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ORIGINAL ARTICLE

Changes in bone mineral density of the distal femur after revision total knee arthroplasty with metaphyseal press-fit stem

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Abstract
Background The effect of postoperative adaptive bone remodeling following a stemmed femoral implant in revision total knee arthroplasty (rTKA) is unknown. The aim of this study was to evaluate bone mineral density (BMD) changes of the distal femur following cemented rTKA with a 100-mm press-fit stem.
Materials and methods Sixteen consecutive patients were included in the study (age range 40–85 years; mean 63.5 years). NexGen® (Zimmer, Warsaw, IN, USA) cemented revision implants were used. All implants had the same press-fit femoral stem length of 100 mm. Clinical examinations with evaluation of the knee function using the Knee Society's Knee Scoring System were used. Measurements of BMD (g/cm^2) were performed by dual-energy X-ray absorptiometry (DEXA) using a Norland XR-46 (Norland Corp. Fort Atkinson, WI, USA) bone densitometer.
Results Knee and function scores improved significantly ($P = 0.005$) from the preoperative values to 1 year of follow-up. In regions of interest (ROI) 1–4, a significant increase in BMD (3.5–6.0%) after 6 months was seen. This increase only remained significant in ROI 4 (4.0%, $P = 0.01$) at 1 year of follow-up.
Conclusions The increase in BMD is probably the result of increased mobility and load on the extremity after implantation of a well-functioning rTKA.

Keywords DEXA · BMD · Distal femur · Revision total knee arthroplasty

Introduction

Operation with implantation of a primary total knee arthroplasty (TKA) or a revision total knee arthroplasty (rTKA) represents a significant trauma to the bone and soft tissue of the affected extremity. It is well known that various traumatic conditions of an extremity can induce bone loss in most patients [1]. In TKA or rTKA, other factors such as stress shielding, wear-debris-induced osteolysis, implant loosening, and bone necrosis due to infection can also play an important role in bone loss, and removal of implants during revision knee surgery can even worsen existing bone loss. Dual energy X-ray absorptiometry (DEXA) [2, 3] can be used to measure changes in bone mineral density (BMD) close to an orthopedic implant. The effect of postoperative adaptive bone remodeling with a stemmed femoral implant in rTKA is unknown. Several studies on BMD changes of the distal femur after TKA exist. A common finding is a decrease in BMD from baseline up to 2 years after operation [4–7]. No studies on BMD changes of the femur after rTKA have previously been published. The aim of this study was to evaluate BMD changes of the distal femur following cemented rTKA with a 100-mm press-fit stem.

Materials and methods

Sixteen consecutive patients with rTKA were included in a study with the aim of measuring adaptive bone remodelling around a stemmed revision femoral implant. There were

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nine men and seven women with a mean BMI of 28 (21–39) and a mean age of 63.5 (range 40–85) years (Table 1). All patients received NexGen® (Zimmer, Warsaw, IN, USA) cemented revision implants (Fig. 1), and either Legacy® knee-constrained condylar ($n = 12$) or Legacy® knee-posterior stabilized ($n = 4$) knees were inserted (Table 1). All implants had the same press-fit femoral stem length of 100 mm (with or without offset), with stem diameter ranging from 15 to 24 mm (average 18.5 mm). The patients also participated in a randomised study of 40 patients with the aim of evaluating the use of trabecular metal cones (Zimmer) for reconstruction of considerable bone loss of the proximal tibia in rTKA. The Anderson Orthopaedic Research Institute (AORI) Bone Defect Classification [8, 9] was used to classify bone loss of the distal femur. All patients had type F2b defects (Table 1). Primary osteoarthritis was the major primary disease leading to the first TKA (Table 1). Eight patients were revised because of aseptic loosening, four because of instability, one because of polyethylene (PE) wear, and three because of deep infection. The same surgeon performed all operations. Clinical examination with evaluation of knee function using the Knee Society's Knee Scoring System [10] were performed preoperatively and with follow-up after 1 year. All patients gave informed consent prior to the study, which was authorized by the local Scientific Ethical Committee of Københavns and Frederiksberg Kommuner (KF 01 276195) and was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki as revised in 2000.

