European Journal of Orthopaedic Surgery & Traumatology (2019) 29:1061–1067
https://doi.org/10.1007/s00590-019-02414-6

ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Peri-prosthetic bone remodeling and change in bone mineral density in the femur after cemented polished tapered stem implantation

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Received: 11 January 2019 / Accepted: 4 March 2019 / Published online: 8 March 2019
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Abstract
Objective We examined longitudinal changes in bone mineral density (BMD) around the femur for 5 years after total hip arthroplasty (THA) using cemented collarless polished double-tapered stem implantation and investigated the influence of BMD changes on radiological remodeling of the femur.
Materials and methods Sixty hips from 56 patients who underwent cemented THA with a collarless polished double-tapered stem were included. BMD was measured 2 weeks postoperatively (baseline), 3 months, 6 months, 1 year and annually thereafter until 5 years after surgery using dual-energy X-ray absorptiometry on the lumbar spine and proximal femur of the operated side according to the Gruen's zone classification. We analyzed predictable factors for BMD preservation in the proximal femur and compared radiological remodeling of the femur and changes in BMD.
Results BMD at 5 years in zone 7 decreased less than 10%, whereas BMD in zone 1 increased to over the baseline (+1.9%). Multiple linear regression analyses revealed that body weight was a predictor for positive BMD change in the proximal femur. The frequency of radiolucency of the femur was significantly lower in patients who exhibited an increase in BMD at 5 years compared with BMD at 2 weeks in zone 7.
Conclusion BMD preservation of the proximal femur after cemented collarless polished double-tapered stem implantation was more effective in heavier patients. Furthermore, the frequency of radiolucency around the stem was significantly lower in patients who exceeded 100% of the baseline BMD in zone 7 at 5 years.

Keywords Bone mineral density · Cemented collarless polished tapered stem · Dual-energy X-ray absorptiometry · Total hip arthroplasty · Radiolucency

Introduction

Bone mineral density (BMD) of the femur after total hip arthroplasty (THA) is affected by patterns of strain distribution changes after stem implantation [1–4]. To achieve long-term stability of the stem, conservation of peri-prosthetic BMD, especially in the proximal femur is considered to be crucial [5].

Previously, we reported a 3-year longitudinal peri-prosthetic dual-energy X-ray absorptiometry (DEXA) study after cemented total hip arthroplasty using collarless polished tapered stems [4]. However, it was only short-term examination after surgery and did not describe the relationship between radiographic appearance and change in BMD.

Therefore, the primary purpose of this study was to report the changes in the femur on DEXA during the 5-year period after cemented collarless polished double-tapered stem implantation. The secondary purpose was to examine the effects of patient factors on BMD preservation in the proximal femur after midterm follow-up, and to assess the relationship between radiological remodeling of the femur and BMD changes.

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Materials and methods

This prospective trial was performed on patients who underwent primary cemented THA for hip osteoarthritis with cemented collarless polished tapered stem (Exeter stem, Stryker Orthopaedics, Mahwah, New Jersey, USA) at Hamamatsu Medical Center. Between November 2008 and March 2010, primary cemented THA was performed for 88 hips in 81 patients. Patient being treated with anti-diabetes mellitus drugs (3 hips of 3 patients), bisphosphonate (5 hips of 4 patients) or hormonal drugs (3 hips of 3 patients) were excluded because of the influence of these treatments on systematic bone metabolism. Fifteen patients (17 hips) were also excluded because of treatment for spinal disease (2 hips in 2 patients), lack of DEXA data (7 hips in 7 patients) and incomplete follow-up data at 5 years (8 hips in 6 patients).

Therefore, 60 hips in 56 patients who completed the clinical, radiological and peri-prosthetic DEXA study 5 years after cemented THA were included in the present study. Informed consent was obtained from all patients, and this clinical study was conducted with the approval of the research ethics committee of Hamamatsu Medical Center (No. H28-23).

The average age of the patients at surgery was 64.6 years (range 41–81 years), and 48 patients were female and 8 were male. All surgeries were performed or supervised by a senior author, and a posterolateral approach was used in all.

