Changes in bone mineral density around a stable uncemented total hip arthroplasty

P. Koroivessis, G. Piperos, A. Michael, A. Baikousis, M. Stamatakis

Orthopaedic Department, General Hospital Agis Andreas, Patras, Greece

Accepted: 6 May 1996

Summary. *Changes in bone mineral density (BMD) around the components of the Zweymueller total hip arthroplasty were measured, using dual energy X-ray absorptiometry, in 36 women who were operated on for primary osteoarthritis. Seven regions of interest were studied. No changes occurred around the screw socket and the greater trochanter, but there was a significant reduction of BMD, only when measured immediately after the operation at the lesser trochanter and at the distal femoral cortex lateral and medial to the tip of the stem. These changes were not related to the age of the patients. The reduction of BMD in the femur was mostly associated with areas where bone had been removed at operation. The press-fit fixation of the Zweymueller stem and the maintenance of its fixation with time did not induce further bone turnover around it. The absence of changes in bone mineral density was due to the relatively small amount of subchondral removed and to the continued stable fixation of the socket.*

Résumé. *Les auteurs ont mesuré chez 36 patientes opérées pour coxarthrose primitive les modifications de la densité osseuse autour des composants de la prothèse totale de Zweymueller en utilisant la méthode d'absorptiométrie (dual energy X-ray absorptiometry: DEXA) selon 7 localisations. Il n'a pas été relevé de modification significative de la densité osseuse autour du cotyle vissé, ni de la région du grand trochanter, alors qu'une réduction significative de cette densité était mesurée juste après l'intervention: 1°) au niveau du petit trochanter ($32,16 \pm 18,15\%$, $P < 0,05$), et 2°)*

au niveau de la corticale fémorale interne et externe à hauteur de l'extrémité de la tige prothétique ($18,6 \pm 12,82\%$, $P < 0,0005$ et $21,96 \pm 15,8\%$, $P < 0,0005$ respectivement). Ces modifications de la densité ne sont pas en relation avec l'âge des patientes. La diminution de la densité au niveau du fémur est due principalement à la perte osseuse liée à la préparation opératoire. La fixation de la tige de Zweymueller par ajustage n'induit pas, dans cette série, d'autres modifications osseuses avec le temps. L'absence de modification de la densité osseuse au niveau de l'os acétabulaire est certainement due à la relative préservation de l'os sous-chondral lors de l'intervention et ensuite à la stabilité de la fixation cotyloïdienne pendant les 4 ans de l'étude.

Introduction

Dual energy X-ray absorptiometry (DEXA) is a noninvasive method of measuring bone mineral density (BMD), and has been found to be an adequate procedure for evaluating the natural history of osteoporosis of the spine and femoral neck [1, 3, 8, 10, 11, 16]. The versatility, precision and accuracy of the latest techniques make measurement of the effect of implantation of a total hip arthroplasty (THA) on the bone mass increasingly feasible [1, 4, 5, 6, 7, 9, 10, 14, 15].

The purpose of this prospective study was to investigate the periprosthetic bone mass after implantation of an uncemented Zweymueller THA immediately after operation, and after one and four years.

Fig. 1. This figure shows the sites of the 7 ROIs used in measuring BMD with DEXA

Fig. 2. Postoperative measurement of BMD at zones I to VII

Fig. 3. Anteroposterior radiograph showing an uncemented Zweymueller THA. The socket is placed close to the pelvic tear-drop, and the femoral stem is in contact with the medial cortex

Patients and methods

A prospective study using DEXA was made to follow the changes in BMD around the screw socket and stem of an uncemented Zweymueller THA. Thirty-six women with primary osteoarthritis of the hip had the operation; their average age was 55 years (range 40 to 69 years), SD = 9 years; 21 were postmenopausal and 15 premenopausal. Exclusions were imposed in order to avoid changes in BMD which were not related to the operation. These included any previous operation, any infection in the hip, the use of oestrogen, cortisone, calcitonin or other medication for osteoporosis during the previous 2 years, clinical and radiological signs of loosening during the 4 years of observation, and an abnormal blood count on admission.

