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A proximal fixed anatomic femoral stem reduces stress shielding

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Abstract In 24 patients with total hip replacement using a short anatomic femoral stem, bone mineral density (BMD) was measured after a 7-year follow-up using dual-energy X-ray absorptiometry. The contralateral side was used as a control. The BMD on the side of the prosthesis was lower by a mean of 7% than that on the control side. The difference was greatest in the area of the calcar and laterally and proximally around the stem. BMD at the metaphyseal and diaphyseal areas were the same as on the contralateral side. The bone loss around the proximal aspect of the stem may be related to the proximal porous coating. It is concluded that stress shielding can be diminished by appropriate design of the femoral component.

Résumé Chez 24 patients avec arthroplastie de la hanche utilisant une tige fémorale anatomique courte on a mesuré les densités minérales osseuses (DMO) par absorptiométrie biénergétique aux rayons X après un suivi de 7 ans. Le côté controlatéral a été utilisé comme témoin. Du côté de la prothèse, la DMO était en moyenne 7% plus faible que du côté témoin. La plus forte différence fut enregistrée dans la région du calcar et latéralement autour de la partie proximale de la tige. Les DMO des zones métaphysaires et diaphysaires n'étaient pas différentes de celles enregistrées du côté contralatéral. La perte osseuse autour de la partie proximale de la tige est peut-être due à l'enrobage poreux proximal. La conclusion est que le report de contrainte peut être réduit par la conception de la tige prothétique.

Introduction

Atrophy of bone related to stress shielding has been observed around femoral components in THA [16]. The ex-

tent of the atrophy depends on the elasticity of the stem; the stiffer and thicker the stem, the greater the atrophy [2, 4]. A coating of high modulus increases the atrophy [9]. Bone density seems to be preserved better around isoelastic stems than around stiff stems [15]. New designs of stem have different patterns of strain distribution within the proximal femur. Here we assess the influence of a short anatomic stem with proximal fixation on bone mineral density (BMD) measurements of the proximal femur. Software enhancement by dual-energy X-ray absorptiometry has made it possible to follow the remodeling process in vivo around the stem [9], and has been used in this study.

Patients and methods

Twenty-four patients were selected from 79 consecutive cases operated on at the Oulu University Hospital between 1989 and 1991 using an anatomic proximally porous coated short stem. The mean age of these patients was 60 years (29–79 years). The criteria for selection were: unilateral THA for primary osteoarthritis using an uncemented short anatomic-femoral stem in a patient with an active lifestyle and no disabling general illnesses. Cases of revision and patients with significant osteoarthritis of the contralateral hip were excluded. The mean age of the 24 selected patients (11 male, 13 female) was 63.7 years (51–75 years), and the measurements were performed at a mean interval of 7.0 years (6.3–7.9 years) after THA. The anatomic stem (DePuy, Warsaw, Ind., USA) was 135 mm long, made of titanium with a 40-mm-broad proximal porous coated zone. The lower aspect of the stem was smooth and was doubly curved, to imitate the shape of the proximal medullary cavity. It was inserted without cement after opening the cavity with special, size-adapted broaches in 1-mm increments. A 32-mm stainless steel head was applied to the tapered neck, and uncemented acetabular components were used.

The patients were reviewed with plain X-rays and underwent a thorough clinical examination, where the standard systems for reporting the results of THA as described by the AAOS, the Hip Society and SICOT [8] and questionnaires including a visual analog scale (VAS) [1], and the Nottingham Health Profile (NHP) [7] were used. The clinical outcome was assessed with Harris hip scores (HHS) [6], with an excellent outcome being of 90 points, good 80 and fair 70. The radiographic data were obtained from standard AP and lateral X-rays taken immediately postoperatively, at 6 months and at the time of the survey. The radiological changes were reported in the zones described by Gruen (Fig. 1A) [5].