BMD measurements (g/cm^2) were performed by DEXA using a Norland XR-46 (Norland) bone densitometer. All measurements were performed in the coronal plane of the limb with a scan speed of 45 mm/s using the research scan option. Scans were performed of the distal femur and along the femoral shaft in close relation to the femoral component (pixel size 1.0 mm × 1.0 mm). Furthermore, scans of the distal tibia and fibula just above the ankle joint were performed bilaterally (pixel size 0.5 × 0.5 mm). All scans were performed with patients lying flat on their back, the knee extended, and the ankle in a neutral position with the toes pointing straight up. All patients had their first scans performed within the first 2 weeks after surgery and with follow-up after 3, 6, and 12 months. Custom-made software was used to analyze DEXA scans [11] that allows BMD measurement in close relation to orthopedic implants by excluding pixels considered by the software as metal and allows a variable metal exclusion threshold to be set by the physician. The metal exclusion threshold was set at 4.5 g/cm^2. On the computerized scan plots, five regions of interest (ROI) were selected to measure BMD of the distal femur and femoral shaft. The femur stem was divided into three ROIs of the same size: distal (ROI 1), intermediate (ROI 2), and a proximal (ROI 3). ROI 4 was defined as a total the three ROIs. At the tip of the stem, a distal ROI was defined as ROI 5 (Fig. 2). In the distal tibia and fibula, one ROI was selected 1 cm above the ankle joint line.

Table 1 Demographic, clinical, and operative data

Patient characteristics	Corresponding statistics
Number	16
Age (years)	63.5 (40–85)
Sex (M/F)	9/7
Body mass index	28 (21–39)
Primary disease	
Primary arthrosis	11
Secondary arthrosis	3
Haemofilia	2
Prothesis type	
Constrained condylar	12
Posterior stabilized	4
Femur implant	
Stem length (mm)	100
Stem diameter (mm)	18.5 (15–24)
Numbers of used femur augments per patient	
0	4
1	3
2	7
3	2
Cause of revision	
Aseptic loosening	8
Pain	0
Instability	4
PE-wear	1
Deep infection	3
Classification of femoral bone defects (AORI)	
F2b	16
F3	0
Knee score	
Preoperative	37 (17–57)
1 year	78 (44–100)
Knee function	
Preoperative	24 (0–70)
1 year	61 (15–80)

PE polyethylene, *AORI* Anderson Orthopaedic Research Institute

Statistical analysis

Changes in BMD are given as the mean percentage change together with total range and standard deviation (SD). For evaluation, *t* test for paired data with calculation of the 95% confidence intervals (95% CI) were performed, and P values <0.05 were considered significant.

Fig. 1 Cemented revision total knee arthroplasty (rTKA) with a Legacy® knee-constrained condylar implant with a 100-mm press-fit stem

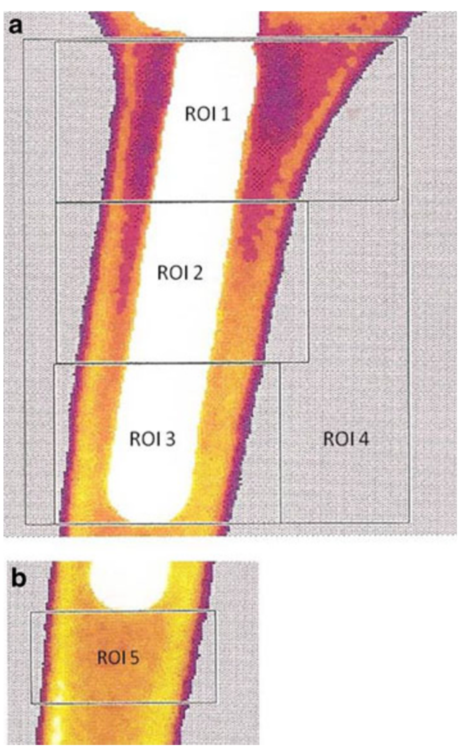

Fig. 2 Dual-energy X-ray absorptiometry (DEXA) scan plots of the distal femur showing the four regions of interest (ROIs). along the stem (**a**) and the fifth at the tip of the stem (**b**)

