Arch Orthop Trauma Surg (2001) 121:282–285

CLINICAL AND EXPERIMENTAL FORUM

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Distal femoral bone mineral density after total knee arthroplasty: a comparison with general bone mineral density

Received: 21 March 2000

Abstract The bone mineral density (BMD) of the distal femur may decrease after cemented total knee arthroplasty (TKA) as a result of the stress shielding effect of the femoral component. The purpose of the study was to determine the changes in BMD of the distal femur compared with those of the femoral necks and the lumbar spine after cemented TKA. BMD of two regions of interest in the distal femur, both femoral necks and the lumbar spine was measured with dual-energy X-ray absorptiometry in 10 patients (age range 41–80 years, mean 62 years) with 12 TKAs preoperatively and during follow-up for 1 year after surgery. The hip and spine measurements were performed for comparison to assess if general changes in BMD occurred after TKA. The median decrease in BMD in the region behind the anterior flange of the femoral component was 22% (95% CI: 12%–33%), while the average decrease in the region just above the femoral component was 8% (95% CI: 2%–13%). The difference in change of BMD between both regions before and 1 year after TKA was significant ($p = 0.03$).We found less than 1% difference in BMD of both femoral necks and the lumbar spine on average between the preoperative and 1 year follow-up measurements (not significant). A significant periprosthetic distal femoral bone resorption occurred after TKA. BMD of the femoral necks and lumbar spine did not differ 1 year after TKA.

Introduction

The bone mineral density (BMD) of the periprosthetic distal femur in cemented and uncemented total knee arthroplasty (TKA) decreases in certain areas after bone remodelling as a result of the stress shielding effect of the femoral component [5, 7, 9]. BMD of the femoral necks and the lumbar spine in patients with osteoarthritis receiving a TKA may also change as a result of reduced general mobility during the rehabilitation phase following TKA or increased mobility thereafter. The purpose of the study was to determine the quantitative distal femoral bone resorption as expected from the stress shielding effect of the femoral component. The hip and spine measurements were performed for comparison to assess if general changes in BMD occurred after TKA.

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Patients and methods

Ten patients (6 female and 4 male) with a mean age of 62 years (age range 41–80 years) were enrolled in the study. Patients with a rheumatic, renal, hepatic or gastrointestinal disease were excluded from the study, as were patients using medication that interfered with mineral metabolism. Twelve cemented TKAs (Press Fit Condylar, Johnson & Johnson, Raynham, Mass., USA) were implanted (7 left, 5 right) for osteoarthritis in these 10 patients. Two patients (G and H, Table 1) had bilateral TKAs with a 2-week interval. In 5 knees the patella was replaced by a patellar component, in 7 knees the patella was not replaced. Five days after surgery, the knees were exercised with a continuous passive motion machine for 3 h daily until discharge from the hospital. One week after TKA the patients started partial weight-bearing with a walker or 2 crutches for a period of 6–12 weeks. Unlimited full weight-bearing of the knee without walking aids was allowed after this period.

The knees were clinically assessed preoperatively and 1 year postoperatively using the Knee Society clinical rating system [4]. A radiographic evaluation of the operated knees was performed 1 year after surgery according to the Knee Society roentgenographic evaluation and scoring system [2]. Osteopenia and osteolysis of the distal femur were noted on the plain radiographs.

BMD of the periprosthetic distal femur was measured using dual-energy X-ray absorptiometry (DEXA) on a lateral view (Hologic 1000, Zaventem, Belgium) before the operation (12 knees), at 3 months (5 knees), 6 months (8 knees) and 12 months (12 knees). The patient was placed in ipsilateral recumbency with the knee in 45 deg of flexion supported by pillows to assure a true lateral scan. The lumbar spine module including subregions with software for metal removal was applied to measure the periprosthetic femoral BMD. Two regions of interest (ROI) were selected: ROI 1 (1.7 cm^2) in the distal anterior area of the femur behind the anterior flange,

Table 1 Bone mineral density (BMD, g/cm^2) measured in the distal femur of 12 knees before and after total knee arthroplasty (TKA). *ROI* region of interest, *t* time from TKA (months)

