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Longitudinal change in periprosthetic, peripheral, and axial bone mineral density after total hip arthroplasty

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Abstract To determine the bone mineral changes after total hip arthroplasty, bone mineral densities (BMD) at the periprosthetic interface, lumbar spine, radius, and calcaneus were measured in a prospective and longitudinal observation. Twenty-four patients (24 joints) who had received a total hip arthroplasty and were followed longitudinally were enrolled in this study. The subjects comprised 2 men and 22 women with a mean age of 69.2 years at the time of surgery. Bone mineral measurements were performed at 1, 3, 6, 12, 18, 24, 30, and 36 months after surgery. The periprosthetic BMD after total hip arthroplasty continued to decrease for 6–12 months after surgery, and then recovered, except in Gruen zone 7 (the calcar region). The calcaneal BMD decreased rapidly for 3 months after surgery before increasing. The lumbar BMD showed a decreasing trend for 12 months after surgery, and then increased gradually. The radial BMD was not affected by surgery. We conclude that changes in the periprosthetic BMD after total hip arthroplasty show an apparent difference between zones, and also differ between the weight-bearing bones and the nonweight-bearing bones.

Key words Bone mineral density · Osteoarthritis · Total hip arthroplasty

Introduction

It is well known that unloading after hip arthroplasty causes a bone mineral decreases in the lower extremities. Recent developments in the techniques of measuring bone mass have made it possible to determine not only the peripheral bone mineral density, but also the periprosthetic bone mineral changes after total hip arthroplasty. There is general agreement that bone mineral density at the proximal femur decreases, and that at the shaft shows little change after total hip arthroplasty.[1–4] Concerning the changes in bone mineral density in the lumbar spine after hip arthroplasty, different results, showing either some or no decrease at 6 months after surgery, have been reported.[5,6]

The long-term clinical outcome is important in total hip arthroplasty, and changes in bone mineral density do not cease during the short period after surgery. The observation periods of previous reports have not been long enough to determine the long-term changes. Moreover, it is important to elucidate not only the periprosthetic bone mineral changes, but also changes at other sites, such as weight-bearing or nonweight-bearing regions, after hip arthroplasty. However, there are no reports of the longitudinal bone mineral changes at the peripheral and axial bone in addition to the periprosthetic bone mineral changes in the same patients.

The aim of this study was to determine bone mineral changes after total hip arthroplasty not only at the periprosthetic interface, but also at the lumbar spine, radius, and calcaneus, by prospective and longitudinal observations.

Patients and methods

Subjects

Twenty-four patients (24 joints) who received total hip arthroplasty at Tottori University Hospital and were followed longitudinally were enrolled in this study. Total hip arthroplasty was performed on one hip joint, and the other hip joint showed no radiological changes in any patient. The patients were 2 men and 22 women, and the mean age was 69.2 years (range 45–79) at the time of surgery. Twenty-two

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patients were osteoarthritic and two had avascular necrosis. The mean body weight of the subjects before surgery was 56.9 kg (range 45–64 kg), and body mass index (BMI) was 22.8 kg/m^2 (range 17.8–29.0 kg/m^2). Two out of 22 women patients were premenopausal at the time of surgery and became menopausal within 5 years after surgery, and five of the others were within 5 years after menopause at the time of surgery. Patients who had diseases or who were taking drugs which could affect bone metabolism were excluded from the study.

Total hip arthroplasty was performed by the posterolateral approach. The greater trochanter was not detached and the presfit stem was fixed without bone cement. The femoral prosthesis was Omniflex (Osteonics, Allendale, NJ, USA) in all patients. This femoral component has a confined porous surface over the proximal one-third of the body of the component (Fig. 1). The porous surface of the stem makes the interface between bone and implant stable, and allows bone ingrowth in the implant surface. The mean duration of nonweight-bearing after surgery was 8.4 weeks (between 5 and 13 weeks), and patients were allowed full weight-bearing 3 weeks later. There were no radiographical signs of loosening or osteolysis at the final evaluation in any patient.

Bone mass measurement

Periprosthetic bone mineral was measured with a bone mineral analyzer (DPX; Lunar, Madison, WI, USA) by dual-energy X-ray absorptiometry (DXA) with software (version 1.2 DPX Orthopedic Software, Lunar, Madison, WI, USA) developed especially for measuring bone density adjacent to metal implants. Seven regions of interest (zones 1–7) were assessed according to the classification of Gruen et al. (Fig. 1). The bone mineral content (BMC, g), area (cm^2), and bone mineral density (BMD, g/cm^2) were calculated for the whole periprosthetic area and in each zone by automatic computerized procedures. Bone mass was represented by BMD in this study.

