Bone loss from the proximal femur after arthroplasty with an isoelastic femoral stem

BMD measurements in 25 patients after 9 years

Timo Niinimäki and Pekka Jalovaara

To quantify the bone loss from the proximal femur after total hip arthroplasty with an isoelastic femoral stem, the bone mineral densities (BMD) around 25 such stems were measured after an 8.5 (7.5–9.5)-year follow-up. The contralateral, healthy side was used as a control. The BMD on the prosthesis side was lower by a mean of 14 percent than on the control side. The difference was greatest in the calcar area and smallest in the cortex medially of the prosthesis stem. The decreases in BMD around the metaphyseal and diaphyseal areas of the stem were smaller than those reported for stiff stems. The marked bone loss in the calcar region is possibly due to stress bypass—i.e., the axial load is transmitted directly into the metaphyseal area of the femoral shaft, causing an increase in its stiffness and in the jamming of the prosthesis stem.

Department of Surgery, University Hospital, SF-90220 Oulu, Finland. Tel +358-49 686827. Fax -81 3155318
Submitted 95-01-04. Accepted 95-04-24

The idea of isoelasticity in orthopedics originated from the observation that a stiff metal plate used for internal fixation caused stress-protection bone atrophy under the plate (Morscher 1984). Similar bone atrophy has been observed in prosthetic hips around cemented femoral stems (Oh and Harris 1978). The extent of atrophy depends on the stem elasticity: the stiffer and thicker the stem, the greater the atrophy (Bobyn et al. 1992). To avoid this stress-shielding atrophy, an isoelastic femoral stem was introduced by Rob Mathys in 1973 (Morscher and Mathys 1974). Software enhancement of X-ray dual-energy densitometry has made it possible to follow in a practical and reliable way the remodeling process in vivo around the femoral stem (Kilgus et al. 1993), and we used this to quantify the bone mineral density (BMD) around the isoelastic stems.

Patients and methods

25 patients were selected from 127 consecutive cases operated on at the Oulu University Hospital in 1983–1985. The mean age of these 127 patients was 64 (37–79) years. The clinical and radiographic survey of 108 patients included in this population has been reported by us earlier (Niinimäki et al. 1994). All the patients were reviewed with plain radiographs and a questionnaire prior to the study. To minimize the confounding effects of patient or prosthesis pathology on bone remodeling, only minor exceptions from faultless recovery were accepted. Thus the inclusion criteria for selection were: a total hip arthroplasty for unilateral primary arthrosis using an uncemented, isoelastic femoral stem, a patient with an active life-style, no disabling general illnesses, and no radiographic signs of prosthesis loosening. At the time of survey, the mean age of the patients (8 men, 17 women) was 59 (37–68) years and the measurements were performed at a mean of 8.5 (7.5–9.5) years after the operation. The patients underwent a clinical examination, where the standard system of terminology for reporting the results of total hip arthroplasty developed by AAOS, the Hip Society and SICOT (Johnston et al. 1990) was used. The clinical outcome was assessed with Harris (1968) hip scores (HHS), using the cut-off point for excellent overall outcome 90 points, for good 80, and for fair 70 points.

The radiographic data were obtained from standard anteroposterior and lateral radiographs taken immediately postoperatively and at the time of the survey. Subsidence and calcar resorption were measured in millimeters. Any broken screws were noted, and radiolucent lines and hypertrophy of the cortical bone were measured in millimeters and located in the Gruen zones (Gruen et al. 1979) as also were endosteal bone formation and osteolytic foci. Ectopic

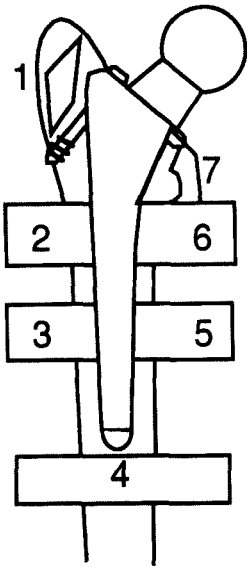

Figure 1. Location of ROIs in the Gruen zones.

