Showa Univ J Med Sci **28**(2), 155～161, June 2016

Original

Periprosthetic Bone Mineral Density Changes after Cementless Total Knee Arthroplasty

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Abstract: Bony atrophy around the components following total knee arthroplasty (TKA) is often observed by radiography. To investigate the underlying cause of this incidence, we sought to quantitatively evaluate postoperative bone changes around the total knee components using dual-energy X-ray absorptiometry (DXA) over time. A retrospective study was conducted to compare bone mineral density (BMD) around the components in 22 patients pre-operatively and at 1, 3, 6, 12, and 24 months after cementless TKA for the treatment of osteoarthritis. In the coronal view, the medial tibia showed that a significant decrease in BMD at 12 months compared with 1 month after surgery ($P < 0.05$), while the sagittal view showed that a significant decrease in BMD only at the anterior femoral condyle at 24 months compared with 1 month postoperatively ($P < 0.05$). TKA improved the leg alignment and load-bearing axis in all patients, but we found that BMD tended to decrease on the medial side of the tibia and the anterior femoral condyle area over time following surgery. Our results suggest that recreating proper valgus alignment of the knee joint provides physiological balancing and condition. A larger prospective study is warranted.

Key words: cementless total knee arthroplasty, bone mineral density, osteoarthritis, dual-energy X-ray absorptiometry

Introduction

To date, 25.3 million people in Japan have osteoarthritis (OA) of the knee[1], which can cause gait disturbance and knee pain due to chronic deformation of the knee joint cartilage and malalignment of the lower extremities. These symptoms reduce the activities of daily living (ADL) and quality of life (QOL)[2]. The most common surgical procedure for knee OA is total knee arthroplasty (TKA), which in the long term also maintains ADL and QOL. It has been shown that the stresses across the joint theoretically disperse axial load to the ligament and muscles with total knee components (REF). However, bony atrophy around the components can occur with the use of a total knee arthroplasty implant (Fig. 1). This phenomenon is referred to as "stress shielding" and was considered to be due primarily to non-physiological

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axial loading in the hip joint[3].

Dual-energy X-ray absorptiometry (DXA) is the most commonly used technique to measure bone mineral density (BMD). It uses two X-ray beams of different energy levels to scan the region of interest and measure attenuation as the beam passes through the bone[4]. Soininvaara *et al*[5-7] qualitatively assessed bone around the knee components after TKA using DXA. However, these studies evaluated only the femoral, or tibial, side, and an analysis of the stress shielding and remodeling of bone around the knee following TKA is needed.

To investigate bone quality at various regions of the knee after cementless TKA, we quantitatively evaluated BMD changes in the tibia and femur using DXA.

Subjects and methods

Patients

This retrospective study was carried out from July 2011 on 22 enrolled patients (2 males and 20 females, 13 right and 9 left). The Ethics Committee of Showa University School of Medicine approved the study protocol.

Patients who had undergone TKA for OA were included in the study, while patients with rheumatoid arthritis, posttraumatic OA, or those undergoing treatment for osteoporosis were excluded from the study. Patients who were cane-dependent or walker-dependent before surgery were also excluded. All patients in the study had received the same cementless implants (LCS COMPLETE, DepuySynthes, Inc., Los Angeles, CA, USA). The patients started partial-weight bearing with a walker 2 weeks after TKA, and undertook full-weight bearing with either a cane or walker 3 weeks after surgery. All alignment angles were evaluated as femoro-tibial angle (FTA), and were measured 1 month following surgery.

Measurements of BMD

BMD of the periprosthetic proximal tibia and distal femur was measured using the Discovery DXA system (Hologic, Inc., Bedford, MA, USA) on both coronal and sagittal views before surgery, and at 1, 3, 6, 12, and 24 months following surgery. In the coronal view, the patient was placed in the supine position on the scanning bed, with the patella in front position and the knee extended. In the sagittal view, the patient was placed in the lateral position with knee extension. The scan commenced 15 cm distal to the inferior edge of the patella, and lasted for 90 seconds (140–100 kV; 2.5 mA; 0.2 mGy; field of view: 22 cm (L) × 11 cm (W)). Fig. 1 depicts the detailed BMD evaluation by DXA at knee regions of interest (ROIs), as described in Soininvaara *et al*[5-8] and Van Loon *et al*[9].