The BMD of the lumbar spine (L2–4) was measured by XR-26 (Norland, Fort Atkinson, WI, USA). The BMD of the radius was measured at distal sites of 1/10, 1/6, and 1/3 of the radial length by DCS-600 (Aloka, Tokyo, Japan). The BMD of the calcaneus was measured by SXA-200 (Dove Medical Systems, Los Angeles, CA, USA). Bone mineral measurements were performed at 1, 3, 6, 12, 18, 24, 30, and 36 months after surgery.

Reproducibility of BMD measurements

Calibration of the instruments was performed before all bone mineral measurements. The reproducibility of the instruments was determined with five time-measurements on different days in five patients. The coefficients of variation for periprosthesis and lumbar spine were 1.8% and 1.6%, respectively. Those for the radius were 1.8%, 1.4%, and 1.2% at the distal 1/10, 1/6, and 1/3 sites, respectively. That for the calcaneus was 0.6%.

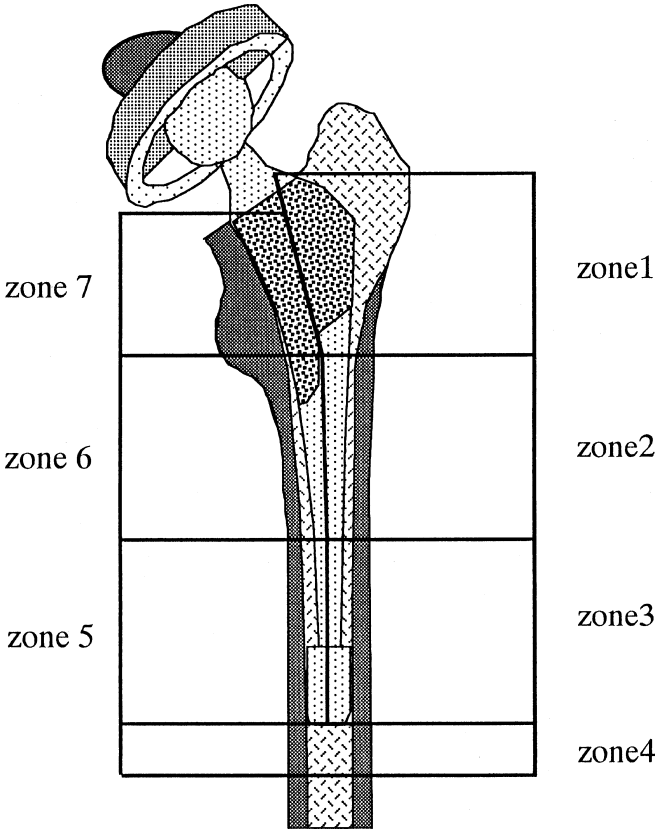

Fig. 1. The seven regions of interest according to Gruen's classification

Statistical analysis

Changes in BMD were expressed as percentage change (%), and were calculated by the following formula, taking BMD before surgery as 100:

$$\%\ \text{change}\ (\%) = \{(\text{BMD} - \text{BMD before surgery})/\text{BMD before surgery}\} \times 100$$

Analysis of variance (ANOVA) was used for comparisons among multiple groups. Multiple comparison tests were performed by Scheffe's test. $P < 0.05$ was regarded as significant. The StatView software (version 4.5, Abacus Concepts, Cary, NC, USA) was used.

Results

Periprosthetic BMD

Longitudinal changes in periprosthetic BMD in each zone after hip arthroplasty are shown in Fig. 2 and Table 1. The patterns of changes in BMD were similar in zones 1–5, and showed a significant decrease from 3 to 12 months, followed by a recovery, but did not recover to its level before surgery (Table 2). In contrast, BMD in zone 6 decreased until 6 months after surgery, and then recovered to its level before the surgery at 36 months after surgery. BMD in zone 7, the area of the calcar region, showed a rapid decrease for 12

months after surgery, and continued to decrease to 73% of its value before surgery at the time of the final follow-up.

Calcaneus

Calcaneal BMD of the hip arthroplasty site showed a rapid decrease until 3 months after surgery (−14.3% at 3 months), showing a significant difference compared with the value before surgery. It then recovered, and became greater at 12 months after surgery than it was before surgery. However, the calcaneal BMD of the nonoperated site showed a decrease until 3 months after surgery (−12.3 % at 3 months), and then increased to its level before surgery after 36 months (Table 3).

Lumbar spine

The BMD of the lumbar spine decreased until 12 months after surgery (−3.7%), and then increased to a greater value than before surgery (Table 3). However, the change was not statistically significant.

Radius

Radial BMD showed no change after surgery at any site in the radius during the whole observation period (Table 3).