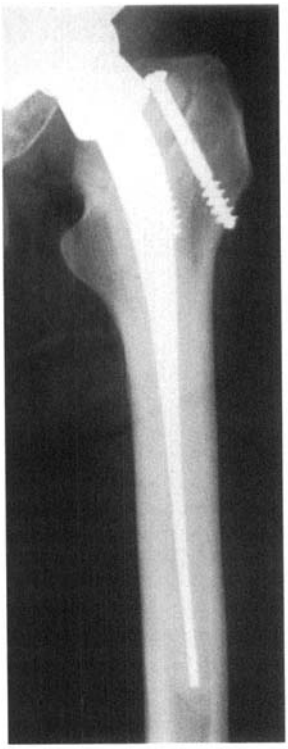

Figure 2. Isoelastic stem after 8 years in the hip of a 55-year-old truck driver who continuously worked in a lumber company.

ossification was assessed according to Brooker et al. (1973). The evaluation of the stability of the stem was based on the extent of subsidence and the number of zones with radiolucent lines. A subsidence of over 5 mm or a radiolucent line in 5 or more Gruen zones without subsidence were assessed as unstable as also were a subsidence of 3–5 mm and a radiolucent line in at least 3 zones (Niinimäki et al. 1994).

The isoelastic femoral stem (Rob Mathys Co., Bettlach, Switzerland) is made of polyacetal resin with a steel core. The rotational load between the bone and the prosthesis is transferred by 2 wings, the axial and bending loads are borne medially via a collar and laterally via 2 lag screws into the greater trochanter. In the metaphyseal area, the large conical stem is cross-hatched with conic recesses to allow the bony ingrowth for final stability. The distal stem is smooth, with 4 longitudinal grooves displaying a low-modulus interface. The operative techniques recommended by the manufacturer were used (Mathys 1992). The length of the straight stem of the prosthesis was 150 mm in each case, and the thickness of the distal prosthesis stem varied from 10 to 18 mm. Noncemented acetabular components were used in all cases.

The bone mineral density was determined with dual-energy radiographic densitometry (Lunar DPX, Lunar Corporation, Madison, WI, U.S.A.). The patient lay supine with both legs in equal rotation and his/her feet together and with a thin pillow under the knees. The scanning was begun 2 cm proximally to the highest lateral tuberculum of the greater trochanter and was continued distally for 20 cm to reach the area distal to the prosthesis tip. The pixel size was 0.6 × 1.2 mm and the non-operated side served as a control. Orthopedic Software Version 1.2 (Lunar Corp.) was used to compute the BMD values. The regions of interest (ROI) were located in 7 anteroposterior zones (Gruen et al. 1979). The ROI in zone 1, the greater trochanter, was adjusted manually to represent an area outside the trochanter fixation screws. In the calcar region, the most medial tip of the lesser trochanter was used as a reference point for locating the borderline between zones 6 and 7; zone 7 extended 20 mm upward from this line and zone 6 downward. The ROIs in zones 3, 4, and 5 were located in the upper parts of the zones (Figure 1), corresponding regions were used on the control side. To avoid interference from the implant, the software detected the boundary between the bony part and the prosthesis stem on the basis of abrupt density change and simulated the stem in the form of a prosthesis mask on the control side. The results of the measurements were expressed as g/cm^2. The BMDs were also analyzed as horizontal fields of the proximal femur, such that zones 1 and 7 consisted of field I, zones 2 and 6 of field II, zones 3

Table 1. Mean BMD (*SD*) values (g/cm²) in 7 Gruen zones of 25 normal and operated femora

Zone	Normal hip		Replaced hip		Difference[a]		95% CI[b]		p
1	0.78	*0.23*	0.68	*0.17*	0.10	*13*	–0.02	0.22	0.090
2	1.20	*0.24*	1.09	*0.31*	0.11	*9*	0.02	0.19	0.021
3	1.70	*0.24*	1.53	*0.26*	0.17	*10*	0.09	0.25	0.000
4	1.77	*0.22*	1.66	*0.21*	0.11	*6*	0.04	0.18	0.002
5	1.75	*0.24*	1.48	*0.25*	0.27	*15*	0.20	0.35	0.000
6	1.22	*0.17*	1.15	*0.24*	0.07	*6*	–0.01	0.15	0.064
7	1.23	*0.22*	0.74	*0.26*	0.49	*40*	0.38	0.62	0.000
All	1.43	*0.41*	1.25	*0.44*	0.18	*13*	0.14	0.22	0.000

[a] Difference between means and difference as *percentages*, [b] Confidence interval.

and 5 of field III and zone 4 of field IV.