For the acetabular component, the cemented cup (Contemporary cup, Stryker Orthopaedics) was used in 58 hips and the cementless metal shell (TriAD HA, Stryker Orthopaedics) with highly cross-linked polyethylene liner (Crossfire liner, Stryker Orthopaedics) was used in 2. For clinical assessment, the Merle d'Aubigné and Postel hip score was assessed preoperatively and at the final follow-up.

For radiological assessment, anteroposterior (AP) radiographs of the hip joints and BMD using DEXA on the lumbar spine and proximal femur of the operated side according to the Gruen's zone classification [6] were analyzed postoperatively until 5 years.

Anteroposterior hip radiographs were taken for all patients pre- and postoperatively at the final follow-up and were evaluated on a consensus basis by 2 observers. Stem subsidence was evaluated according to the method of Fowler et al. [7]. The position of partial radiolucencies (RLCs) [8], radiolucent lines (RLLs) and cortical hypertrophy of the femur around the stem was evaluated using the zones of Gruen et al. modified by Fujita et al. [9], i.e, zone 4 was separated into 2 zones as zone 4M for the medial side and zone 4L for the lateral side, and compared between the postoperative radiograph and at the 5-year follow-up. Partial radiolucency (RLC) was defined as any radiolucent area between the bone and the cement excluding demarcation lines that were significantly progressed compared with the radiograph at 2 weeks postoperatively. On the other hand, the radiolucent line (RLL) was defined as a clear radiolucent area combined with the parallel reactive radiosclerotic line.

BMD was measured 2 weeks postoperatively (baseline) [10] and after 3 and 6 months, 1 year and annually until 5 years using DEXA scans on the lumbar spine (L2–L4) and proximal femur. Measurements in the coronal plane were made using the same Lunar Prodigy (GE Medical Systems, Madison, WI, USA). We scanned the proximal femur from 2.0 cm distal to the tip of the stem and analyzed BMD (g/cm^2) in 7 regions of interest according to the Gruen's zone classification [4]. We used orthopedic software (enCORE version 13.60.033, GE Medical Systems, Madison, WI, USA) to avoid interference from the femoral stem, and it automatically detected the interface between the cement mantle and metallic stem. Therefore, the BMD value included the cement mantle.

The BMD ratio at each follow-up was calculated as (BMD at follow-up /BMD at 2 weeks) × 100 (%), and the BMD ratio change at each follow-up was calculated as (BMD at follow-up /BMD at 2 weeks − 1) × 100 (%).

Factors for BMD preservation at the proximal femur

Correlations between patient factors (age, gender, height, body weight, operated side, Merle d'Aubigné and Postel hip scores at 5 years and stem alignment) and BMD ratio at 5 years in Gruen zones 1 and 7 were analyzed using univariate and multivariate analyses.

Relationship between radiological remodeling findings and BMD ratio at the proximal femur

Patients were classified into 3 groups based on the change in BMD ratio in zone 7 at 5 years as follows: increase group (I group): The BMD ratio in zone 7 at 5 years was more than 100%, moderate decrease group (M-D group): The BMD ratio in zone 7 at 5 years was between 100 and 80% and severe decrease group (S-D group): The BMD ratio in zone 7 at 5 years was less than 80%. To analyze the relationship between the radiographic remodeling findings, the number of patients with partial RLCs in 3 zones or more were counted in each group (I group, M-D group and S-D group).

Statistics

The StatMate version 5.01 (ATMS Co., Ltd., Tokyo, Japan) software package was used for statistical analyses, which was developed as the add-on package for function calculation of Microsoft Excel (Microsoft Corp., Redmond, WA, USA) to perform statistical function frequently used in biostatistics. We investigated the differences between pre- and postoperative Merle d'Aubigné and Postel hip scores with the Wilcoxon rank sum test. Differences in the BMD ratio between baseline and each postoperative time on BMD examination of the lumbar spine and among each Gruen zone were evaluated using the paired Student's *t*-test after one-way analysis of variance.

