Periprosthetic tibial bone mineral density changes after total knee arthroplasty

One-year follow-up study of 69 patients

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Background The critical structure supporting the prosthetic components in total knee arthroplasty (TKA) is tibial trabecular bone. The quality of tibial bone can be evaluated by bone mineral density (BMD) measurements.

Patients and methods We prospectively measured changes in BMD in the proximal tibia after cemented TKA in osteoarthrotic knees. 69 patients were scanned by dual-energy X-ray absorptiometry (DXA) within a week after surgery, and after 3, 6 and 12 months.

Results At baseline, the medial region of interest (ROI) BMD was higher in the varus knees than in the valgus aligned knees ($p = 0.02$). The medial metaphyseal ROI showed a decrease in BMD during the follow-up in preoperatively varus knee joints ($p < 0.001$). In preoperatively valgus knees, there was a slight increase in medial compartment BMD which was not significant ($p = 0.2$). Alignment correction in both groups showed bone remodeling giving similar medial and lateral BMD values, suggesting that the bone became equally strong in both compartments of the metaphysis. There was no association between increasing American Knee Society (AKS) scores and bone remodeling.

Interpretation We suggest that this remodeling is caused by postoperative changes in tibial loading. Our results support the clinical importance of recreating proper valgus alignment of the knee joint in the TKA operation, thus possibly providing better conditions for longevity of the tibial component.

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The critical biological structure supporting the prosthetic components in knee arthroplasty is the tibial trabecular bone (Hvid 1988, Li and Nilsson 2000). Failure to achieve perfect surgical realignment and/or ligament balance of the knee joint are the major factors contributing to mechanical looening of the tibial component. This is probably due to abnormal load distribution and insufficient supportive strength of the trabecular bone.

In normally aligned valgus knees, tibial metaphyseal bone has been shown to have higher bone mineral density (BMD) on the medial side (Li and Nilsson 2000). This finding is supported by the finding that during walking, approximately 70% of total load is typically transmitted through the medial compartment in the normal knee joint (Hurwitz et al. 1998). Degenerative joint disease, osteoarthrosis (OA) when severe, leads to relative sclerosis beneath the loaded condyle and relative porosis beneath the unloaded condyle, with the strongest bone being found on the concave side of the deformity (Terauchi et al. 1998). In previous studies, the tibial BMD of the medial compartment has been shown to be significantly higher than that of the lateral compartment, both in mild and severe OA (Akamatsu et al. 1997, Wada et al. 2001).

Plain radiographs can be used to assess the position of a prosthesis and the alignment of the knee joint, to evaluate the bone-prosthesis and the bone-cement interfaces, and to provide evidence of infection, loosening or subsidence (Mintzer et al. 1990, Soininvaara et al. 2000). However, the quantitative evaluation of periprosthetic bone density is unreliable on plain radiographs. Changes in bone density must exceed 20–50% in order to be visually observable on standard radiographs (Mintzer et al. 1990, Robertson et al. 1994, Petersen et al. 1995, Lewis et al. 1998, Trevisan and Ortolani 1998, Trevisan et al. 1998, Karbowski et al. 1999, Spittlehouse et al. 1999, Soininvaara et al. 2000).

Dual x-ray absorptiometry (DXA) measurements are seven times more accurate than visual evaluation (Lewis et al. 1998), and BMD has been shown to correlate closely with the mechanical properties of bone. DXA can provide reproducible, high-quality measurements of periprosthetic BMD. Commercially available software allows the measurement of BMD adjacent to metal implants (Insall et al. 1989, Robertson et al. 1994, Kroger et al. 1998, Trevisan and Ortolani 1998, Trevisan et al. 1998, Karbowski et al. 1999, Spittlehouse et al. 1999, Soininvaara et al. 2000), with an average precision error of 2.2–2.9% in the tibial regions of interest (ROI) (Soininvaara et al. 2000).

We aimed to investigate the periprosthetic bone changes around cemented tibial components. Specifically, we focused on knee alignment and its effect both on the baseline BMD and postoperative changes.