Patient	Knee	Gender	Side of TKA	ROI 1				ROI 2			
				t = 0	t = 3	t = 6	t = 12	t = 0	t = 3	t = 6	t = 12
A	1	Male	Left	0.637	0.689	0.701	0.688	1.044	1.040	0.966	0.840
B	2	Male	Left	0.668		0.595	0.413	1.061		1.029	0.961
C	3	Female	Right	0.592			0.438	1.123			1.006
D	4	Male	Left	0.753	0.558		0.489	1.232	1.117		0.977
E	5	Female	Right	0.968			0.590	1.060			0.978
F	6	Male	Left	1.185		0.978	1.005	1.552		1.341	1.356
G	7	Female	Left	0.849	0.574	0.569	0.546	0.784	0.753	0.697	0.681
G	8	Female	Right	0.760	0.675	0.631	0.660	0.785	0.869	0.863	0.906
H	9	Female	Left	0.854		0.631	0.496	1.181		1.104	1.141
H	10	Female	Right	0.847		0.625	0.558	1.231		1.243	1.166
I	11	Female	Left	0.531			0.475	0.797			0.824
J	12	Female	Right	1.049	1.054	1.025	1.191	1.238	1.222	1.148	1.152
Average				0.808	0.710	0.719	0.629	1.091	1.000	1.049	0.999
Standard deviation				0.193	0.201	0.179	0.237	0.226	0.189	0.208	0.183

and ROI 2 (4.4 cm^2) in the supracondylar area just superior to the anterior flange of the femoral component (Fig. 1).

Reproducibility measurements of the lateral distal femoral scans were performed in 3 patients with a TKA who were scanned twice on the same day.

BMD of the lumbar spine (L1–4) was measured by DEXA in a standard anteroposterior direction preoperatively (10 patients), at 6 months (6 patients) and at 12 months after TKA (10 patients). For quality control, a calibration was performed daily with a spine phantom.

BMD of the proximal femora was measured by DEXA in a standard anteroposterior direction preoperatively (9 patients), at 6 months (6 patients) and at 12 months after TKA (9 patients). One patient (D, Table 1) with bilateral hip prostheses was excluded from the hip measurements.

The 95% confidence intervals (CI) were calculated for the changes in BMD. The data were statistically analysed using the paired *t*-test, and a *p* value of less than 0.05 was considered significant.

The present study was approved by the local ethics committee, and all patients gave their informed consent.

Results

The median preoperative Knee Society Knee Score was 49 points (range 12–85 points), the median 1-year knee score was 88 points (range 60–100 points). The median preoperative functional score was 50 points (range 40–60 points), the median 1-year functional score was 80 points (range 60–100). In four patients, postoperative complications were observed: one wound haematoma was evacuated (Patient F, Table 1), one decubitus of the heel healed with conservative treatment (Patient J, Table 1). In one knee a medial collateral ligament augmentation was performed for instability during the prosthesis implantation (Patient E, Table 1), and one knee was manipulated under general anaesthesia for decreased range of motion, 2 months after TKA (Patient D, Table 1).

The radiographic 1-year follow-up was uneventful; all the knees were in good alignment, and the components were in the correct position. Radiolucent lines (1 mm) were present in femoral zone 4 (2 knees) and tibial zone 1

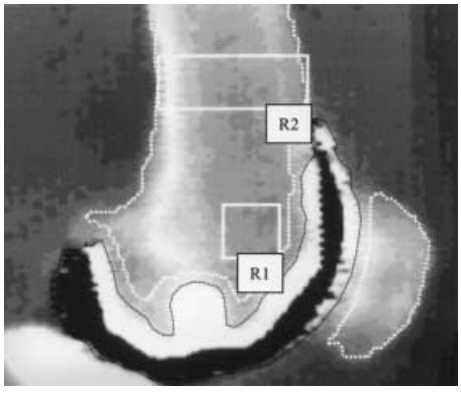

Fig. 1 Lateral dual-energy X-ray absorptiometry (DEXA) scan of a distal femur with a femoral component of a TKA, with regions of interest 1 (*R1*) and 2 (*R2*)