To analyze factors for BMD preservation at the proximal femur, univariate analyses were performed using Pearson's correlation coefficient (age at op, height, body weight and stem axis), Spearman's rank correlation coefficient (*M–P* score at 5 years) or Student's or Welch's *t*-tests (gender and operated side). Multivariate analyses were carried out using the multiple regression analysis for variables with a *p* value <0.2 based on univariate analyses.

Patients with partial RLCs in 3 zones or more were categorized into the 3 groups (I, M-D and S-D group) and compared with the likelihood ratio test (*G* test). Body weight among groups was compared using Tukey's test after one-way analysis of variance. A probability value (*p* value) of <0.05 was considered significant.

Results

The mean Merle d'Aubigne and Postel hip score improved from 11.3 points (8–14 points) before surgery to 16.5 points (13–18 points) at the final follow-up ($p<0.01$).

On radiographic assessment, no patient exhibited progressive RLLs, osteolysis or stem migration. Stem subsidence at 5 years after the surgery was less than 2 mm in all.

On radiological remodeling of the femur at the latest follow-up of 5 years, there was no cortical hypertrophy or radiolucent lines at any zones. However, 26 of 60 hips presented partial RLCs in at least 1 zone, and 18 of these 26 hips presented partial RLCs at 3 zones or more. Figure 1 shows the distribution of RLCs.

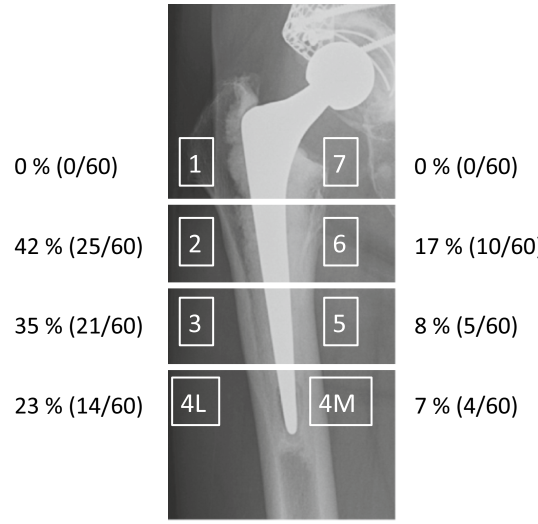

Fig. 1 Distribution of partial radiolucencies (RLCs) at 5 years

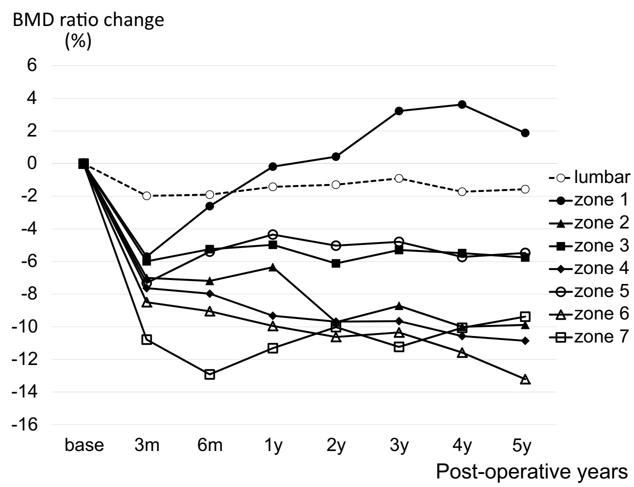

Fig. 2 Changes in BMD ratio in each Gruen zone and spine (L2-4) over 5 years, as measured using dual-energy X-ray absorptiometry (DEXA). BMD ratio change (α month) was calculated as (BMD α month/BMD 2 weeks 1) 100 (%)