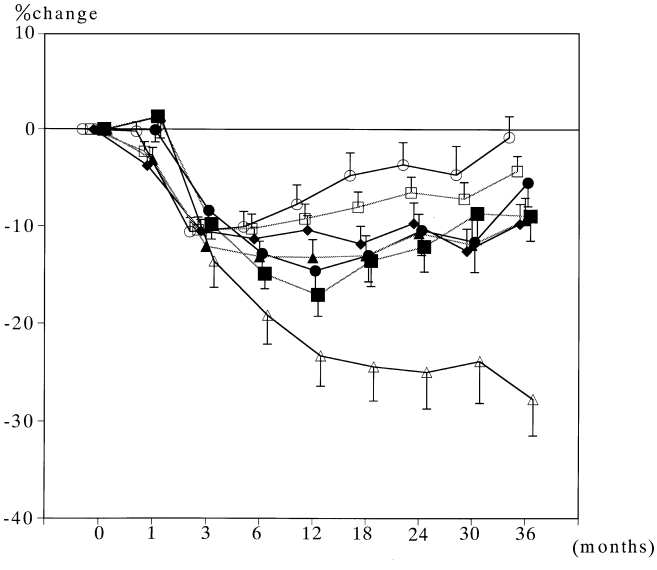

Fig. 2. Changes in periprosthetic bone mineral density. *Solid squares*, zone 1; *solid circles*, zone 2; *solid triangles*, zone 3; *solid diamonds*, zone 4; *open squares*, zone 5; *open circles*, zone 6; *open triangles*, zone 7. Data are the mean and SEM

Discussion

Periprosthetic bone mineral changes after total hip arthroplasty have been documented in several cross-sectional studies. These reports showed that BMD at the proximal end of the femur decreases, and that at the distal end of the prosthesis does not change.[1–4,8,9] A cross-sectional study by McCarthy et al.[2] showed a 40% reduction at the calcar region and a 28% reduction at the midshaft of the femur. Trevisan et al.[4] showed a large decrease in BMD in zones 1, 3, and 7, and a small decrease in zones 2, 4, and 5. In a longitudinal study, Adolpson et al.[5] reported a reduction of only 6% at the midshaft of the femur within 6 months after surgery.

The results of our study correspond well with the results of these previous reports, i.e., BMD in the proximal femur decreased because of stress shielding, whereas that in the shaft showed little change after total hip arthroplasty. We obtained additional information regarding the longitudinal

Table 2. Significant differences in changes in periprosthetic bone mineral density

	Postoperative duration (months)							
	1	3	6	12	18	24	30	36
Zone 1	ns	*	*	**	ns	ns	ns	ns
Zone 2	ns	*	**	**	**	ns	ns	ns
Zone 3	ns	*	**	**	**	ns	ns	ns
Zone 4	ns	*	**	*	**	ns	ns	ns
Zone 5	ns	*	*	*	ns	ns	ns	ns
Zone 6	ns	*	*	ns	ns	ns	ns	ns
Zone 7	ns	**	**	**	**	**	**	**

Significant difference from baseline (preoperative value): $*P < 0.05$; $**P < 0.01$; ns, not significant

Table 1. Periprosthetic bone mineral density

	Postoperative duration (months)								
	0	1	3	6	12	18	24	30	36
Zone 1	0.676 (0.125)	0.683 (0.130)	0.611 (0.134)	0.586 (0.138)	0.574 (0.162)	0.599 (0.152)	0.602 (0.164)	0.634 (0.159)	0.626 (0.137)
Zone 2	1.400 (0.184)	1.399 (0.207)	1.286 (0.222)	1.233 (0.229)	1.209 (0.267)	1.232 (0.287)	1.259 (0.276)	1.254 (0.300)	1.252 (0.229)
Zone 3	1.515 (0.192)	1.469 (0.216)	1.337 (0.232)	1.326 (0.243)	1.324 (0.258)	1.327 (0.268)	1.359 (0.255)	1.336 (0.284)	1.353 (0.244)
Zone 4	1.496 (0.202)	1.439 (0.206)	1.340 (0.209)	1.332 (0.207)	1.348 (0.236)	1.334 (0.242)	1.360 (0.256)	1.315 (0.260)	1.367 (0.230)
Zone 5	1.596 (0.193)	1.558 (0.192)	1.431 (0.210)	1.436 (0.211)	1.453 (0.227)	1.481 (0.235)	1.495 (0.234)	1.482 (0.233)	1.487 (0.218)
Zone 6	1.398 (0.166)	1.396 (0.196)	1.256 (0.226)	1.259 (0.240)	1.290 (0.261)	1.339 (0.261)	1.347 (0.270)	1.334 (0.281)	1.334 (0.237)
Zone 7	1.025 (0.217)	1.023 (0.179)	0.873 (0.192)	0.816 (0.197)	0.778 (0.209)	0.772 (0.216)	0.767 (0.244)	0.759 (0.222)	0.744 (0.224)
Total	1.188 (0.174)	1.185 (0.174)	1.102 (0.176)	1.087 (0.179)	1.078 (0.206)	1.095 (0.202)	1.112 (0.214)	1.107 (0.214)	1.108 (0.170)