All the operations were performed by one surgeon (PK) using the same technique [9]. The numbers of right and left operated on hips were the same. The screw socket was implanted near to its anatomical site close to the pelvic tear-drop, after removing only osteophytes and degenerate cartilage. We estimated that not more than 2 mm of subchondral bone was removed, especially medially and distally. The stem was always inserted in the posterior third of the femur after removing one third of the cancellous bone of the greater trochanter to accommodate the proximal lateral flange of the stem. We removed approximately 4 mm to 6 mm of cancellous and cortical bone as measured on anteroposterior radiographs from around the tip of the stem during reaming the femoral canal in order to achieve perfect primary stability of the right-angular conical stem. No additional bone grafts, screws or

Table 1. The bone mineral density around Zweymueller components (g/cm²)

Zone	Preoperative measurement	SD	First ^(a) postop. measurement	SD	Second ^(b) postop. measurement	SD	Third ^(c) postoperative measurement	SD	Probability (one-way ANOVA)
I	1.375	0.324	1.418	0.333	1.369	0.424	1.331	0.414	N.S.
II	1.037	0.282	0.897	0.284	0.911	0.354	0.914	0.285	N.S.
III	0.916	0.198	0.874	0.246	0.829	0.226	0.847	0.312	N.S.
IV	0.682	0.12	0.661	0.083	0.666	0.131	0.695	0.15	N.S.
V	1.031	0.282	0.661	0.205	0.758	0.181	0.776	0.198	***
VI	1.476	0.217	1.160	0.241	1.134	0.252	1.098	0.216	***
VII	1.538	0.214	1.270	0.269	1.268	0.273	1.187	0.216	***

(NS = not significant)

(Probability***: $P < 0.0001$)^(a) = 2 weeks postoperatively)^(b) = 12 months postoperatively)^(c) = 48 months postoperatively)

rings were used to augment the bone of the acetabulum or femur. Full weightbearing with 2 sticks was encouraged on the first postoperative day.

Seven regions of interest (ROIs) were defined (Fig. 1): 3 in the acetabulum around the socket (I to III), and 4 in the femur around the stem (IV to VII) [9]. The same areas were used to measure BMD (g/cm²) using specific hip software, with a standard pilot level at the tip of the stem. Measurements were carried out with exactly the same technique during the 4 years after implantation in every patient and in all 7 ROIs in the operated and unoperated hip at the following times: (1) immediately after operation; (2) 2 weeks later; (3) at one year, and (4) at 4 years after operation. The results of the measurements for the hips which were operated on were used to study the changes in BMD over time.

The periprosthetic acetabular and femoral BMD were determined by a Norland XR-26 X-ray mark II bone densitometer (Norland, Wisconsin, US) with a stationary anode X-ray tube (100 KV constant potentials; 1 mA constant anode current; samarium filter, K-edge = 46.8 KeV). Minimum filtration is 3 mm aluminium equivalent. The samarium chosen as the filter material produces energy peaks at 46.8 KeV and 80 KeV. Measurement scan point resolution times line spacing (pixel size) varies from 0.5×0.55 mm to 6×6 mm. The pixel size used in this study was 1.3×1.3 mm (Figs. 1, 2) because it was included in the specific hip scan modality of the manufacturer.

Patients were studied lying on the table with both legs held in 20° of internal rotation at the hip, and the same anteversion of the femoral neck, in a specially made splint which was applied in the same way to both hips [9].

The high density detection mode of the Norland densitometer was used for the large high density artefacts created by the prosthetic implants (metal, ultrahigh molecular weight polyethylene and ceramic) to be excluded automatically from the analysis. The software enabled reliable measurements to be made, using the same ROIs, for each individual at the level of the greater trochanter, lesser trochanter and the tip of the stem over time in all the hips examined. DEXA software has been recently modified to allow measurement of the BMD of periprosthetic bone close to metal implants [13].

The scans obtained from the operated hips at 4 different times of observation were compared with each other (paired t-test) in every ROI as follows: (1) preoperatively to 2 weeks, one year and 4 years postoperatively; (2) 2 weeks postoperatively to one year and 4 years postoperatively; (3) one year postoperatively to 4 years postoperatively.

