Changes in bone mineral density adjacent to two biomechanically different types of cementless femoral stems in total hip arthroplasty

B. Zerahn, M. Storgaard, T. Johansen*, C. Olsen, G. Lausten, I.-L. Kanstrup

Department of Orthopaedic Surgery and Department of Clinical Physiology and Nuclear Medicine, Herlev Hospital, University of Copenhagen, Denmark

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Abstract. *We have compared the differences in bone mineral density (BMD) adjacent to two biomechanically different cementless femoral stems used for total hip arthroplasty. Measurements were performed 12 to 38 months after surgery in a cross sectional study of 29 patients. Of these, 15 had arthroplasties using an "off the shelf" type cementless femoral stem (Spotorno), while 14 had a custom made cementless stem (Evolution-K). Dual X-ray absorptiometry (DXA) measurements revealed that the patients who had a Spotorno stem had a significantly lower BMD in the operated leg compared to the non-operated side in both Gruen zones 1 and 7, whereas no significant differences were found in these areas in the Evolution-K group. For both types of prosthesis there was a significant and similar decrease in BMD of the proximal tibia on the operated side.*

Résumé. *Le but de cette étude a été de comparer les différences de densité minérale osseuse (DMO) des zones adjacentes à deux prothèses totales de hanche sans ciment, biomécaniquement différentes. Les mesures furent pratiquées de 12 à 38 mois après la chirurgie dans une étude transversale sur 29 patients. Quinze patients avaient une prothèse produite en série sans ciment (Spotorno). Quatorze patients avaient une prothèse faite sur mesure sans ciment (Evolution-K). – La comparaison des mesures d'absorptiométrie radiologique à double énergie révélèrent que la DMO des patients ayant une prothèse Spontorno était significativement inférieure du côté opéré par rapport au côté non opéré dans les zones Gruen 1 et 7. Il n'y avait pas de différence dans*

ces zones dans le groupe des prothèses Evolution-K. Pour les deux types de prothèse, il y avait une diminution significative et similaire de la DMO au niveau de la partie proximale du tibia du côté opéré. – Nos résultats suggerent que la conception biomécanique de la prothèse Evolution-K faite sur mesure est favorable en ce qui concerne la perte minérale osseuse péri-prothétique.

Introduction

Remodelling of bone adjacent to the proximal part of both cemented and cementless stems is considered to be an important factor in the long term survival of total hip prostheses [2, 7]. Early and precise evaluation of bone loss with different types of stems may be important for the improvement of stem designs.

Methods of quantifying bone mineral density (BMD) in bone adjacent to femoral implants, such as quantitative computerised tomography (QCT) or magnetic resonance imaging (MRI), have been found to be inaccurate, as they are not able to subtract the irregular reflective effects of the metallic implants [2, 16, 18]. Quantitative grey-scale analysis of radiographs has been generally used but the precision of this method is low, being about 30% [8].

Dual X-ray absorptiometry has become available as a reliable measurement of postoperative stress remodelling of BMD around cementless femoral implants, and a comparison between different types of femoral implants is now possible [9]. This method utilises an X-ray tube with a K-edge filter that separates the X-ray spectrum into two bands of energy. An algorithm is then used to subtract energy loss due to soft tissue. Improvements of the software specially developed for assessing BMD adjacent to femoral hip

Reprint requests to: B. Zerahn, Department of Clinical Physiology/Nuclear Medicine, Herlev University Hospital, DK-2730 Herlev, Denmark

* Decreased

implants (model DPX-L, Lunar, Madison, Wisconsin) have made it possible to compare the BMD of the intact and non-operated femora by overlaying a computerised mask of the implant on the image of the intact femur. The exact amount of bone covered by the implant can thus be subtracted and the BMD of the bone in specified regions of interest can then be compared.

We examined the bone-loss in an "off the shelf" stem type hip prosthesis (Spotorno CLS) and a "custom made" femoral implant (Evolution-K). In order to eliminate the influence of differences in weight bearing upon the BMD, we also measured the BMD of both proximal tibiae [13].

Materials and methods

Subjects

Twenty-nine patients with unilateral total cementless hip arthroplasty of either the Evolution-K (14 patients) or Spotorno type (15 patients) were included in the project. Informed consent was obtained from all subjects and the investigation was approved by the ethical committee of Copenhagen County, Denmark.

Measurements were performed 12 to 38 months after surgery. Age, height, weight, sex, time since implantation, differences in leg length, pain, and preoperative morphologic cortical index (MCI) (Fig. 1) were recorded. BMD values from both hips and both proximal tibiae were obtained in all patients.

Ten patients in the Evolution-K group and 13 patients in the Spotorno group had undergone a total hip arthroplasty (THA) because of osteoarthritis, two patients in each group because of fracture sequelae, and two patients in the Evolution-K group because of a dysplastic hip joint.