DEXA assessment for all patients

Overall, BMD changes in the lumbar spine and each Gruen zone were nearly equivalent with those reported in our previous 3-year DEXA study [4], but a slight decrease was observed after 3 and 5 years in Gruen zone 6 of the femur (Fig. 2). Although a slight decrease in the lumbar spine BMD (L2–L4) was observed at 3 months, it stabilized after 3 months until the last follow-up at 5 years. During the first year of observations, BMD ratio changes in all zones decreased significantly within the range of − 5.7% (zone 1) to − 12.9% (zone 7). For the proximal part of the femur in zone 1 in particular, the BMD ratio change increased gradually after decreasing at 3 months (− 5.7%) and exceeded the baseline after the first year. It then increased gradually until 3 years. After 3 years, annual differences in the change in BMD ratio in zone 1 were not significant. In zone 7, the BMD ratio change decreased by more than 10% at 3 months (− 10.9%) and 6 months (− 12.9%) and then began to increase until − 9.4% at 5 years compared with the BMD at 2 weeks after stem implantation.

Table 1 Results of univariate and multivariate analyses for factors that may affect BMD ratio (%) at 5 years in Gruen zones 1 and 7

Variables	Mean (SD)	Number	BMD ratio (%) at 5 years					
			Gruen zone 1			Gruen zone 7		
			Univariate	Multivariate		Univariate	Multivariate	
			p values	*p* values	*β*	*p* values	*p* values	*β*
Age at op. (years)	64.6 (8.6)		0.104	–	–	0.158	–	–
Gender (hips): male/female		8/52	0.022	–	–	0.251	–	–
Height (cm)	153.0 (7.2)		< 0.001	–	–	0.243	–	–
Body weight (kg)	54.8 (8.5)		< 0.001	< 0.001	0.970	0.002	0.002	0.727
Operated side: right/left		27/33	0.952	–	–	0.182	–	–
M–P score at 5 years	16.4 (1.1)		0.306	–	–	0.957	–	–
Stem axis	0.55 (0.5)		0.156	–	–	0.115	–	–

Univariate analyses were performed using Pearson's correlation coefficient (age at op, height, body weight and stem axis), Spearman's rank correlation coefficient (M–P score at 5 years) or *t*-test (gender and operated side). Multivariate analyses were performed using the multiple regression analysis for variables that had a *p* value < 0.2 based on univariate analyses

M–P score Merle d'Aubigné and Postel hip score

Factors for BMD preservation at the proximal femur

The results of univariate and multiple regression analyses of factors for BMD preservation at the proximal femur (Gruen zones 1 and 7) are shown in Table 1. On univariate analyses, there were positive correlations between BMD ratio (%) at 5 years in Gruen zone 1 and body size (height [$r = 0.424$, $p < 0.001$] and body weight [$r = 0.517$, $p < 0.001$, Fig. 3a], respectively). The BMD ratio (%) at 5 years in Gruen zone 1 was significantly higher in male patients (male: 112.7% ± 14.9% vs. female: 112.7% ± 14.9%, $p = 0.022$). There was a positive correlation between BMD ratio (%) at 5 years in Gruen zone 7 and body weight ($r = 0.385$, $p = 0.002$, Fig. 3b). Multiple regression analysis demonstrated that body weight was an independent predictive factor for a high BMD ratio at 5 years in Gruen zones 1 and 7.

Relationship between radiological remodeling findings and BMD ratio at the proximal femur (Table 2)

Patients were divided into 3 groups according to the BMD ratio in zone 7 at 5 years, and the average ± standard deviation of the BMD ratio was 1.12 ± 0.10, 0.90 ± 0.10 and 0.72 ± 0.08 in the I group ($n = 15$), M-D group ($n = 29$) and S-D group ($n = 16$), respectively. The average ± standard deviation of body weight in each group was 59.5 ± 10.5 kg, 55.0 ± 7.2 kg and 49.9 kg ± 6.2 kg in the I group, M-D group and S-D group, respectively. The average body weight in the I group was significantly higher than that in the S-D group ($p < 0.01$, Tukey's test).

