Hydroxyapatite-coated compaction short stem represents a characteristic pattern of peri-prosthetic bone remodelling after total hip arthroplasty

Shinya Hayashi1 · Shingo Hashimoto1 · Yuichi Kuroda1 · Naoki Nakano1 · Tomoyuki Matsumoto1 · Tomoyuki Kamenaga1 · Takahiro Niikura1 · Ryosuke Kuroda1

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Abstract

Purpose We aimed to investigate the differences in peri-prosthetic bone remodelling between the full hydroxyapatite (HA)-collared compaction short stem and the short tapered-wedge stem.

Methods This retrospective cohort study enrolled 159 consecutive patients (159 joints) undergoing total hip arthroplasty (THA) using the full HA compaction short (n = 64) and short tapered-wedge (n = 95) stems. Body mass index (BMI), peri-prosthetic bone mineral density (BMD), and clinical factors, including the Japanese Orthopaedic Association score and the University of California Los Angeles (UCLA) activity score were assessed and compared.

Results Stem related complications were seen in three cases. Both groups showed similar peri-prosthetic BMD changes. Peri-prosthetic BMD was almost maintained in the distal femur and Gruen zone 6 with both type of stems, but significant BMD loss was found in zones 1 and 7 in both groups and in zone 2 of the full HA compaction stem group. No significant correlations were found between the proximal femoral BMD changes and the age, BMI, and UCLA score in both the full HA compaction and tapered-wedge stem groups. Femoral bone shape affected the peri-prosthetic BMD changes in the tapered-wedge stem group but not in the full HA compaction group. The stem collar of the full HA compaction stem did not affect peri-prosthetic BMD, but unique bone remodelling in the calcar region was observed in 27.6% cases. A significant difference in the peri-prosthetic BMD changes at Gruen zone 2 was found in patients with or without thigh pain.

Conclusion Peri-prosthetic bone remodelling remained unaffected by clinical and radiographic factors after THA with the new short full HA compaction stem. Therefore, this new stem may be useful in a variety of cases.

Keywords Total hip arthroplasty · Short tapered-wedge stem · Full hydroxyapatite-coated compaction short stem · Bone mineral density

Introduction

Load bearing of the peri-prosthetic bone after total hip arthroplasty (THA) is critical to maintain bone strength [1]. Once a femoral prosthesis has been implanted, daily activities result in mechanical loading of the femoral bone around and below the stem by the implanted stem. However, there are many other factors involved in stress sharing and, consequently, in stress shielding, and these factors influence bone mineral density (BMD) [2]. Stress shielding in the femur often occurs in the calcar region because it is highly unlikely that the loading of and stress distribution in the proximal femur will ever be replicated in the presence of an intramedullary prosthesis [3, 4], and the decreased BMD may lead to aseptic loosening, stem subsidence, and peri-prosthetic fractures [3, 5]. Therefore, implants should aim to replicate the physiological stress distribution pattern [6].

Hydroxyapatite (HA) is widely used in THA to improve implant survivorship through accelerated early bone remodelling [7, 8]. This bioactive coating is believed to enhance the initial fixation by osseointegration [7, 8]. The ACTIS stem (DePuy Synthes, Warsaw, IN, USA) is a medial-collared, triple-tapered short stem. A medial collar provides
improved stability, avoiding subsidence with a porous sintered titanium bead coating present proximally and a grit-blasted surface present distally and is entirely HA-coated. It is designed to enhance immediate stability, increase early fixation, and allow easy insertion. Further, the implant is inserted using a hybrid of compaction and cutting broach, which enables compaction of the cancellous bone toward the cortical rim until axial and rotational stability is achieved. The cancellous bone is maintained without the implant contacting to the femoral cortex, and the HA-coated femoral stem is inserted into a compacted sleeve of cancellous bone.