Patients and methods

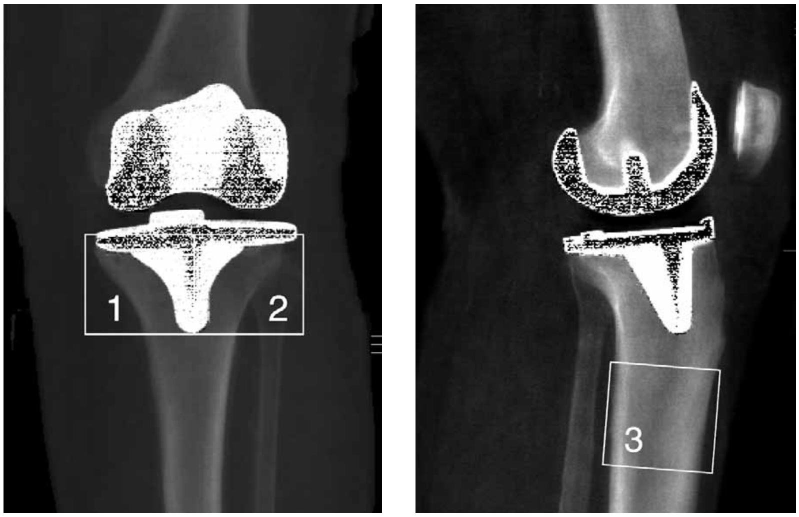
69 patients (49 women) were recruited from the waiting list of the orthopedic department at Kuopio University Hospital between May 1997 and May 2000. The study population consisted of patients with primary (n = 65) or post-traumatic (n = 4) knee OA. 51 had varus and 18 valgus deformity. Previous joint replacement of the ipsilateral or contralateral knee was considered an exclusion criterion. Patients were free from diseases and medication known to influence bone mineral metabolism throughout the follow-up period. The mean age of the patients at the time of operation was 67 years (SD 6.8), mean weight was 80 kg (SD 14), and mean BMI was 30 kg/m^2 (SD 4.7). The baseline characteristics of the patients and their American Knee Society (AKS) score (Insall et al. 1989) values are presented in Table 1. Our study protocol was approved by the Research Ethics Committee of Kuopio University Hospital. All patients provided written informed consent.

Table 1. General baseline characteristics and AKS (American Knee Society) score values at follow-up for the study subjects

Baseline characteristics	Male	Female
No. of patients	20	49
Age, years (SD)	67 (8.2)	67 (6.2)
Weight, kg (SD)	85 (8.9)	78 (14.5)
Height, cm (SD)	174 (6.4)	161 (6.3)
Body mass index (SD)	28 (3.0)	30 (5.1)
AKS score values		
At baseline	105 (22.0)	93 (29.5)
At 3 months	167 (21.2)	164 (26.2)
At 12 months	176 (23.3)	173 (32.5)

BMD of the proximal tibia was measured after TKA within 1 week of operation, and at 3, 6 and 12 months, using fan-beam dual X-ray absorptiometry (Lunar Expert XL, Lunar Company Inc., Madison, WI, USA). ROIs were metaphyseal (close to the prosthesis) and diaphyseal (below the implant) (Figure). The precision, expressed as the coefficient of variation for repeatedly measured BMD in these ROIs, was 2.9% (range 2.3–3.3%). We used a leg-holding device provided by the manufacturer to obtain a reproducible position. Bone mineral density (BMD, g/cm^2) was analyzed using the software developed by the manufacturer. The software enables bone mineral analysis in the presence of metal in the scanning field. In order to minimize operator-related inaccuracies, no attempt was made to exclude a cement mantle from the analysis. An edge-detection algorithm defines the outlines of bone, soft tissue, air, artifact and neutral areas. To recognize these areas properly, plastic background was used as recommended by Lunar (personal communication). ROI sizes were automatically the same since we used the prosthesis flanges as reference points in each measurement of the same patient. (Soininvaara et al. 2000).

Cemented TKA was performed using Duracon Modular prostheses (Howmedica Inc. Rutherford, NJ, n = 37), Nexgen prostheses (Zimmer, Warsaw, IN, USA, n = 23) or AMK prostheses (DePuy, Warsaw, IN, USA, n = 9). All patients were operated by senior orthopedic surgeons.



Periprosthetic regions of interest (ROIs) in the tibia: metaphyseal medial (ROI 1), lateral (ROI 2), diaphyseal (ROI 3).

Full weight bearing was allowed immediately after the operation. All patients received prophylactic antibiotic (kefuroxim) and antithrombotic (enoxaparin/dalteparium) medication. 2 patients received additional antibiotics for superficial wound irritation, but bacterial cultures were negative. There were no registered intraoperative complications, or complications during the hospital stay that delayed discharge from the hospital. No other complications were encountered and all patients attended scheduled follow-up examinations regularly.