All data were analysed over time using one-way analysis of variance (ANOVA) (Table 1). Reproducibility and reliability were assessed at the 7 ROIs (Figs. 1, 2) in 23 of the 36 hips which were operated on, as well as in 20 hips which were not operated on. Three subsequent scans on each patient were performed over a period of 21 days and the Pearson coefficient (r) of variation (ANOVA) of the measurements for each ROI was: $r_I = 0.87$, $r_{II} = 0.76$; $r_{III} = 0.9$; $r_{IV} = 0.834$; $r_V = 0.865$; $r_{VI} = 0.86$ and $r_{VII} = 0.93$. The reference was at the tip of the stem. A manually guided template programme that saved, in each case, the ROI positioning by using the Norland software in the hip scan modality, was applied in order to ensure the exact position of the ROIs in successive DEXA scans.

Results

No statistically significant difference was found in BMD values before operation, postoperatively and in the evaluation at follow up between the right and left operated hips in all 7 ROIs.

There was no correlation between the age of the patients and their BMD values at each of the 7 ROIs at any of the 3 evaluations.

The overall results of the BMD measurements are shown in Table 1.

At ROI V, the area of the lesser trochanter, there was a statistically significant decrease between the preoperative value and the first postoperative measurement at an average of $32.16 \pm 18.1\%$ (t -test, $P < 0.0005$). No further changes were observed at one and 4 years (Table 1).

At ROI VI, the lateral femoral cortex around the tip of the stem, the BMD decreased between the preoperative and first postoperative measurement at an average of $18.6 \pm 12.82\%$ t -test, ($P < 0.0005$). No further changes were seen in the subsequent measurements.

At ROI VII, the medial cortex around the tip of the stem, there was a statistically significant decrease of the preoperative BMD value at an average of $21.96 \pm 15.8\%$ (t -test, $P < 0.0005$). No further changes were observed.

The changes in BMD over time at ROIs V, VI and VII were statistically significant (one-way ANOVA, $P < 0.0001$).

Discussion

Implantation of an uncemented hip prosthesis may theoretically produce a rise in stress or strain in some areas and a reduction in others. In a previous experimental study, computed finite element stress was correlated with BMD after remodelling following the insertion of an uncemented femoral prosthesis, and it was shown that in many areas the BMD was reduced [13]. In the areas where stress is reduced, resorption would be expected. Where the stress was higher, there was periosteal or endosteal new bone formation and increased density [2]. In contrast to this, we did not find any stress-related changes in BMD around the component we used, and this differs from a previous report which found a linear relation between mechanical factors, such as stress and strain, and BMD [12].

Our results show reduction in BMD around the stem at 2 weeks after operation, and we believe this is due to thinning of the cortex produced by reaming the femoral canal. The absence of changes at one and 4 years may be because of the stable primary fixation of the stem at these times. Bone remodelling is continuous and it is not known what occurs between these observations.

Bone loss around the Zweymueller socket was not measurable in the early or late phases because of the minimal bone resection.

It has been shown on plain radiographs that the strain adaptive bone remodelling processes ceases after a few years [7, 5, 14]. Plain radiographs, however, are not a suitable method of determining net changes in bone mass of less than 30%. Others have shown using DEXA that bone remodelling around an uncemented stem may continue for up to 7 years [7, 14], but the measurements were made in only 2 ROIs in the region of the lesser trochanter. The type of THA was not the same as in our series and the pixel size of the surface of bone varied depending on the type of densitometer used. These studies are therefore not comparable to our own and we suggest that the lower precision (1.3×1.3 mm) of the Norland apparatus may be responsible for the failure to detect small changes in BMD.

Kiratli et al. [7] and Steinberg et al. [14] have shown that periprosthetic femoral BMD is reduced with increasing time after the insertion of PCA uncemented THAs, ranging from 28% to 47%. Kearns-McCarthy et al. [4] found that after im-

plantation of cemented THAs there was a 40% loss of BMD in the lesser trochanter and 28% loss in the medial and distal cortex, 3 years after operation. They also found that 7 to 14 years after operation, the bone loss was 40% proximally and 49% distally.