The precision error in vivo was analyzed as the coefficient of variation (SD/mean), expressed as a percentage(%CV). This error, which was mainly due to the position of the patient during the measurement, was found to be 1.2% in repeated investigations of the uninvolved femora of 12 patients by 1 operator. The precision error increased to 1.8% when the analysis of the results of a single measurement was repeated by 2 experienced operators. This increase was due to inaccuracy in the positioning of the ROIs on the proximal femur on the computer screen.

The preoperative difference between the femora was determined by measuring the BMD of both femora in 6 patients before the operation and the effect of the operation by repeating the measurement 5 days after the operation. The criteria for including these patients were the same as were used for the study population. The mean BMD was preoperatively 1.8% lower on the side to be operated, the difference being highest, –5%, in zone 1, and lowest, 3%, in zone 5 (Table 3). The postoperative BMD of 6 femora operated on using an uncemented stem was lower by an average of 1.7% than the preoperative value, the difference being highest, –5%, in zone 1 and lowest, 4% in zone 2 (Table 3).

The results were analyzed with an SPSS statistical pack. The significances of the differences were analyzed by using the paired t-test and the normality of the distributions was checked with M-estimators.

Results

The overall functional outcome using HHS was excellent in 13 patients, good in 6 and fair in 6 patients. Subsidence of the stem was observed in 6 stems. It was 3 mm in 3 hips and 2 mm in 3 hips. Radiolucent lines were present around 19 stems in zone 1, in 5 in zone 2 and 5 in zone 5. All stems were judged to be stable (Figure 2). Calcar resoption was found in 8 hips and slight ectopic ossification (Brooker stage 1) in 7 hips.

Comparison between the prosthesis and the uninvolved sides

The change in mean BMD values between the prosthesis and the uninvolved femora of all zones averaged 14% (Table 1). The differences in the BMD values between the prosthesis and normal side were significant ($p < 0.05$) in all zones, except zone 1. The greatest difference (40%) was observed in the calcar area (zone 7) and the smallest difference (6%) was noted in the medial distal area (zone 4). The differences were also small (8% and 7%) in the medial and lateral mid-areas (zones 2 and 6).

Comparison between horizontal fields on the prosthesis and the uninvolved femora

When the proximal femur was analyzed in terms of horizontal fields, the absolute value of the mean proximal–distal BMD increased evenly in both femora, while the change in mean BMD, expressed in percentages from the value of the uninvolved side, decreased rapidly from the most proximal to the lower fields. It was 29 % in field I, 7 % in field II, 13% and 6% in fields III and IV (Table 2).

Comparison between the Gruen zones

A comparison between the proximal zones showed the density in zone 7 to be lower than in zone 1 on the control side (p 0.000), but not on the prosthesis side. A difference was observed in the BMDs between the proximal and distal zones laterally (zones 2–3) and medially (zones 5–6) around the stem both in the study group and in the controls (p 0.000). No difference was seen between the corresponding medial and lateral Gruen zones (zones 2 and 6 or 3 and 5) around the femoral stem in either group.

Table 2. Mean BMD (*SD*) values (g/cm²) in 4 horizontal fields of 25 normal and operated femora

Field	Normal hip	Replaced hip	Difference[a]	95% CI[b]	p
I	1.01 *0.32*	0.71 *0.22*	0.30 *30*	0.20 0.40	0.000
II	1.21 *0.21*	1.12 *0.27*	0.09 *7*	0.03 0.15	0.004
III	1.73 *0.24*	1.51 *0.25*	0.22 *13*	0.16 0.28	0.000
IV	1.77 *0.22*	1.66 *0.21*	0.11 *6*	0.06 0.16	0.000
All	1.43 *0.41*	1.25 *0.44*	0.18 *13*	0.14 0.22	0.000

[a] Difference between means and difference as *percentages*, [b] Confidence interval.