The AKS score was used to evaluate knee status and function during daily activities. It was recorded by the surgeon preoperatively and at each follow-up visit. The maximum value for the AKS score is 200, consisting of knee status (100) and knee function (100) (Insall et al. 1989). Both preoperatively and at each follow-up visit, a long, standing radiograph was exposed to measure the tibiofemoral angle, necessary for AKS scoring. The severity of the OA was classified on the preoperative radiographs using the classification of Ahlbäck (Ahlbäck 1968, Petersson et al. 1997).

Statistics

95% confidence intervals were calculated for the changes in BMD. For statistical analysis, we used SPSS software, version 10.0 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used to confirm that data from each follow-up visit were normally distributed when stratified according to gender, prosthesis models, and preoperative alignment. Epsilon-corrected repeated measures ANOVA was performed to explore the influence of patient age, gender, BMI, preoperative Ahlbäck's grading, prosthetic design and AKS score changes on BMD.

Results

The highest periprosthetic bone loss was observed during the first 3 months after TKA in the diaphyseal ROI (3.8%), while BMD losses in the metaphyseal ROIs ranged from 2.6% in the medial compartment to 0.06% in the lateral compartment. At 1-year follow-up, the decrease in BMD was in the medial metaphysis 6.6% ($p < 0.001$) and in diaphysis 4.7% ($p < 0.001$). In contrast, the lateral metaphyseal ROI did not change (+0.4%, $p = 0.2$). There were no differences in bone loss between genders ($p = 0.06$–0.6) or between prostheses models used at either medial ($p = 0.8$) or lateral ($p = 0.9$) metaphyseal ROIs. BMD in lateral metaphyseal did not change significantly (Table 2).

The mean alignment corrections seen between preoperative and postoperative knee radiographs were 12 and 6.5 degrees for knees preoperatively

Table 2. Mean periprosthetic tibial BMD (SD) values at 0, 3, 6 and 12 months follow-up in 69 TKA patients. P-values from repeated measures ANOVA

	0 months	3 months	6 months	12 months	p-value
Medial metaphyseal ROI	1.21 (0.25)	1.17 (0.23)	1.14 (0.24)	1.12 (0.25)	<0.001
Lateral metaphyseal ROI	1.29 (0.31)	1.28 (0.29)	1.31 (0.29)	1.29 (0.30)	0.2
Diaphyseal ROI	1.11 (0.23)	1.07 (0.24)	1.06 (0.24)	1.06 (0.25)	<0.001

Table 3. The mean (SD) operative correction of preoperative varus and valgus deformity measured postoperatively and after follow-up periods of 3 months and 1 year

	Preoperative varus				Preoperative valgus		
	Varus		Valgus		Varus	Valgus	
	n	angle (SD)	n	angle (SD)	n	n	angle (SD)
Preoperative (SD)	51	5.0 (3.4)				18	11.4 (7.0)
Postoperative	1	1.0 (0)	50	7.1 (1.8)	0	18	7.7 (1.9)
At 3 months	3	0.7 (1.2)	48	7.1 (2.8)	0	18	8.3 (2.9)
At 1 year	3	1.7 (1.5)	48	6.3 (3.1)	0	18	7.4 (2.8)

classified as varus and valgus, respectively (Table 3). Analysis of the radiographs taken at 3 months and 1 year showed that the alignment correction remained nearly the same over time (Table 3). Preoperatively varus and valgus aligned knees had statistically significantly different baseline values (t-test, $p = 0.02$) for BMD of the medial metaphyseal ROI. Also, by MANOVA analysis, the BMD responses differed significantly up to 6 months (Table 2) and then remained unchanged. This early decrease resulted in a leveling of the BMD in the medial condyle between the two groups.

The clinical and functional status of the knees improved during the follow-up. The mean preoperative AKS score was 96 (SD 28), at 3 months it was 165 (SD 25), and it was 174 (SD 29) at 1 year. Age, gender, grade of arthrosis and AKS score had no influence on BMD changes in any of the 3 regions studied ($p > 0.05$), except BMIs positive association on lateral BMD changes ($p = 0.04$).

Discussion

The baseline BMD of the medial proximal tibia varied substantially among our patients. This wide variation may be explained by degenerative changes. The mechanical and morphological properties of the proximal tibia differ as a result of bone remodeling due to malalignment, progressive subluxation, metaphyseal microfractures and changed activity levels. Many patients with OA of the knee are relatively immobile because of pain and deformity. Thus, they lose the beneficial effects of weight bearing on BMD. The stage of the degenerative process has been shown to be associated with a large variation in BMD values (Lewis et al. 1998, Zhang et al. 2000).