Our study has advantages over those previously reported: (1) it was prospective; (2) changes of BMD were measured in 7 ROIs after an unique type of THA implanted with the same technique by the same surgeon; (3) the reduction in bone mass was measured at 2 weeks after operation, and (4) it was applied to a homogenous group of females. The findings support our radiographic observation that the Zweymueller components, particularly the stem, do not induce substantial stress shielding with subsequent remodelling and cortical thinning. This suggests that the risk of loosening may be reduced with this type of THA.

It is possible that repeated measurement of BMD may be of diagnostic value in detecting loosening before radiographic changes are present.

References

1. Ho CP, Kim RW, Schaffler MB, Sartoris DJ (1990) Accuracy of dual-energy radiographic absorptiometry of the lumbar spine: cadaver study. *Radiology* 176: 171–176
2. Huiskes R, Weinans H, Dalstra M (1989) Adaptive bone remodeling and biomechanical design considerations for noncemented total hip arthroplasty. *Orthopaedics* 12: 1255–1261
3. Kelly TL, Slovic DM, Schoenfeld DA, Neer RM (1988) Quantitative digital radiography versus dual photon absorptiometry of the lumbar spine. *J Clin Endocrinol Metab* 67: 839–847
4. Kearns-McCarthy C, Steinberg GG, Agren M, Leahey D, Wyman E, Baran DT (1991) Quantifying bone loss from the proximal femur after total hip arthroplasty. *J Bone Joint Surg [Br]* 73: 774–778
5. Kearns-McCarthy C, Steinberg GG, Wyman E, Agren M, Baran D (1990) Quantitation of bone resorption of the proximal femur in total hip arthroplasty [Abstract]. *J Bone Miner Res* 5: 178
6. Kilgus DJ, Shimaoka EE, Tipton JS, Eberle RW (1993) Dual-Energy Absorpsiometry measurement of bone mineral density around porous coated cementless femoral implants. *J Bone Joint Surg [Br]* 75: 279–287
7. Kiratli BJ, Heiner JP, McKinley N, Wilsen MA, McBeath AA (1991) Bone mineral density of the proximal femur after uncemented total hip arthroplasty. *Transactions of the 37th Annual Orthopaedic Research Society, Anaheim, CA, March 4–7*, pp 545–551
8. Korovessis P, Konstantinou D, Tzortzides F, Partheni M, Papadakis N (1994) Spinal bone mineral density changes following Halo-vest immobilization for cervical trauma. *Eur Spine J* 3: 206–208
9. Korovessis P, Piperos G, Michael A (1994) Periprosthetic bone mineral density after Mueller and Zweymueller total hip arthroplasties. *Clin Orthop* 309: 214–221

10. Mazess RB (1990) Bone densitometry for clinical diagnosis and monitoring. In: DeLuca HF et al (eds) Osteoporosis: physiological basis, assessment and treatment. Proceedings of the 19th Steenbock Symposium, Elsevier, New York, pp 63–85
11. Mazess RB, Gifford C, Barden H, Hanson J, Denton D, De Souza A (1989) Measurement of spinal density in the lateral projection [abstract]. *J Bone Miner Res* 4 (Suppl 1) 444
12. Rubin CT, Lanyon LE (1987) Osteoregulatory nature of mechanical stimuli: Function as a determinant for adaptive remodeling in bone. *J Orthop Res* 5: 300–305
13. Skinner HB, Kilgus JD, Keyak J, Shimaoka EE, Kim AS, Tipton JS (1994) Correlation of computed finite element stresses to bone density after remodeling around cementless femoral implants. *Clin Orthop* 305: 178–186
14. Steinberg GG, Kearns-McCarthy C, Baran D (1991) Quantification of bone loss of the proximal femur after total hip arthroplasty. Transactions of the 37th Annual Orthopaedic Research Society, Anaheim, California, March 4–7, Vol 1, pp 221–224
15. Stulberg BN, Eberle RW, Fox JS, Richmond BJ (1989) The technical aspects of periprosthetic bone mineral density in uncemented total hip arthroplasty [Abstract] 2nd International Symposium for Custom Prostheses, Chicago, Ill., p 63
16. Wahner HW, Dunn WL, Brown ML, Morin RL, Riggs BL (1988) Comparison of dual-energy Xray absorptiometry and dual photon absorptiometry for bone mineral measurements of the lumbar spine. *Mayo Clin Proc* 63: 1075–1079