Bone-preservation strategies involve the development of neck-preserving short stems designed to avoid stress shielding and increase peri-prosthetic bone formation [9]. The Tri-Lock bone preservation (BPS) stem (DePuy Synthes) is a short tapered-wedge stem with a small shoulder shape, short anterior–posterior width, and short length. Stem lengths (from stem shoulder to distal end) of both the full HA compaction and tapered-wedge stems are within the range of 95—119 mm. Short stems potentially preserve more bone stock, which improves proximal load transfer, and show lower stress shielding than long stems [10, 11]. Maintenance of peri-prosthetic BMD after THA with the Tri-Lock BPS stem has been previously reported [12].

Both the full HA-collared compaction short stem and short tapered-wedge stem were developed for minimally invasive THA and made from the same titanium alloy, but the geometry, type of surface coating and concept of both stems differ substantially. We hypothesized that peri-prosthetic bone remodelling may differ according to the stem design. Therefore, this study aimed to answer the following questions:

(1) Is there any difference in the peri-prosthetic BMD change after THA between the full HA-collared compaction short stem and the short tapered-wedge stem?
(2) Is there any relation between the pre-operative clinical factors and post-THA BMD change?
(3) Does the stem collar of the HA compaction stem affect peri-prosthetic bone remodelling?

Briefly, this study aimed to investigate the differences in peri-prosthetic bone remodelling between the full HA-collared compaction short stem and the short tapered-wedge stem.

Materials and methods

Patients’ characteristics

This retrospective cohort study enrolled 159 consecutive patients (159 s) who underwent THA using the full HA compaction short stem (ACTIS; DePuy Synthes, Warsaw, IN; 64 joints) (Fig. 1a) or the short tapered-wedge stem (Tri-Lock BPS; DePuy Synthes; 95 joints) (Fig. 1b) at our institution between January 2016 and April 2017 (tapered-wedge) and April 2017 and November 2018 (full HA compaction). The pre-operative diagnoses were osteoarthritis (grade 4 according to the Tönnis classification) (114 joints), avascular necrosis of the femoral head (30 joints), and rheumatoid arthritis (15 joints). Patients with a distorted anatomy of the proximal femur, osteoporosis (lumbar spine BMD < 0.8), metabolic bone disease, and bilateral THA were excluded.

All procedures were performed via the mini-anterolateral supine approach by a single senior surgeon. Full weight-bearing was allowed for all patients a day after the operation. Body mass index (BMI) was assessed at the time of the operation. The post-operative follow-up included dual energy X-ray absorptiometry (DEXA) scanning and evaluation of clinical factors, including hip function, which was evaluated using two grading methods: (a) the Japanese Orthopaedic Association (JOA) score, which allocates 40 points for pain, 20 points for range of motion, 20 points for walking ability, and 20 points for activities of daily living, with a maximum total score of 100 points [13] and (b) the University of California Los Angeles (UCLA) activity score, which describes subjects’ level of activity from 1 (“no physical activity, dependent on others”) to 10 (“regular participation in impact sports”). The JOA scores, UCLA scores, and radiographic finding were evaluated at 2 years postoperatively.

DEXA measurements

DEXA scanning was performed using a DPX-L scanner (GE Lunar Corporation, Madison, WI, USA). DPX-L total body scans were performed using the software version 1.35, which
set the appropriate transverse speed at 16 cm/s, 8 cm/s, or 4 cm/s depending on the subject’s height. Patients were positioned supine with their leg in the neutral position and a knee and foot support to facilitate the scanning of the anterior–posterior projection of the proximal femur, including the area distal to the prosthesis, using an edge-detection technique.

Peri-prosthetic BMD was determined postoperatively in seven regions of interest (ROI) based on the Gruen zones [14]. The seven Gruen zones were positioned based on the distal tip and shoulder of the prosthesis. The two most proximal Gruen zones (1 and 7) were also combined to create a proximal femur ROI, which represents the region where porous coating of the uncemented stems is normally situated. The values were expressed as area BMD in grams per square centimetre. The BMD around the stem was assessed within 1-month postoperatively (baseline BMD) and 6, 12, 18, and 24 months postoperatively by a technician from the radiology department who was blinded to the stem used. BMD ratios were calculated by dividing each BMD value at 6, 12, 18, and 24 months postoperatively by the BMD value obtained within 1-month postoperatively.