Reduction in BMD was significant in the medial metaphyseal and diaphyseal ROIs. The bone loss in the diaphysis probably represents operation-induced loss and bone loss due to postoperative disuse, which is most pronounced during the first 3 months. In the medial metaphysis the decreases were less than 5% during the first 6 months, and quite modest at 1 year (below 6.6%), as compared to 20% at 6 months (Petersen et al. 1995), and 15–27% at 1 year found in patients with uncemented tibial components (Petersen et al. 1995, Regner et al. 1999). Our results are in closer agreement with a 5% reduction at 6 months (Spittlehouse et al. 1999), and with 10% bone loss at 1 year, which have also been reported previously (Karbowski et al. 1999). Changes in the proximal tibial BMD which were not statistically significant have also been described (Li and Nilsson 2001). Tibial bone loss is caused by load changes on the metaphyseal bone under the tibial implant, while the higher bone losses in femoral bone are induced by stress-shielding in periprosthetic bone (Karbowski et al. 1999, Spittlehouse et al. 1999, Soininvaara et al. 2000).

Our main finding was that medial metaphyseal BMD of varus and valgus knees had significantly different baseline values. The changes in BMD differed significantly from each other up to 6 months. Due to decrease in varus knees and slight increase in valgus knees, the one-year follow-up medial ROI BMD values became almost equal. Bone remodeling tending towards similar values, in the medial metaphysis and between the medial and lateral compartments, may reflect a more physiological alignment of the knee joint, and more optimal loading conditions. Previously, Li and Nilsson (2000) found a similar association between bone remodeling and knee alignment.

We found no influence of prosthesis design on BMD changes, either in medial or lateral metaphyseal ROIs. The tibial components used in our study have rather short non-weight-bearing intramedullary stems, which do not therefore contribute to proximal tibial bone remodeling. If a long tibial stem contacts cortical bone, it may unload the tibial condyles, resulting in more severe proximal metaphyseal BMD loss (Lewis et al. 1998, Taylor et al. 1998, Lonner et al. 2001). A metal backing was used in all of our prostheses. Finite element analyses have revealed that the addition of metal reduces the overall stresses on the cancellous surface and results in a more even distribution of stresses, especially under eccentric varus or valgus loading conditions (Taylor et al. 1998, Lonner et al. 2001). In finite element analysis, the morphology of the tibial bone surface has also been found to have a significant influence on cancellous bone stresses generated by press-fit prostheses, but not by cemented implants. A cemented implant neutralizes uneven bone stresses, both with flat or unevenly resected surfaces (Taylor et al. 1998). These factors may have contributed to our results.

We found slightly higher baseline BMD values than reported previously from both preoperative (Li and Nilsson 2000) and postoperative scans (Li and Nilsson 2001). The ratio of the BMD of medial condyles compared to that of lateral condyles has been found to increase significantly with the progression of OA (Akamatsu et al. 1997). Several studies have shown higher medial BMD, but there are also studies with higher lateral BMD values (Li and Nilsson 2001). In our patients, subchondral osteosclerosis and peripheral osteophytes had already been removed before the baseline scan, thus decreasing the overall medial metaphyseal BMD. For the lateral ROI, overprojection of the fibula may cause some additive effects on BMD. We outlined the uncovered fibula manually to exclude it from measurements and used a leg-holding device to gain repeatable positioning of the knee.

The mechanical properties of the trabecular bone in the proximal metaphyseal tibia have been considered to be important biological determinants of the success rate of TKA. Petersen et al. (1995) have shown that a high preoperative tibial trabecular bone BMD leads to less continuous migration in cementless prostheses. Periprosthetic tibial fractures are most commonly depressions or split fractures involving the interface between the tibial tray and the bone (Thompson et al. 2001). Felix et al. (1997) found that 60% of periprosthetic tibial fractures were metaphyseal (type I), most often involving the medial condyle. Although these fractures are rare, they occur without trauma, they cause varus collapse and distorted alignment, and are challenging to treat. According to Thompson et al. (2001), knees initially in valgus or neutral alignment show a significantly increased risk of postoperative fracture. The authors encourage others to pay careful attention to these patients, especially when associated with low BMD, and to consider cementing the tibial implant to reduce fracture incidence (Thompson et al. 2001).

We observed that after TKA, the medial metaphyseal BMD of knees both in varus and valgus alignment remodeled towards equal values from statistically different baseline bone densities. The one-year medial BMD also closely approximated the lateral BMD values, which in turn showed non-significant changes during the follow-up. The resultant equilibrium in bone density and strength possibly offers better conditions for longevity of the tibial component.

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