Partial RLCs in 3 zones or more (RLC-positive hips) were observed in 1 of 15 hips (6.7%), 12 of 29 hips (41.4%) and 9 of 16 hips (56.3%) of the I group, M-D group and S-D group, respectively. The difference in the frequency of RLC-positive hips among the 3 groups was significant ($p < 0.01$, *G* test). Partial RLC occurred mainly on the lateral side of the femur (zones 2, 3, and 4L). Using kappa statistics, intra- and inter-observer variabilities for counts of RLC-positive hips were 0.961 and 0.718, respectively.

Discussion

Cemented collarless polished double-tapered stems function as a taper within the cement mantle, and weight-bearing force onto the femoral head is therefore converted to hoop force around the stem [11]. Biomechanical analyses revealed that this hoop stress is maximal at the proximal part of femur [12] and may stimulate bone formation in this area according to Wolff's law of strain-adaptive remodeling [11].

A short-term DAXA study around the stem reported that BMD loss at the proximal medial part of the femur using this type of stem is less than that using conventional cementless stems [4, 13]. Although the change in BMD ratio at 5 years in Gruen zone 1 and zone 7 in the current midterm follow-up study was + 1.9% and − 9.4%, respectively, Inaba et al. [13] reported that the BMD change at 3 years after insertion of 3 types of cementless stems in Gruen zones 1 and 7 decreased to less than − 5% and − 20%, respectively. The ability to restore the femoral bone quality may be 1 factor affecting the long-term clinical follow-up [14, 15] for this type of cemented stem. The present results suggest that a heavier body weight leads to effective Wolff's law reactions

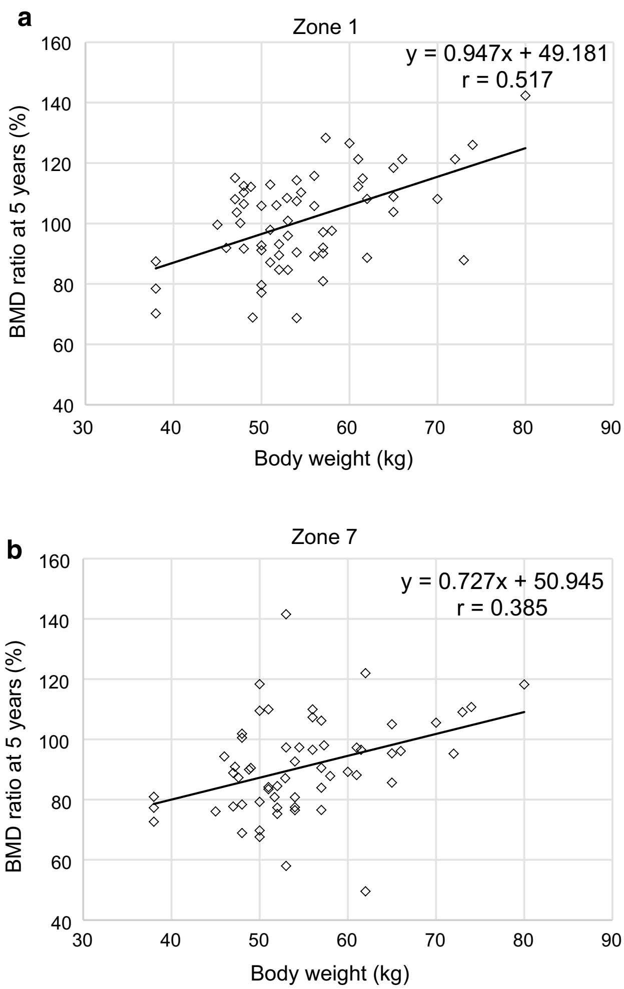

Fig. 3 **a** Correlation between BMD ratio (%) in Gruen zone 1 at 5 years after surgery and body weight (kg), **b** correlation between BMD ratio (%) in Gruen zone 7 at 5 years after surgery and body weight (kg)

at the cement–bone interface of the proximal medial femur after collarless polished tapered stem implantation, and this phenomenon may influence BMD preservation of the femur.

On the other hand, in patients with lower body weights, this effect does not work well, and BMD at the proximal part of the femur may decrease similarly with the stress shielding phenomenon observed for cementless implants. Hence, a certain degree of load created by moderate or heavy body weight or active daily walking may be a factor affecting longevity of the femoral component.