Table 3. The preoperative difference between the control side and the involved side in mean BMD (*SD*) values (g/cm²) in various Gruen zones of 6 patients and the effect of the operation

	Zone 1	2	3	4	5	6	7
Control side	0.87 *0.16*	1.72 *0.22*	1.83 *0.24*	1.79 *0.23*	1.81 *0.27*	1.58 *0.16*	1.40 *0.21*
Involved side	0.82 *0.24*	1.66 *0.34*	1.80 *0.26*	1.80 *0.27*	1.87 *0.27*	1.51 *0.24*	1.38 *0.30*
5 days postop.	0.79 *0.22*	1.73 *0.33*	1.76 *0.26*	1.77 *0.26*	1.84 *0.26*	1.45 *0.14*	1.36 *0.26*
Difference							
control–involved	–0.05	–0.06	–0.03	0.01	0.06	–0.07	–0.02
percent	*–4.9*	*–3.8*	*–1.4*	*0.9*	*3.0*	*–4.5*	*0.0*
involved–5 days postop	–0.03	0.07	–0.04	–0.03	–0.03	–0.06	–0.02
percent	*–3.6*	*4.4*	*–2.5*	*–1.7*	*–1.6*	*–3.8*	*–1.5*

Discussion

Several authors have reported findings concerning the overall reliability of dual-energy radiographic densitometry. Reliability refers to accuracy—i.e., the similarity between actual and measured values, and precision—i.e., the similarity between repeated measurements. In the studies by Kiratli et al. (1992), accuracy proved to be < 0.7% in a phantom model and the precision error < 1.5% in a cadaver femur. Mazess et al. (1989) obtained a precision error of 0.6% in a phantom. These studies employed the same measurement equipment (DEXA) as we did, and it can thus be assumed that the accuracy of our measurements is similar.

The bone loss due to a hip prosthesis can be reliably determined only with serial measurements from the operation onwards. Our findings demonstrated the bone loss in terms of the difference between the prosthesis and the normal side 9 years after the operation. This involves sources of error, such as the possible preoperative difference in the BMDs between the sides and the effect of the operation as such. The magnitude of these sources of error was evaluated, and the error seemed to diminish the difference between the operated and control sides, which means that the true bone loss tends, in fact, to be smaller than was indicated by our results.

The various methods of prosthesis fixation and the stiffness of the stem apparently contribute to bone loss. Engh et al. (1992) defined bone loss as a difference between the prosthetic and uninvolved sides, in the same way as we did. They inserted a similar porous-coated stem into the contralateral hip in 5 deceased patients who had previously had a unilateral arthroplasty and observed the bone loss to be greatest (45%) in the proximal third of the prosthetic stem. Kilgus et al. (1993) reported a 35% loss in the area of the proximal third of an extensively porous-coated stem after 5–7 years of follow-up. These results indicate a greater loss of BMD with high-modulus coating and a relatively stiff stem than we were able to observe here with a low-modulus bone-prosthesis interface of a flexible, isoelastic stem. Even greater bone losses have been reported in association with cemented stems. McCarthy et al. (1991) measured an average loss of 28% in the medial cortex 3 years and over 40% 7–14 years after a cemented arthroplasty, respectively. We found 40% and 7.3% decreases in BMD in the corresponding locations using an isoelastic stem. The reduction in BMD in the calcar region seems to be of the same magnitude with cemented and isoelastic stems, but bone density in the diaphyseal area is better preserved with the isoelastic stem.

In extensively porous-coated and cemented stems, the stress is borne by the coating or the cement from a large area of the metaphysis into the diaphysis; the calcar therefore remains unloaded and displays bone atrophy. The isoelastic prosthesis stem has a collar which should load the calcar and even the most prox-

imal femur and therefore preserve bone quality. We found, however, an unexpected atrophy of the calcar region. A possible explanation may be stress bypass: the collar stress initially is transferred to the metaphyseal area by axially-loaded cortical bone and the metaphyseal bone becomes thicker and stiffer over time, in accordance with Wolff's law, and jams the conical stem into the medullary canal. Thus the stress bypasses the most proximal part of the femur, and causes proximal atrophy (Van Rietbergen et al. 1993).

Huiskes et al. (1992) studied stress patterns by using a strain-adaptive bone remodeling theory and a computer-simulation model and compared the bone losses around a stiff stem and an isoelastic one. They concluded that the overall mean bone loss with a stiff titanium stem was 23% and was as high as 68% in the calcar, 35% around the midstem, 3% around the lower stem and 4% at the tip of the stem. With an isoelastic stem, this calculated bone loss was reduced to 9%, of which half was in the calcar area, one fifth in the midstem and none more distally. It could be demonstrated that an increasing amount of stiff bone around the stem reduced the bone loss. Thus, the mechanical match and the elasticity relations between the bone and the stem were the principal features (Huiskes et al. 1992). These theoretical results are in close agreement with our findings, which seem to indicate a near-physiological compressive stress on the medial side and a strain stress on the lateral side. The strain stress via lag screws may also explain the small decrease in BMD in zone 2, in addition to the stress bypass.