**Statistical analysis**

All data are expressed as mean ± standard deviation (SD) unless otherwise indicated. The differences in patients’ backgrounds between the full HA compaction and tapered-wedge groups were analysed using the Mann–Whitney U test (Table 1). The frequency of the Dorr types between the two groups was analysed using the Chi-square test (Table 2). Sequential changes in BMD within each group were analysed via one-way analysis of variance using Tukey’s post hoc test. Additionally, the BMD at each timepoint was compared between the groups using the Mann–Whitney U test (Table 3). Correlations between peri-prosthetic BMD changes and the clinical factors (age, BMI, and UCLA score) in the two groups were analysed using the Spearman’s rank correlation coefficient (Table 4). The differences in BMD changes among Dorr types were analysed via one-way analysis of variance using Tukey’s post hoc test (Table 5). To analyse the influence of collar-calcar contact on the peri-prosthetic BMD changes, we compared these changes based on whether the full HA compaction

#### Table 1 Patient’s background

|                      | Full HA compaction | Tapered wedge | p value |
|----------------------|--------------------|---------------|---------|
| Number of patients   | 64 (male 15, female 49) | 95 (male 21, female 74) |         |
| Age (years)          | 65.5 ± 12.6        | 66.4 ± 9.5    | 0.929   |
| BMI (kg/m²)          | 24.1 ± 4.2         | 23.8 ± 3.4    | 0.950   |
| JOA score (points)   | 95.1 ± 6.8         | 94.9 ± 7.2    | 0.803   |
| UCLA score (points)  | 6.3 ± 1.7          | 6.3 ± 1.5     | 0.807   |

#### Table 2 Number of patients with Dorr types

| Dorr type | HA full compaction | Tapered wedge | p value |
|-----------|--------------------|---------------|---------|
| A         | 6 (9.4%)           | 3 (3.2%)      | 0.087   |
| B         | 53 (82.8%)         | 84 (88.4%)    | 0.277   |
| C         | 5 (7.8%)           | 8 (8.4%)      | 0.937   |

#### Table 3 Comparison of BMD changes between Full HA compaction and Tapered wedge stem at 6, 12, 18, and 24 months postoperatively in the Gruen zones

| Zone     | HA full compaction | Tapered wedge | p value |
|----------|--------------------|---------------|---------|
| Zone 1   | 6 m 0.94 ± 0.07    | 0.94 ± 0.10   | 0.992   |
|          | 12 m 0.92 ± 0.10   | 0.93 ± 0.17   | 0.231   |
|          | 18 m 0.90 ± 0.09   | 0.95 ± 0.14   | 0.025*  |
|          | 24 m 0.91 ± 0.07   | 0.93 ± 0.11   | 0.122   |
| Zone 2   | 6 m 0.95 ± 0.08    | 0.99 ± 0.10   | 0.019*  |
|          | 12 m 0.94 ± 0.10   | 0.99 ± 0.11   | 0.006*  |
|          | 18 m 0.94 ± 0.08   | 1.01 ± 0.13   | 0.004*  |
|          | 24 m 0.93 ± 0.08   | 1.01 ± 0.13   | <0.001* |
| Zone 3   | 6 m 1.02 ± 0.05    | 1.00 ± 0.13   | 0.266   |
|          | 12 m 1.03 ± 0.05   | 1.02 ± 0.14   | 0.994   |
|          | 18 m 1.03 ± 0.07   | 1.04 ± 0.15   | 0.327   |
|          | 24 m 1.03 ± 0.07   | 1.04 ± 0.15   | 0.157   |
| Zone 4   | 6 m 1.03 ± 0.04    | 1.00 ± 0.09   | 0.001*  |
|          | 12 m 1.04 ± 0.05   | 1.00 ± 0.06   | <0.001* |
|          | 18 m 1.04 ± 0.05   | 1.02 ± 0.11   | 0.040*  |
|          | 24 m 1.04 ± 0.07   | 1.02 ± 0.06   | 0.010*  |
| Zone 5   | 6 m 1.03 ± 0.06    | 1.02 ± 0.10   | 0.008*  |
|          | 12 m 1.05 ± 0.08   | 1.02 ± 0.11   | 0.002*  |
|          | 18 m 1.06 ± 0.08   | 1.04 ± 0.14   | 0.025*  |
|          | 24 m 1.05 ± 0.09   | 1.05 ± 0.12   | 0.760   |
| Zone 6   | 6 m 0.99 ± 0.11    | 0.99 ± 0.13   | 0.480   |
|          | 12 m 0.98 ± 0.13   | 0.97 ± 0.15   | 0.446   |
|          | 18 m 0.99 ± 0.11   | 1.00 ± 0.14   | 0.970   |
|          | 24 m 0.98 ± 0.12   | 0.99 ± 0.12   | 0.645   |
| Zone 7   | 6 m 0.92 ± 0.17    | 0.90 ± 0.21   | 0.462   |
|          | 12 m 0.87 ± 0.18   | 0.90 ± 0.19   | 0.640   |
|          | 18 m 0.83 ± 0.16   | 0.91 ± 0.21   | 0.970   |
|          | 24 m 0.85 ± 0.21   | 0.84 ± 0.15   | 0.645   |