Results

Knee and function scores improved significantly ($P = 0.005$) from the preoperative values of 37 and 24 to 78 and 61 at 1 year of follow-up. In ROIs 1–4, a significant increase in BMD reaching 3.5–6.0% after 6 months was seen during the first 3–6 months after surgery. This increase only remained significant in ROI 4 (4.0%, $P = 0.01$) at 1 year of follow-up (Table 2). In ROI 5, no significant changes was observed during the first postoperative year. BMD changes of the distal tibia showed a temporary decrease of 4.4% ($P = 0.03$) in the operated legs, but this increase was not significant at the 1-year follow-up. In the contralateral distal tibia, no significant changes in BMD were seen (Table 2).

Discussion

Clinical outcome after 1 year of follow-up was comparable with other studies on rTKA with considerable bone loss, where bone loss at the proximal tibia and/or femur was reconstructed with stemmed femoral implants and impaction bone grafting [12, 13] with or without metal augments [14]. We found at 6 months of follow-up a significant increase in BMD of 3.5–6% in all ROI along the stem. However, after 1 year, the increase (4%) in BMD was only significant in ROI 4. In ROI 5 above the stem, no significant changes in BMD were observed.

To our knowledge there exists no published studies on BMD changes at the distal femur after rTKA. Existing knowledge comes from finite element studies on stemmed femoral implants and studies evaluating changes in BMD around the femoral component without stem after TKA. In a finite element study, Van Lenthe et al. [15] studied bone loss and remodelling patterns of four femoral components: two primary TKAs and two stemmed revision prostheses with stem diameter of, respectively, 18 and 12 mm. They found that the revision prostheses tended to cause more bone loss than the primary implants, especially in the distal regions. They also found that prostheses with a thick press-fit stem comparable with the implants in our study would be expected to lead to an increased bone loss of the most distal femur due to increased stress shielding. However, in the ROI proximally along the stem comparable with the ROI used in this study, they found stresses and strains slightly higher than in the femur without TKA or rTKA and thus predicted minimal increase in BMD in the most proximal ROI.

Our results are consistent with the findings made by Van Lenthe et al. [15]. We believe that the increase in BMD along the proximal parts of the femoral stem was caused by an increase in strain created by altered mechanical load. This remodelling of the periprosthetic bone is well known

Table 2 Bone mineral density (BMD) changes in the distal tibia of the operated [revision total knee arthroplasty (rTKA)] and contralateral legs

ROI	BMD (g/cm^2) Post	Δ BMD (%) 0–3 months	*P* value	Δ BMD (%) 0–6 months	*P* value	Δ BMD (%) 0–12 months	*P* value
Operated							
Mean	0.693	−2.5		−4.4		−1.3	
Range	0.184–1.032	−24.1 to 11.4		−17.6 to 3.3		−16.3 to 12.3	
SD	0.23	9.5		5.6		7.7	
95% CI		−8.2; 3.2	0.39	−7.8; −1.1	0.03	−5.7; 3.2	0.39
Not operated							
Mean	0.678	−1.6		1.84		1.6	
Range	0.284–1.024	−18.5 to 12.6		−10.64 to 18.47		−16.4 to 23.7	
SD	0.226	8.8		8.44		13.1	
95% CI		−6.5; 3.3		−2.8; 6.5		−5.3; 8.6	
			0.35		0.51		0.77

P unpaired and paired Student's *t* test, *SD* standard deviation, *CI* confidence interval

Table 3 Changes in bone mineral density (BMD) of the distal femur around the revision total knee arthroplasty (rTKA)

