 1996;11:1033-9.
11. Nakamura K. Measurement of periprosthetic bone mineral density after cementless hip arthroplasty by dual energy x-ray absorptiometry: longitudinal and cross-sectional evaluation. *J Orthop Sci* 1996;1:113-22.
12. Smart RC, Barbagallo S, Slater GL, et al. Measurement of periprosthetic bone density in hip arthroplasty using dual-energy x-ray absorptiometry: reproducibility of measurements. *J Arthroplasty* 1996;11:445-52.
13. Korovessis P, Droutsas P, Piperos G, et al. Course of bone mineral content changes around cementless Zweymueller total hip arthroplasty: a 4 year follow-up study. *Arch Orthop Trauma Surg* 1997;116:60-5.
14. Nishil T, Sugano N, Masahara K, et al. Longitudinal evaluation of time related bone remodelling after cementless total hip arthroplasty. *Clin Orthop* 1997;339:121-31.
15. Sabo D, Reiter A, Simank HG, et al. Periprosthetic mineralization around cementless total hip endoprosthesis: longitudinal study and cross-sectional study on titanium threaded acetabular cup and cementless Spotorno stem with DEXA. *Calcif Tissue Int* 1998;62:177-82.
16. Martini F, Kremling E, Schmidt B, Sell S, Mayer F. Bone mineral density of the proximal femur after unilateral cementless total hip arthroplasty. *Int Orthop* 1999;23:104-6.
17. Rosenthal L, Bobyn JD, Brooks CE. Temporal changes of periprosthetic bone density in patients with a modular noncemented femoral prosthesis. *J Arthroplasty* 1999;14:71-6.
18. Yamaguchi K, Masuhara K, Ohzono K, et al. Evaluation of periprosthetic bone-remodelling after cementless total hip arthroplasty: the influence of the extent of porous coating. *J Bone Joint Surg [Am]* 2000;82-A:1426-31.
19. Venesmaa PK, Kröger HPJ, Miettinen HJA, et al. Monitoring of periprosthetic BMD after uncemented total hip arthroplasty with dual-energy x-ray absorptiometry: a 3 year follow-up study. *J Bone Miner Res* 2001;16:1056-61.
20. Adolphson P, von Sivers K, Dalén N, Jonsson A, Dahlborn M. Bone and muscle mass after hip arthroplasty: a quantitative computed tomography study in 20 arthrosis cases. *Acta Orthop Scand* 1993;64:181-4.
21. Schmidt R, Freund J, Hirschfelder H, Pitto RP. Osteodensitometry in uncemented total hip arthroplasty using computer tomography. *Biomed Technik (Berl)* 2000;45:70-4.
22. West JD, Mayor MB, Collier JP. Potential errors inherent in quantitative densitometric analysis of orthopaedic radiographs: a study after total hip arthroplasty. *J Bone Joint Surg [Am]* 1987;69-A:58-64.
23. Engh CA, McAuley JP, Sychterz CJ, Sacco ME, Engh CA Jr. The accuracy and reproducibility of radiographic assessment of stress-shielding: a postmortem analysis. *J Bone Joint Surg [Am]* 2000;82-A:1414-20.
24. Mirsky EC, Einhorn TA. Bone densitometry in orthopaedic practice. *J Bone Joint Surg [Am]* 1998;80-A:1687-98.
25. Goh JCH, Low SL, Bose K. Effect of femoral rotation on bone mineral density measurements with dual energy x-ray absorptiometry. *Calcif Tissue Int* 1995;57:340-3.
26. Martini F, Leberer C, Mayer F, et al. Precision of the measurement of periprosthetic bone mineral density in hips with a custom-made femoral stem. *J Bone Joint Surg [Br]* 2000;82-B:1065-71.
27. Wixson RL, Stulberg SD, Van Flandern GJ, Puri L. Maintenance of proximal bone mass with an uncemented femoral stem: analysis with dual-energy x-ray absorptiometry. *J Arthroplasty* 1997;12:365-72.
28. Gruen TA, McNeice GM, Amstutz HC. Modes of failure of cemented stem-type femoral components. *Clin Orthop* 1979;141:17-27.
29. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;1:307-10.
30. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty: an end-result study using a new method of result evaluation. *J Bone Joint Surg [Am]* 1969;51-A:737-55.
31. Amstutz HC, Thomas JBJ, Jinnah R, et al. Treatment of primary osteoarthritis of the hip: a comparison of total joint and surface replacement arthroplasty. *J Bone Joint Surg [Am]* 1984;66-A:228-41.
32. McCarthy CK, Steinberg GG, Agren M, et al. Quantifying bone loss from the proximal femur after total hip arthroplasty. *J Bone Joint Surg [Br]* 1991;73-B:774-8.
33. Gröbl A, Chiari C, Gruber M, et al. Cementless total hip arthroplasty with a tapered, rectangular titanium stem and a threaded cup: a minimum ten-year follow-up. *J Bone Joint Surg [Am]* 2002;84-A:425-31.