Fourteen patients, 9 women and 5 men, had an Evolution-K implant. These individuals were offered a custom made prosthesis at the discretion of the surgeon, because the shape or size of their proximal femoral shaft was considered unsuitable for a standard cementless prosthesis. They were scanned at a mean of 21.2 months postoperatively (range: 12 to 30 months). Their mean age, weight, and height at the time of scanning were 50.1 years (30 to 64 years), 80.9 kg (55 to 108 kg), and 169 cm (156 to 192 cm), respectively. The mean MCI of this group was 3.0 (2.3 to 3.7) for the operated site and 3.2 (2.3 to 3.9) for the non-operated side.

The 15 patients, 7 women and 8 men, who had a Spotorno implant, were scanned at a mean of 21.7 months postoperatively (12 to 38 months). Their mean ages, weights and heights at the time of scanning were 52.7 years (31 to 59 years), 76.5 kg (range 60 to 90 kg), and 169 cm (157 to 179 cm), respectively. The mean MCI for this group was 2.8 (2.4 to 3.2) for the operated side and 2.7 (2.3 to 3.4) for the other side.

Measurements

When performing a Gruen analysis each of the six zones adjacent to the implant were given the height of one third of the implant length. However, in order to be able to compare region number 7 in the Gruen analysis between the operated and non-operated side, we reduced the height of that region. The BMD value for each Gruen zone is expressed in g/cm² reflecting a two-dimensional image of the bone as seen in the anteroposterior plane.

Fig. 1. Schematic drawing of the proximal femur. The morphological-cortical index is calculated from the ratio between CD and AB. The two distances can be measured on a standard radiograph of the femur

Fig. 2. Schematic drawing of the proximal tibia. A square placed immediately below the medial subchondral plate indicates the region used for BMD measurements

Scanning was performed with the patient in the supine position. The leg was secured in a neutral position by standardised supports for the foot and thigh.

For scanning of the tibia the scanned leg was supported in a 10 degree inwardly rotated position. BMD values were obtained from a 1 cm² region of interest (ROI) placed immediately below the medial subchondral plate of the proximal tibia (Fig. 2). A system quality assurance programme was performed daily in accordance with the manufacturers instructions.

Prosthesis types

The custom made femoral stems (Evolution-K, Fehling Werke, Tübingen, Germany) were individually shaped on the basis of a CT-scan of the proximal femur of the patient. After reaming with an individually-adapted reamer of the same size and shape as the prosthesis itself, a perfect press fit of the prosthesis into the femoral canal was obtained in every instance.

The standard femoral stem (Spotorno CLS, Protek AG, Bern) which has a double-wedge shape, was inserted by means of the conventional uncemented technique. The approximate size of the prosthesis was estimated by templates on radiographs of the proximal femur to fit with a minimum of 2 mm impacted cancellous bone surrounding the implant. None of the femoral stems were coated with hydroxyapatite. In all patients, an uncemented standard press fit acetabular cup with a porous coating (Harris-Galante, Zimmer, Warsaw, In) was used. Both prostheses were made of a Ti-Al alloy and had similar sand blasted surface coatings.

Statistical analysis

The Wilcoxon test for non-parametric comparisons of two groups was used for comparing differences in BMD in Gruen zones 1 to 7 and in the proximal tibia between the operated and non-operated leg for each of the two stem types. A *P*-value of less than 0.05 was accepted as being significant.

Results

There were no differences between the two groups regarding age, sex, height, body weight, and time from surgery to BMD measurements. Equally, there were no differences between patients with Spotorno prostheses and patients with Evolution-K prostheses regarding MCI and BMD of the non-operated leg.

Differences between the operated and non-operated leg in terms of the BMD of the proximal tibia and of the Gruen zones 1 to 7 are listed in Table 1.

A significant increase in BMD in Gruen zone 5 was found in the operated compared to the non-operated side in patients with Evolution-K prostheses. A significant decrease in BMD was found in the Gruen zones 1 and 7 in the operated compared to the non-operated leg in patients with Spotorno prostheses. A trend towards a decrease in BMD was found in Gruen

Fig. 3. Radiographs of a 63-year old woman with a Spotorno prosthesis, obtained 6 years after surgery. Marked bone resorption of the proximal femur is evident

Fig. 4. Radiographs of a 57-year-old woman with an Evolution-K prosthesis, obtained 3 years after surgery. There is no evidence of bone resorption in the proximal femur