	BMD (g/cm^2) Postoperative	Δ BMD (%) 0–3 months	*P* value	Δ BMD (%) 0–6 months	*P* value	Δ BMD (%) 0–12 months	*P* value
ROI 1							
Mean	0.848	4.5	0.03	6.0	0.01	3.4	0.07
Range	0.634–1.112	−5.3 to 16.4		−3.9 to 15.7		−3.4 to 10.8	
SD	0.153	5.9		5.8		4.9	
95% CI		0.5; 8.5		2.1; 9.9		−0.3; 7.2	
ROI 2							
Mean	1.014	3.1	0.06	4.1	0.03	3.4	0.12
Range	1.285–1.014	−5.0 to 9.6		−4.7 to 16.1		−7.7 to 14.4	
SD	0.193	4.7		5.6		5.7	
95% CI		−0.1; 6.2		0.4; 7.9		−1.0; 7.8	
ROI 3							
Mean	1.236	2.2	0.03	3.5	0.02	2.8	0.27
Range	0.718–1.657	−3.3 to 5.6		−1.6 to 11.9		−9.6 to 15.0	
SD	0.251	2.8		4.0		6.9	
95% CI		0.3; 4.0		0.80; 6.1		−2.6–8.1	
ROI 4							
Mean	0.998	3.4	0.01	4.7	0.00	4.0	0.01
Range	0.641–1.310	−0.8 to 10.3		1.9–9.7		−0.7 to 10	
SD	0.184	3.7		2.9		3.1	
95% CI		0.9; 5.8		2.8; 6.6		1.5; 6.3	
ROI 5							
Mean	1.276	−0.7	0.63	−0.8	0.42	0.4	0.84
Range	0.640–1.988	−5.6 to 3.9		−5.3 to 3.9		−6.7 to 8.3	
SD	0.352	3.7		3.0		4.8	
95% CI		−3.8; 2.4		−3.0; 1.4		−3.7; 4.4	

ROI region of interest, *SD* standard deviation, *CI* confidence interval

P values Student's *t* test

and is described in Wolff's law [16]: bone remodels and models to adapt to altered mechanical loads (adaptive bone remodeling).

Prospective studies on BMD changes after THA report a tendency of decrease in BMD during the first year after surgery. The decreases are greatest in the proximal ROIs (calcar region), unrelated to the method of fixation, and range from 11.5% to 28%. The decrease in BMD diminishes distally to the tip of the stem [17–22] or shows small gain in BMD [23–25] (Table 3).

Studies on BMD changes at the distal femur after TKA report decreases in BMD ranging from 2.6% to 36% at

2 years of follow-up [4–7]. The bone loss is typically located behind the anterior flange of the femoral implant and reported to be caused by stress shielding. The ROI behind the anterior flange is located at the distal part of the femur, whereas the ROIs in this study are located at the more proximal parts of distal femoral shaft. Even though most studies on changes in BMD after TKA have shown loss of bone mineral with time [4–6], Petersen et al. [26] reported a significant increase (6,1%) in BMD at the lateral tibia condyle 2 years after TKA with uncemented tibial components without hydroxyapatite. Initial temporary increases in BMD within the first operative year after TKA were seen in another study [27].

Patients participating in our study all suffered from failed TKAs that resulted in periods of reduced mobilization or long-term immobilization, e.g., patients undergoing two-stage revision surgery. Given the fact that immobilization and reduced mobility suppresses BMD [28], the increase in BMD seen in this study is probably the result of increased mobility and load on the extremity after implantation of a well-functioning rTKA, thus stimulating femoral bone-to-bone formation.

There are some limitations to our study. The effect of canal filling could not be evaluated, as all femoral stems were in tight press fit. Furthermore, we only evaluated a femur stem length of 100-mm and thus could not measure a possible effect of the stem length on the bone remodelling pattern. In addition, the effect of pre- or preoperative femoral bone loss on the postoperative changes in BMD could not be considered, as all cases were F2b. Finally, the study included only a small sample size, which makes the results less certain, and this should be kept in mind in the interpretation of the results.

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Conflict of interest None.

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