Fig. 2 Lateral radiograph of a distal femur 12 months after TKA showing distal anterior femoral osteopenia behind the femoral component (*arrowheads*)

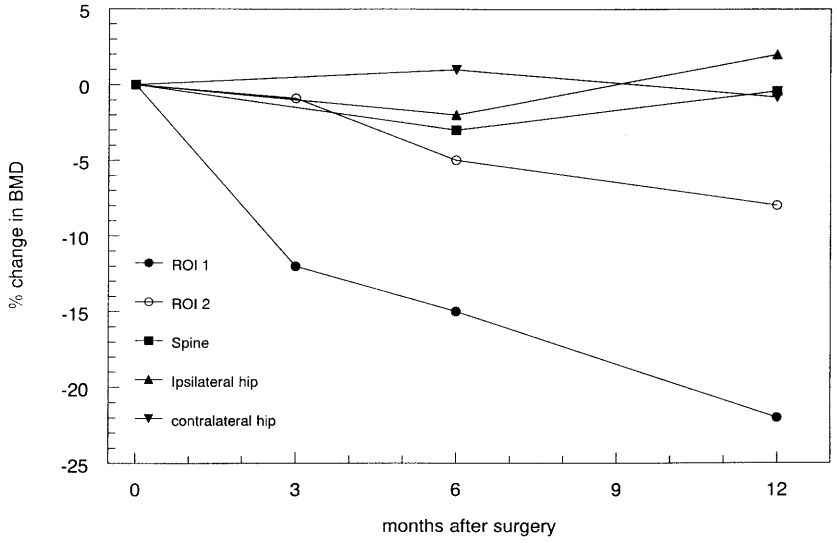

Fig. 3 Changes in BMD of the distal femur (*ROI 1 + 2*), the lumbar spine (*Spine*) and the femoral necks (*ipsilateral and contralateral hip*) before and after TKA

Table 2 BMD (g/cm^2) measured in the lumbar spine (L1–4) in 10 patients before and after TKA. *t* time from TKA (months), patients G and H had a bilateral TKA

Patient	t = 0	t = 6	t = 12
A	1.022	1.019	1.030
B	1.149	1.075	1.071
C	0.796		0.767
D	0.994		1.042
E	1.256		1.198
F	1.196	1.181	1.241
G	0.914	0.833	0.914
H	0.903	0.903	0.922
I	0.856		0.857
J	1.115	1.074	1.114
Average	1.020	1.014	1.016
Standard deviation	0.155	0.127	0.150

(3 knees). All but 2 knees showed an osteopenic area behind the anterior flange of the femoral component on the plain radiographs (Fig. 2). Osteolysis was not recorded.

The mean coefficient of variance of the lateral femoral DEXA scans was 1.3% (range 0.9%–1.6%) for ROI 1 and 0.53% (range 0.2%–1.2%) for ROI 2.

The decrease of BMD (preoperative vs 12 months) of the distal femur in ROI 1 was significant: 0.179 g/cm^2 (CI: 0.087–0.271 g/cm^2) or 22% (CI: 12%–33%), while the average decrease in ROI 2 was 0.092 g/cm^2 (CI: 0.034–0.149 g/cm^2) or 8% (CI: 2%–13%) (Table 1, Fig. 3). The decrease in BMD in ROI 1 was significantly higher than in ROI 2 ($p = 0.03$) when the preoperative measurements were compared with the measurements at 12 months. The changes in BMD at 0, 3 and 6 months were not significant. The loss of BMD in ROI 1 appeared to be greater in bilateral TKA, but failed to achieve statistical difference due to the low number of parameters in the subjects.