Table 1. Differences between operated and non-operated side

Prosthesis	Region	Difference %	Mean difference g/cm ²	SD g/cm ²	<i>P</i>
Evolution-K	Tibia BMD	-11.6	-0.104	0.101	<0.01
Spotorno	Tibia BMD	-14.8	-0.129	0.112	<0.001
Evolution-K	Gruen 1	4.2	0.037	0.157	n.s.
Spotorno	Gruen 1	-15.7	-0.145	0.120	<0.001
Evolution-K	Gruen 2	1.9	0.031	0.194	n.s.
Spotorno	Gruen 2	-3.4	-0.057	0.167	n.s.
Evolution-K	Gruen 3	1.9	0.006	0.135	n.s.
Spotorno	Gruen 3	2.0	0.037	0.122	n.s.
Evolution-K	Gruen 4	-0.7	-0.013	0.135	n.s.
Spotorno	Gruen 4	-0.3	-0.006	0.22	n.s.
Evolution-K	Gruen 5	6.2	0.120	0.124	<0.05
Spotorno	Gruen 5	3.5	0.067	0.198	n.s.
Evolution-K	Gruen 6	-4.7	-0.077	0.261	n.s.
Spotorno	Gruen 6	-6.0	-0.102	0.221	0.05<p<0.1
Evolution-K	Gruen 7	-11.9	-0.163	0.314	n.s.
Spotorno	Gruen 7	-28.4	-0.409	0.202	<0.001

n.s.=non significant

zone 7 of the operated leg in patients with Evolution-K prostheses and in Gruen zone 6 of the operated leg for patients with Spotorno prostheses. These differences remained significant when calculating data for patients only with a primary arthropathy. Selected radiographs exemplifying these changes are shown in Figs. 3 and 4.

A significant decrease was found in BMD of the proximal tibia in the operated compared to the non-operated leg in both groups (Table 1).

Discussion

Dual-energy X-ray absorptiometry is a reproducible method for quantitative analysis of bone mineral density adjacent to metallic implants. The precision of this method has been found between 1.8 and 6.8% [3, 10, 11, 15, 17]. The radiation dose for each hip scan is 0.05 mSv.

Even though the subjects were not selected at random, no significant differences were found between persons with Spotorno prostheses and individuals with Evolution-K prostheses in terms of MCI and BMD of the non-operated leg or age, sex, height, weight, and follow-up period. As the preoperative conditions between the two groups were comparable they could not have had any influence on the difference between the two groups regarding the changes in BMD adjacent to the prostheses.

The relative reduction of BMD in the proximal tibia of the operated side indicates a dissimilarity in the loading between the operated and non-operated leg, which in part may account for the general decrease in BMD found in bone adjacent to the prostheses. Since no difference between the bone loss in the proximal tibia of the operated leg was found between the two prosthesis types, the differences regarding bone loss adjacent to the prostheses must be as a consequence of the biomechanical impact of stem design. Numerous factors are known to induce periprosthetic stress-shielding and thereby loss of BMD [1, 19]. Engh et al. [5] demonstrated a significant bone loss in the proximal part of the femur adjacent to cementless femoral stems compared to the non-operated side in cadavers. In another study, Engh et al. (1994) [6] showed that remodelling of the proximal femur after insertion of uncemented prostheses mainly takes place during the first two postoperative years. Kiratli et al. (1992) [11] found a significant bone loss in the proximal femur as early as 12 months after the implantation of cementless femoral stems.

As the Spotorno stem is double wedge-shaped, the weight distribution from the stem to the femur is uneven, and this factor is probably the main reason for the accelerated bone loss in the Gruen zones 1 and 7 in this group.

In cemented total hip arthroplasties McCarthy et al. [14] have shown a decrease in BMD of between 40 and 49%. Compared to other studies of bone loss adjacent to uncemented prostheses our findings are in

agreement with those of Dickob et al. (1993) [4], who found an average bone loss adjacent to the Spotorno CLS stem (Protek) of 26.4%; this value is fairly low compared to other cementless prosthesis types tested in the same study. [i.e. 17.2% for the PM stem (Aesculap), 40.8% for the DePuy profile stem, and 71.3% for a macroporous stem (Lord, Judet)]. In contrast, the patients with Evolution-K femoral stems showed only a trend towards a significant bone loss compared to the non-operated side in Gruen zone 7 in our study. Martini et al. (1996) [12] found a significant loss of BMD in all seven Gruen zones in 23 patients with the Evolution-K prosthesis. Even though this loss was fairly low (maximum 21% or 0.3 g/cm² in Gruen zone 7) in comparison with the study of Dickob et al. (1993) [4] it contrasts with our own findings. Differences in average age, the number of patients tested, and their selection may have contributed to this discrepancy. Nevertheless, the bone loss adjacent to Evolution-K prostheses appears to be very low in both studies.

We found that the custom made femoral stems preserve adjacent bone in the proximal regions of the femur more efficiently than the off-the-shelf type uncemented stems. This finding favours the use of the Evolution-K design, especially in younger patients, as an increased durability can be expected due to less periprosthetic bone loss. Nevertheless, both long term clinical results as well as prospective studies are needed to support such recommendations.

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