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The evaluation of the stability of the stem was based on the extent of subsidence and the number of zones with radiolucent lines. Instability was deemed to be indicated by subsidence after 6 months, or early subsidence of more than 3 mm, or a radiolucent line in four or more Gruen zones without subsidence. Ectopic ossification was evaluated as described by Brooker et al. [3]. BMD was determined with dual-energy X-ray absorptiometry (Lunar DPX; Lunar, Madison, Wis., USA). The patient lay supine with both legs in equal rotation and his/her feet together. The scanning began 2 cm proximally to the highest aspect of the greater trochanter and was continued distally for 20 cm to the area distal to the tip of the prosthesis. The pixel size was 0.6×1.2 mm and the non-operated side was used as a control. Orthopaedic Software Version 1.2 (Lunar) was used to compute the BMD values. The regions of interest (ROI) were located in seven anteroposterior Gruen zones (Fig. 1A). 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 upwards from this line and zone 6 downwards. The ROIs in zones 3, 4 and 5 were located in the upper aspects of the Gruen zones (Fig. 1B). Corresponding regions were used on the control side. To avoid interference from the implant, the software detected the boundary between the bone and the stem with abrupt changes of density, and simulated the stem in the form of a mask on the control side. The results of the measurements were expressed as g/cm².

The precision error in vivo was analysed as the coefficient of the variation (SD/mean) expressed as a percentage (%CV). This error, which was mainly due to the position of the patient during measurement, was determined to be 1.2% by repeated investigation of the uninvolved femur in 12 patients by one operator. The

precision error increased to 1.8% when the analysis of a single measurement was repeated by two experienced operators. This increase was due to inaccuracy in the positioning of the ROIs on the computer screen. The effect of the unilateral osteoarthritis and operation as a source of error was evaluated in six patients. The preoperative BMD was 1.8% lower on the side to be operated on, the difference being highest (5%) in zone 1, and lowest (3%) in zone 5. The postoperative BMD 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.

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

Results

The overall function outcome using HHS was excellent in 15 patients and good in nine. The VAS for hip pain gave a mean of 1.8 on a 0–10 (no pain–extreme pain) scale. In the NHP, where “yes” indicated the undesired option, the patients gave 24 “yes” answers out of a possible 240 questions concerning standing, walking on the flat and walking up stairs. Slight (<2 mm) radiolucent lines were present around four stems in Gruen zone 1, around three in zone 3, and six in zone 4. All stems were judged stable. Calcar resorption was seen in six hips. Slight ectopic ossification (Brooker stage 2) was present in two hips. Endosteal bone formation was present in zone 4 in 13 femora. Femoral hypertrophy was present in 14 cases in zone 2, 15 in zone 3, 11 in zone 4, 13 in zone 5, and 9 in zone 7. There was a mean reduction by 7% in the value of the BMD for the ROIs (Gruen zones) on the operated compared with the non-operated side (Table 1). The greatest difference (–28%) was seen in the area of the calcar (the ROI in Gruen zone 7) and the smallest difference (+3%) was noted in the medial distal area (zone 5). The differences were also small (–6% and –5%) in the lateral distal area and medial mid-zone (zones 3 and 6) and distally beyond the stem (5%) in zone 4. The differences in BMD values in different zones between the two sides were statistically significant ($P<0.05$) in all zones except 5 and 6. When ROIs were considered in horizontal pairs (Table 2) this difference was not seen below the stem in zone 4. There was a statistically significant difference between the femora on the normal and operated side in the medial aspect when the lateral and medial aspects were compared separately (Table 3).

Fig. 1 A Gruen zones. B Location of ROIs (measurement area) in the Gruen zones

Table 1 Differences of mean BMD values after 7 years on Gruen zones in normal femur vs. prothetized femur in 24 patients with a short anatomic stem

	Normal femur		Prothetized femur		Difference of means (g/cm ²)	Change (%)
	Means (g/cm ²)	SD	Means (g/cm ²)	SD		
Zone 1	0.89	0.15	0.73	0.21	–0.16	–18
Zone 2	1.78	0.24	1.65	0.30	–0.13	–7
Zone 3	1.89	0.29	1.78	0.22	–0.11	–6
Zone 4	1.86	0.22	1.77	0.27	–0.09	–5
Zone 5	1.67	0.28	1.73	0.26	0.05	3
Zone 6	1.68	0.28	1.68	0.38	0.00	0
Zone 7	1.24	0.34	0.98	0.19	–0.26	–21
All zones	1.57	0.43	1.47	0.47	–0.10	–6

Table 2 Differences of mean BMD values after 7 years on horizontal parallel Gruen zones in normal femur vs. prosthethized femur in 24 patients with a short anatomic stem