Regions of interest (ROIs)

The ROIs in the coronal view of the knee joint were divided into the following areas: (1) cR1: upper tip of the femoral component on the femoral axis, (2) cR2: the lateral side of the tibial component at the height of the center of the fibula head, (3) cR3: the medial side of the tibial component at the height of the center of the fibula head, and (4) cR4: the lower tip of

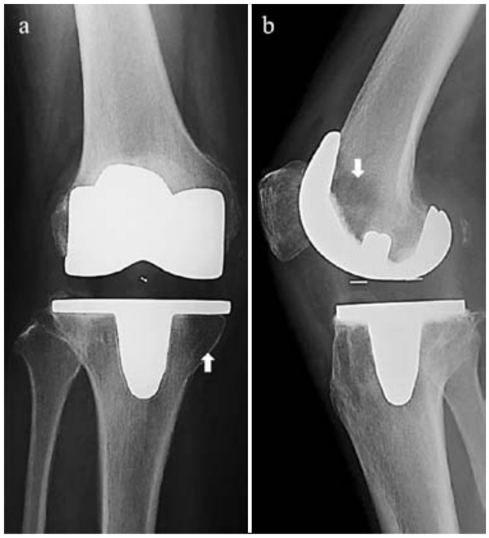

Fig. 1. A radiograph of the TKA surgery shows bone atrophy of the proximal medial tibia (a) and anterior femoral condyle (a), indicated by arrows.

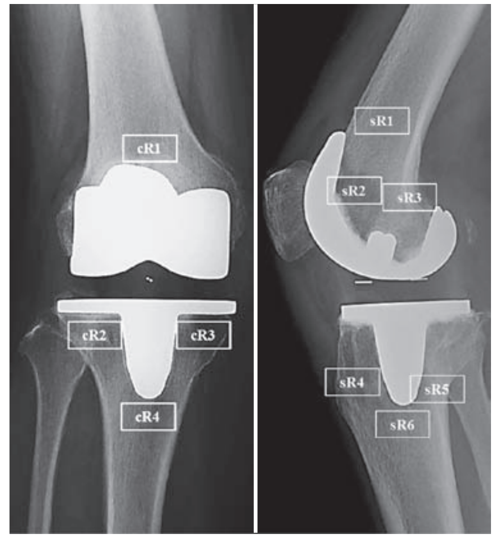

Fig. 2. Radiograph showing the regions of interest (ROIs) used to measure bone mineral density by DXA in the coronal and sagittal views, preoperatively and at 1, 3, 6, 12, and 24 months postoperatively.

the tibial component. The sagittal view was divided into the following areas: (1) sR1: at the height of the upper margin of the femoral component on the femoral axis, (2) sR2: the dorsal side of the femoral component at the height of the center of the patella; (3) sR3: the intersecting point with the peg of the femoral component at the height of the center of the patella, (4) sR4: the tibial tuberosity area; (5) sR5: the most distal dorsal side of the tibial component, and (6) sR6: the lower tip of the tibial component (Fig. 2).

Statistical Analysis

The 95% confidence intervals (CI) were calculated for the changes in BMD. For statistical analyses, we used JSTAT software. Comparisons of the changes in BMD were performed using ANOVA with Dunnett's post hoc test. We defined the 1-month postoperative data as a point of reference.

Results

Patients

At the time of surgery, the average patient age was 76.0 ± 5.7 years, average height was 150.0 ± 5.0 cm, average body weight was 56.6 ± 11.6 kg, and average body mass index (BMI) was 24.9 ± 4.0 kg/m^2. FTA was corrected from an average of 182.3° ± 4.0° before surgery to 171.2° ± 2.3° after surgery.

Coronal view

Changes in BMD were evaluated in each ROI at 3, 6, 12, and 24 months after surgery, and

Table 1. Average (± SD) femoral and tibial periprosthetic BMD (g/cm^2) measured preoperatively and at postoperative 1, 3, 6, 12, and 24 months in 22 patients

Coronal View		pre-operation	postoperative 1 month (basis)	postoperative 3 months	postoperative 6 months	postoperative 12 months	postoperative 24 months	p-value
Femur								
Diaphysis	cR1	0.45±0.21	0.43±0.13	0.41±0.10	0.43±0.13	0.35±0.10	0.33±0.08	0.078
Tibia								
Lateral	cR2	0.55±0.21	0.70±0.18	0.70±0.22	0.69±0.20	0.56±0.16	0.52±0.16	0.19
Medial	cR3	0.71±0.17	0.73±0.15	0.69±0.19	0.62±0.17	0.55±0.10*	0.53±0.10	0.035
Diaphysis	cR4	0.73±0.22	0.71±0.18	0.71±0.20	0.70±0.21	0.69±0.19	0.57±0.19	0.81
Sagittal View								
Femur								
Diaphysis	sR1	0.65±0.25	0.71±0.17	0.64±0.18	0.68±0.15	0.63±0.14	0.53±0.11	0.25
Anterior Condyle	sR2	0.65±0.14	0.65±0.15	0.59±0.19	0.58±0.19	0.48±0.13*	0.43±0.08*	0.004
Posterior Condyle	sR3	0.77±0.23	0.92±0.20	0.84±0.24	0.89±0.21	0.78±0.17	0.68±0.13	0.13
Tibia								
Tuberosity	sR4	0.53±0.13	0.55±0.09	0.53±0.12	0.54±0.14	0.51±0.10	0.50±0.13	0.83
Posterior	sR5	0.77±0.23	0.95±0.22	0.89±0.19	0.88±0.24	0.74±0.22	0.59±0.17	0.30
Diaphysis	sR6	0.52±0.20	0.56±0.15	0.52±0.16	0.55±0.18	0.51±0.13	0.47±0.17	0.48