*p < 0.05
stem collar was in contact with the femoral calcar region or not. The differences in the BMD changes between the stem collar-calcar contact and non-contact groups were analysed using the Mann–Whitney \( U \) test (Table 6). The differences in the BMD changes in patients with or without thigh pain at 24 months postoperatively were analysed using the Mann–Whitney \( U \) test (Table 7). A \( p \) value < 0.05 was considered statistically significant. Post hoc power analysis was performed using G*Power 3 [15]. For a sample size of 64 and 95 among three Dorr classifications and a type-I error (\( \alpha \)) of 0.05 (one-way ANOVA), the study is expected to provide a power (1-\( \beta \)) of 0.80 and 0.93 for detecting large effect sizes (0.4) with respect to the endpoint of peri-prosthetic BMD changes at 24 months.

| Table 4 | Comparison of mean age, BMI, and UCLA score between Full HA compaction and Tapered wedge stem |
|---------|-----------------------------------------------|
| Zone 1  | Correlation coefficient | \( p \) value |
|         | Full HA compaction | Tapered wedge |
|         | Age | BMI | UCLA | Age | BMI | UCLA |
| Zone 1  | 0.038 | 0.152 | 0.092 | 0.047 | 0.200 | 0.141 |
| Zone 2  | 0.108 | 0.040 | 0.037 | 0.076 | 0.015 | 0.100 |
| Zone 3  | 0.011 | 0.062 | 0.129 | 0.013 | 0.023 | 0.185 |
| Zone 4  | 0.203 | 0.047 | 0.161 | 0.169 | 0.050 | 0.085 |
| Zone 5  | 0.013 | 0.193 | 0.002 | 0.016 | 0.126 | 0.146 |
| Zone 6  | 0.030 | 0.189 | 0.989 | 0.883 | 0.252 | 0.177 |
| Zone 7  | 0.038 | 0.006 | 0.062 | 0.139 | 0.076 | 0.025 |