Data are mean values (g/cm^2)
SD is presented in parentheses

Table 3. Change in the bone mineral density of the calcaneus, lumbar spine, and radius

	Postoperative duration (months)								
	0	1	3	6	12	18	24	30	36
Calcaneus									
Operated side	0.286 (0.081)[a]	0.271 (0.086)	0.245 (0.090)[c]	0.264 (0.085)	0.294 (0.076)	0.263 (0.081)	0.287 (0.076)	0.290 (0.092)	0.297 (0.081)
Nonoperated side	0.309 (0.084)[b]	0.294 (0.090)	0.271 (0.082)[d]	0.294 (0.097)	0.282 (0.095)	0.281 (0.081)	0.286 (0.087)	0.298 (0.092)	0.302 (0.057)
Lumbar spine	0.876 (0.158)	0.863 (0.160)	0.845 (0.172)	0.848 (0.178)	0.844 (0.171)	0.870 (0.183)	0.885 (0.171)	0.884 (0.121)	0.882 (0.161)
Distal radius									
1/10 site	0.416 (0.098)	0.419 (0.058)	0.419 (0.058)	0.400 (0.088)	0.401 (0.080)	0.406 (0.084)	0.398 (0.087)	0.405 (0.093)	0.411 (0.096)
1/6 site	0.473 (0.099)	0.477 (0.090)	0.478 (0.102)	0.460 (0.093)	0.457 (0.084)	0.461 (0.093)	0.484 (0.101)	0.471 (0.092)	0.469 (0.101)
1/3 site	0.596 (0.135)	0.598 (0.121)	0.588 (0.120)	0.576 (0.126)	0.569 (0.115)	0.581 (0.107)	0.581 (0.128)	0.591 (0.129)	0.593 (0.150)

Data are mean values (g/cm^2)
SD is presented in parentheses
[a] vs [b], [a] vs [c], [b] vs [d], $P < 0.05$

bone mineral change in each zone. First, BMD in zone 7, the calcar region, continued to decrease for 3 years after surgery. Second, BMD in the other zones decreased for 6–12 months after surgery, and then recovered. Third, the recovery in zones 5 and 6, medial midshaft, was the best among all zones. Recently, Kerner et al.[10] calculated the strain in periprosthetic bones using finite-element models. The authors concluded that strain-adaptive remodeling can explain periprosthetic bone loss. The difference in mechanical stress probably results in the difference in bone mineral density in those regions.

Concerning the BMD in the lower extremities after total hip arthroplasty, Ruegsegger et al.[11] observed changes in the tibial BMD by quantitative computed tomography, showing a decrease until 20 weeks after surgery, and then a gradual increase thereafter. The present study showed obvious postoperative calcaneal bone mineral changes in both operated and nonoperated sites. The values at both sites decreased for 3 months after surgery, and then increased. BMD even at the nonoperated site took more than 6 months to recover to its level before surgery. The nonweight-bearing period probably affects the bone mineral density of the operated site, and the reduced physical activity after surgery possibly decreases the loads on the calcaneus at the nonoperated site after surgery.[12] The nonweight-bearing period in the present study was longer than that previously reported. Since a shorter nonweight-bearing period implies less reduction in BMD, early weight-bearing could prevent an obvious decrease in BMD of the lower extremities after total hip arthroplasty.

Several previous reports have concluded that lumbar BMD decreases after total hip arthroplasty and does not recover to the value before surgery.[13,14] However, Martini et al.[6] showed no change in lumbar BMD after hip surgery. In our study, lumbar BMD showed a decreasing trend for 6 months after surgery, and then an increase. Although this decrease was not statistically significant, it suggests that the influence of surgery on lumbar BMD may continue for 12 months after surgery.

Radial bone is not affected by hip arthroplasty. It is reasonable that radial BMD showed no change after total hip arthroplasty in our observations because surgery to the lower limbs causes no restriction of the upper extremities.

Revision surgery after total hip arthroplasty is unavoidable in some patients in the decade after primary surgery. Although many factors affect the clinical outcome of surgery, the bone quality of the proximal femur is crucial for adequate fixation of the prosthesis. Bone quality is also important in stabilizing the prosthesis during revision surgery. The patterns of periprosthetic, peripheral, and axial bone mineral changes that we have shown in this longitudinal study have shed light on the bone mineral status after total hip arthroplasty.

We conclude that periprosthetic BMD after total hip arthroplasty continues to decrease for 6–12 months after surgery, and then recovers except in zone 7, the calcar region. The calcaneal BMD decreased rapidly for 3 months after surgery, before increasing thereafter. The lumbar BMD showed a decreasing trend for 12 months after surgery, and then increased gradually. Radial BMD was not affected by surgery.

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