	Normal femur		Prosthethized femur		Difference of means (g/cm ²)	Change (%)
	Means (g/cm ²)	SD	Means (g/cm ²)	SD		
Zones 1 and 7	1.06	0.31	0.86	0.24	-0.21	-20
Zones 2 and 6	1.73	0.26	1.66	0.34	-0.06	-3
Zones 3 and 5	1.78	0.30	1.75	0.20	-0.03	-2

Table 3 Differences of mean BMD values after 7 years on medial and lateral sides of the stem in normal femur vs. prosthethized femur in 24 patients with a short anatomic stem

	Normal femur		Prosthethized femur		Difference of means (g/cm ²)	Change (%)
	Means (g/cm ²)	SD	Means (g/cm ²)	SD		
Medial side	1.53	0.53	1.39	0.51	-0.14	-9
Lateral side	1.52	0.36	1.46	0.44	-0.07	-5

Discussion

Several authors have reported the reliability of dual-energy X-ray absorptiometry, in terms of which reliability refers to accuracy (the similarity between actual and measured measurements) and precision (the similarity between repeated measurements). In the studies of Kiratli et al. [10], accuracy proved to be <0.7% in a phantom model and the precision error <1.5% in a cadaver femur. Mazess et al. [12] obtained a precision of error of 0.6% in a phantom model. Kroger et al. [11] showed a precision area in vivo which varied from 1% to 5.6% depending on the ROI and type of prosthesis, with an average of 2.3% for uncemented stems. These studies used the same equipment (DEXA) as we did, and it can be assumed that the accuracy of our measurements is of the same order. The bone loss associated with THA can only be reliably determined by serial postoperative measurements. The methods for determining BMD around femoral components were not available when these arthroplasties were performed. Our findings show the bone loss after a relatively long follow-up. This includes sources of error, such as the possible preoperative differences in BMDs between the sides and the effects of the operation. The magnitude of these sources of error was evaluated at less than 2% and diminishes the difference between the operated and the control sides. Thus the true bone loss was less than indicated by our results. Kroger et al. [11] compared pre- and immediate postoperative values of BMD, and reported the greatest loss of up to 19% in zone 7. In our measurements this difference was much less, suggesting that the shape of this stem approximated to the shape of the medullary cavity in the proximal femur and thus less bone was removed at operation.

Our results show that the bone loss around the short anatomic proximally fixed uncemented stem was less than reported for other types of stem. Engh et al. [4] defined bone loss as the difference between the operated and the non-operated sides, in the same way as we have, and showed the bone loss to be greatest (45%) around the proximal third of the stem. Kilgus et al. [9] reported a 35% loss in the area around the proximal third of an extensively porous-coated

stem at 5–7 years follow-up. These results indicate a greater loss of BMD with a high-modulus coating and a relatively stiff stem. We have previously reported the results using the low-modulus bone prosthesis interface of a flexible isoelastic stem where the average loss of BMD was 14% [15]. McCarthy et al. [13] showed an average loss of 28% in the medial cortex 3 years and more than 40% 7–14 years after a cemented arthroplasty. Pritchett compared different types of stem and showed that a stem with physiological proximal loading is associated with the maintenance of the BMD, with a mean loss measured, as the difference between femora, of 8%; whereas this difference, when using the cemented Muller straight stem, was 57%.

The reduction in BMD is highest with all types of stem in the region of the calcar. The same phenomenon was observed here with a proximally porous coated short stem. This atrophy may be the result of the method of fixation by porous coating, which disperses the load evenly around the femoral neck and diminishes stress on the calcar, which, in accordance with Wolff's law, leads to its atrophy. This may also lead to hypertrophy of the cortical bone, which may be responsible for thigh pain in well fixed stems as is seen by VAS and Harris scores with some radiologically soundly fixed stems. Munting et al. [14] reported a series of stemless femoral implants and showed the BMD to be maintained equally on both sides or to increase if the initial value was low. We believe that the follow-up here was long enough for physiological equilibrium in the proximal femur to have been restored. The proximally porous-coated short anatomic stem seemed in the long term to be associated with preservation of bone mass better than has been reported for cemented and longer stiff prostheses. This study also demonstrated that the remodelling process was a function of time. Thus the design of the stem has an effect on bone remodelling by allowing the loading of the bone as proximally as possible; and long stiff stems should be avoided.

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