*Significant BMD changes compared with 1 month postoperative (ANOVA)

compared with data collected 1 month postoperatively (Table 1). In the coronal view, cR1, cR2, and cR4 showed no significant change between before and after surgery; however, cR3 (medial side of the tibial component) showed a significant decrease in BMD at 12 months after surgery compared with 1 month postoperatively ($P = 0.035$).

Sagittal view

Changes of BMD in each ROI evaluated in the sagittal view at 3, 6, 12, and 24 months after surgery were the same as those in the coronal view compared to 1 month postoperatively in sR1, sR3, sR4, sR5, and sR6. However, sR2 (anterior femoral condyle) showed a significant decrease in BMD in the sagittal view at 12 and 24 months compared with 1 month postoperatively ($P = 0.004$).

Discussion

The most important findings in this study are that mild bone atrophy was observed around the knee after TKA at the medial tibial condyle and distal femoral anterior metaphysis. This finding was demonstrated by detailed BMD analysis by high-solution DXA in selected ROIs, and revealed 21 % bone loss in the distal femur and 25% in the tibia, compared with normal annual bone loss (Bohr and Schaadt. 1987, Chcovich. 1989)[10, 11].

Only a few studies have reported the efficacy of measuring BMD around the knee after TKA following the development of high-solution DXA[12]. Soininvaara *et al*[5–7] measured periprosthetic tibial BMD, but these data did not cover both the tibial and femoral sides, and involved only short-term follow-up and a cemented TKA. Petersen *et al*[13] looked at cementless TKA, but the BMD measurement was by dual photon absorptiometry rather than DXA, and only the tibial side was measured. We consider that simultaneous measurement of both femoral and tibial bones is clinically important for such studies. In addition, Mau–Moeller[14] measured both tibial and femoral bones, but the follow-up period was only 3 months, and we believe that most patients likely reduce their activity level in the first 6 months post-surgery and then gradually return to the preoperative level over the subsequent 6 months, with improvements on the preoperative state only achieved fully at 2 years postoperative[15]. Thus, studies such as ours should collect data for at least 2 years after surgery. In a similar study of cemented TKA, the thick cemented bone area was also suggested to influence BMD measurement[5–7, 16].

The presence of good BMD around the knee is an important factor in the longevity of TKA, and previous studies have concentrated on preventing decreases in BMD and bone atrophy after TKA[15, 17, 18]. Bone atrophy around the components and stress shielding following TKA is often observed on radiograph.

Using DXA, we quantitatively evaluated BMD around the components preoperatively and 1, 3, 6, 12, and 24 months postoperatively in the coronal and sagittal views. DXA is the most commonly used technique to measure BMD. It uses two X-ray beams of different energy levels to scan the region of interest and measure the attenuation as the beam passes through the bone[4].

In the coronal view, our results showed a significant decrease in BMD of the proximal medial tibia at 12 months compared with 1 month after surgery. In the sagittal view, BMD in the anterior femoral condyle area was significantly reduced at postoperative 12 and 24 months compared with 1 month postoperatively. The FTA was corrected from 182° before surgery to 171° after surgery. The varus deformity was corrected, and leg alignment changed. The loading axis was changed to the lateral side, with weight decreases at the proximal medial tibia. Bony response and adaptation might occur as per Wolff's law after mechanical stimulation and repeated load[19]. Less cyclic loading likely leads to bone atrophy under the TKA components resulting in stress shielding[13, 19]. In our study, no significant bone reduction in the proximal medial tibia was observed at 24 months after surgery, suggesting that the BMD is stable in this area. However, decreases in BMD of the proximal tibia have been reported to persist even at 10 years following surgery[20]. Although correction of FTA changes the load-bearing axis of the leg and causes stress shielding, it is unclear when stress shielding ends.

There are some limitations in this study. First, it is a retrospective design and the sample size is small (22 patients). A prospective blinded study on a larger number of patients will enhance the evidence level. Second, this study did not use specialized analysis software at the time of examinations[12]. Further prospective studies that reveal the appropriate follow-up period and incidence of bone remodeling are needed.

Conflict of interest disclosure

The authors have no conflicts of interest to declare.

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[Received December 21, 2015 : Accepted February 2, 2016]