We believe our follow-up was long enough to result in a new equilibrium in the structure of the proximal femur. The isoelastic femoral stem seemed in the long run to preserve the bone mass much better than has been reported for cemented and stiff prostheses. This was the goal desired, but its clinical significance is still not clear and the stress bypass phenomenon makes it more complex. The remodeling process should be investigated more thoroughly over time and in different locations to permit a better understanding of the impact and the clinical consequences of stems of this kind.

Acknowledgement

The authors thank Juhani Heikkilä, M.Sc., for his assistance and support with the technical arrangements of measurements.

References

Bobyn J D, Mortimer E S, Glassman A H, Engh C A, Miller J E, Brooks C E. Producing and avoiding stress shielding. Laboratory and clinical observations of noncemented total hip arthroplasty. Clin Orthop 1992; 274: 79–96.

Brooker A F, Bowerman J W, Robinson R A, Riley L H. Ectopic ossification following total hip replacement: incidence and a method of classification. J Bone Joint Surg (Br) 1973; 55 (8):1629–32.

Engh C A, McGovern T F, Bobyn J D, Harris W H. A quantitative evaluation of periprosthesis remodelling after cementless total hip arthroplasty. J. Bone Joint Surg (Br) 1992; 74 (7): 1009–20.

Gruen, T A, McNeice, G M, Amstutz, H C. "Modes of failures" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop 1979; 141: 17–27.

Harris W H. 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) 1968; 51 (4): 737–55.

Huiskes R, Weinans H, Van Rietbergen B. The relationship between stress shielding and bone resorption around total hip stems and the effects of flexible materials. Clin Orthop 1992; 274: 124–34.

Johnston R C, Fitzgerald R H, Harris W H, Poss R, Müller M E, Sledge C B. Clinical and radiographic evaluation of total hip replacement: A standard system of terminology for reporting results. J Bone Joint Surg (Am) 1990; 72 (2): 161– 8.

Kilgus D J, Shimaoka E E, Tipton J S, Eberle, R W. Dual-energy x-ray absorptiometry measurement of bone mineral density around porous-coated cementless femoral implants. J Bone Joint Surg (Br) 1993; 75 (2): 279–87.

Kiratli B J, Heiner J P, McBeath A A, Wilson M A. Determination of bone mineral density by dual x-ray absorptiometry in patients with uncemented total hip arthroplasty. J Orthop Res 1992; 10 (6): 836–44.

Mathys R Sr (ed). Isoelastic hip prostheses. Manual of Surgical and Operative Techniques. Hogrefe & Huber Publishers, Bühl/Baden 1992; 17–62.

Mazess R, Collick B, Trempe J, Barden H, Hanson, J. Performance evaluation of a dual-energy X-ray bone densitometer. Calcif Tissue Int 1989; 44 (3): 228–32.

McCarthy C K, Steinberg G G, Agren M, Leahey D, Wyman E, Baran D T. Quantifying of bone loss from the proximal femur after total hip arthroplasty. J Bone Joint Surg (Br) 1991; 73 (6): 774–8.

Morscher, E W. Nine-year experience with isoelastic hip endoprosthesis made with plastic material. In: The Cementless Fixation of Hip Endoprosthesis (Ed. Morscher E W). Springer-Verlag, Berlin 1984; 184.

Morscher E W, Mathys R. La prothèse totale isoélastique de hanche fixée sans ciment. Acta Ortop. Belg 1974; 40 (5–6): 321–47.

Niinimäki T J, Puranen J P, Jalovaara P K A. Total hip arthroplasty using isoelastic femoral stems. J Bone Joint Surg (Br) 1994; 76 (3): 413–18.

Oh I, Harris W H. Proximal strain distribution in the loaded femur. J Bone Joint Surg (Am) 1978; 60 (1): 75–83.

Van Rietbergen B, Huiskes R, Weinans H, Sumner D R, Turner T M, Galante, J O. The mechanism of bone remodeling and resorption around press-fitted THA stems. J Biomechanics 1993; 26 (4–5): 369–82.