Furthermore, bisphosphonates treatment after hip arthroplasty could be considered to prevent bone loss around the proximal femur in patients with lower body weights. The previous studies analyzing the bisphosphonate treatment effect for patients with a cemented stem failed to show any positive effect on prevention for bone loss [16, 17], since the patients with cemented stems experienced less bone loss than patients with cementless stems. On the other hand, the systematic analysis by Knusten et al. [18] showed encouraging effect of this treatment for patients with stiff cementless femoral stem designs producing more stress shielding bone atrophy. Hence, further studies for this treatment should be considered for low body weight patients with cemented collarless polished double-tapered stem.

Radiological peri-prosthetic remodeling patterns after cemented stem implantation have been previously reported. Schmalzried et al. [8] examined autopsy specimens of well-fixed cemented stems and found that radiolucency between the cement mantle and the outer femoral cortex on radiographs indicates a second medullary canal formed by radial struts of trabecular bone between the endosteal surface of the cement mantle and the outer femoral cortex. This radiolucency may indicate endosteal remodeling of the femoral cortices influenced by the biomechanical circumstances of loading.

Although several studies have demonstrated that cortical thinning after cemented stem implantation correlates with aging, preoperative stovepipe femoral bone morphology and stem design, the influence of BMD change on radiographic findings remains unclear [19, 20]. To the best of our knowledge, this is the first study reporting the detailed relationship between peri-prosthetic BMD change and radiographic

Table 2 Relationship between frequency of partial radiolucencies (RLC) and BMD ratio at 5 years in Gruen zone 7

BMD ratio at 5 years in Gruen zone 7	> 100% I group ($n = 15$)	100–80% M-D group ($n = 29$)	< 80% S-D group ($n = 16$)
No. of RLC-negative hips	14	17	7
No. of RLC-positive hips	1	12	9
Frequency of RLC-positive hips[a]	6.7%	41.4%	56.3%
Body weight (mean ± SD)	59.5 ± 10.5 kg[b]	55.0 ± 7.2 kg	49.9 ± 6.2 kg

I group increase group; *M-D group* moderate decrease group; *S-D group* severe decrease group; *RLC-negative hips* radiolucency in less than 3 Gruen zones; *RLC-positive hips* radiolucency in 3 Gruen zones or more

[a] $p < 0.01$ (likelihood ratio test; *G* test)

[b] $p < 0.01$ versus S-D group, Tukey's test

remodeling patterns of the proximal femur after arthroplasty using a collarless polished tapered stem.

The present study has several limitations. In terms of radiographic assessment, manual radiological measurements were less accurate than other methods such as computer-assisted technologies. Thus, radiographs were evaluated on a consensus basis by 2 authors. Furthermore, the BMD may have been overestimated and BMD ratios may have been underestimated in this study because scanning data included the cement mantle. The BMD was calculated as the bone mineral content (BMC, g)/area (cm^2). As the BMC includes the density of the cement mantle, which is of radiopaque contrast and unlikely to change over time [21], the resulting BMD may be greater than that in the bony area only. Moreover, the actual area undergoing change was only the bony area, which was a part of the total calculated area in each Gruen zone.

Although we found a positive correlation between body weight and BMD ratio in the proximal femur at 5 years after THA, it is uncertain whether very high body weight, such as more than 80 kg, leads to a greater BMD increase in clinical settings. As the present patients were all Japanese, the maximum body weight in the present cohort was 80 kg. As such, the positive effects of body weight on BMD preservation in the proximal femur in severely obese patients are undetermined.

Conclusion

In conclusion, BMD preservation at the proximal femur after collarless polished double-tapered stem implantation was more effective in heavier patients. Proper load created by moderate or heavy body weight, or even by active daily walking, may increase the fixation longevity of this type of cemented femoral component.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study was performed according to the Declaration of Helsinki and approved by the Local Research Ethics Committee (No. H28-23).

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