Table 3 BMD (g/cm^2) measured in both hips in 9 patients before and after TKA

Patient	Side of TKA	Left hip			Right hip		
		t = 0	t = 6	t = 12	t = 0	t = 6	t = 12
A	Left	0.724	0.692	0.737	0.747	0.738	0.725
B	Left	0.622	0.641	0.671	0.837	0.894	0.868
C	Right	0.634		0.594	0.611		0.625
E	Right	0.837		0.850	0.733		0.736
F	Left	0.935	0.928	0.961	0.967	0.976	0.992
G	Left + right	0.706	0.725	0.675	0.702	0.609	0.654
H	Left + right	0.810	0.796	0.770	0.787	0.758	0.833
I	Left	0.624		0.620	0.686		0.671
J	Right	0.991	0.975	0.971	1.052	1.007	1.035
Average		0.765	0.793	0.761	0.791	0.830	0.793
Standard deviation		0.137	0.134	0.140	0.140	0.154	0.148

The coefficient of variance for the lumbar spine measurements for the duration of the study was 0.35%. BMD of the lumbar spine did not change significantly, with an average increase of –0.17 g/cm^2 (CI: –0.021–0.030 g/cm^2) or 0.4% (CI: –3%–2%) in the year after TKA (Table 2, Fig. 3).

The average BMD of the left and right femoral neck also remained similar over the study period, with a decrease of 0.004 g/cm^2 (CI: –0.024–0.017 g/cm) or 0.5% (CI: –3–2%), and an increase of 0.002 g/cm^2 (CI: –0.018–0.020 g/cm^2) or 0.1% (CI: –2–3%), respectively (Table 3, Fig. 3). The change of BMD of the femoral necks between the ipsilateral and contralateral hip was also not significant (Fig. 3).

Discussion

In TKA, the patellar pressure is not applied to the anterior femoral condyles but is shielded by the femoral component and redistributed to the proximal bone-cement-implant interface. A prediction of the femoral bone resorption resulting from this stress shielding phenomenon was performed with a computer finite element model [6]. Van Lenthe et al. introduced a long-term prediction based on a strain-adaptive bone remodelling theory and reported severe bone resorption in the anterior and mid-distal femoral regions behind the anterior flange of a bonded femoral component.

In a radiographic study, a progression of osteopenia in the distal anterior femur was observed up to 1 year in 68% of 147 TKAs, independent of the type of fixation or implant design [8]. Cameron and Cameron observed progressive osteopenia at the anterior femoral condyles for up to 2 years in almost all cemented TKAs, in particular in patients with rheumatoid arthritis [1]. However, plain radiographs are inaccurate in estimating bone mineralization [3]. A change in BMD of the distal femur after TKA of 25% or more was detected on plain radiographs by all observers in a comparative study [10]. DEXA was far more sensitive in this experimental study, with 100% detection of the smallest degree (3%) of bone loss.

In our study a median 22% decrease in BMD in the distal femur in the area behind the anterior flange of the femoral component was found, as predicted by the computer finite element analysis. DEXA studies of distal femoral BMD were performed in uncemented and cemented TKA. A 7%–27% decrease in BMD behind the anterior flange and directly above uncemented femoral components was found in a study of 28 women, 6–12 months after TKA [7]. Petersen et al. followed 8 patients after uncemented TKA for 5 years with DEXA and reported an average decrease of 36% of BMD behind the anterior flange of the femoral component [9]. The decrease in BMD did not continue after 2 years. Karbowski et al. found a 21.5% decrease of distal femoral BMD in 12 patients 9 months after cemented TKA [5]. Apparently, a decrease in BMD of the distal femur of 20%–40% occurs within 1 year after TKA due to stress shielding, independent of the type of fixation of the femoral component.

BMD in the lumbar spine and both femoral necks of our patients 1 year after cemented TKA was similar to the preoperatively measured general BMD. Apparently, the patients' general mobility 1 year after surgery was roughly comparable to their preoperative status. A prospective DEXA study in TKA patients that would correlate the activities of daily life with the general BMD of the lumbar spine and hips could assess the potential improvement in postoperative mobility status compared with the preoperative mobility status.

In conclusion, a significant periprosthetic distal femoral bone resorption occurred after cemented TKA, especially behind the anterior flange of the component. The general BMD was unaffected by TKA 1 year after surgery.

Acknowledgements We thank Mr. M. Engels and Mrs. M.T.P. v.d. Ven for their skillful assistance in recording the DEXA data.

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