| Table 5 | Comparison of BMD changing at 24 months among Dorr A, B, and C |
|---------|-----------------------------------------------|
| Zone 1  | HA full compaction | Tapered wedge |
|         | Dorr A | Dorr B | Dorr C | \( P \) value | Dorr A | Dorr B | Dorr C | \( P \) value |
| Zone 1  | 0.91 ± 0.04 | 0.92 ± 0.14 | 0.87 ± 0.06 | 0.632 | 0.97 ± 0.04 | 0.93 ± 0.11 | 0.92 ± 0.11 | 0.812 |
| Zone 2  | 0.93 ± 0.11 | 0.94 ± 0.08 | 0.94 ± 0.15 | 0.985 | 0.99 ± 0.06 | 1.00 ± 0.13 | 1.11 ± 0.11 | 0.099 |
| Zone 3  | 1.03 ± 0.06 | 1.02 ± 0.06 | 1.07 ± 0.09 | 0.314 | 1.00 ± 0.05 | 1.03 ± 0.15 | 1.06 ± 0.04 | 0.068 |
| Zone 4  | 1.06 ± 0.07 | 1.04 ± 0.07 | 1.06 ± 0.03 | 0.645 | 1.02 ± 0.07 | 1.09 ± 0.27* | 1.01 ± 0.06* | 0.002 |
| Zone 5  | 1.08 ± 0.09 | 1.04 ± 0.08 | 1.03 ± 0.10 | 0.621 | 1.03 ± 0.06 | 1.04 ± 0.14 | 1.03 ± 0.07 | 0.266 |
| Zone 6  | 1.03 ± 0.10 | 0.99 ± 0.13 | 1.00 ± 0.07 | 0.705 | 1.09 ± 0.02 | 1.10 ± 0.15* | 0.98 ± 0.11* | 0.043 |
| Zone 7  | 0.90 ± 0.30 | 0.88 ± 0.20 | 0.86 ± 0.18 | 0.844 | 0.88 ± 0.01 | 0.84 ± 0.15 | 0.86 ± 0.19 | 0.770 |

* \( p < 0.05 \)

| Table 6 | Comparison of BMD change whether stem collar contacting to femoral calcar or not |
|---------|-----------------------------------------------|
| Stem collar contact to the femoral calcar (\( N = 35 \)) | Stem collar does not contact to the femoral calcar (\( N = 29 \)) | \( p \) value |
| Zone 1  | 0.92 ± 0.16 | 0.91 ± 0.07 | 0.975 |
| Zone 2  | 0.95 ± 0.08 | 0.92 ± 0.09 | 0.341 |
| Zone 3  | 1.04 ± 0.07 | 1.01 ± 0.07 | 0.330 |
| Zone 4  | 1.05 ± 0.07 | 1.04 ± 0.06 | 0.282 |
| Zone 5  | 1.04 ± 0.11 | 1.05 ± 0.07 | 0.495 |
| Zone 6  | 0.98 ± 0.13 | 1.01 ± 0.12 | 0.495 |
| Zone 7  | 0.85 ± 0.19 | 0.88 ± 0.22 | 0.286 |

| Table 7 | Comparison of BMD change whether thigh pain was occurred or not |
|---------|-----------------------------------------------|
| Thigh pain + (\( N = 18 \)) | Thigh pain − (\( N = 77 \)) | \( p \) value |
| Zone 1  | 0.94 ± 0.11 | 0.93 ± 0.11 | 0.520 |
| Zone 2  | 1.07 ± 0.12 | 1.00 ± 0.12 | 0.047* |
| Zone 3  | 1.09 ± 0.07 | 1.03 ± 0.07 | 0.052 |
| Zone 4  | 1.04 ± 0.05 | 1.02 ± 0.06 | 0.110 |
| Zone 5  | 1.04 ± 0.10 | 1.05 ± 0.14 | 0.495 |
| Zone 6  | 0.99 ± 0.10 | 0.99 ± 0.12 | 0.802 |
| Zone 7  | 0.78 ± 0.12 | 0.86 ± 0.15 | 0.105 |

* \( p < 0.05 \)
postoperatively, in both full HA compaction and tapered-wedge groups, respectively.

Ethics

The study protocol was approved by the institutional review board on September 8, 2011 (No. 1220).

Results

Patients’ characteristics

The mean patient age at operation was 66.2 ± 10.4 years. At the clinical evaluation performed 24 months postoperatively, the mean BMI was 23.8 ± 3.7 kg/m², JOA score was 95.0 ± 7.0, and UCLA score was 6.3 ± 1.5. We divided the patients into two groups: the full HA compaction short-stem group and the tapered-wedge stem group. Thigh pain did not occur at 24 months after THA in the full HA compaction group but occurred in 18.9% (18/95) of patients in the tapered-wedge stem group. The mean values of the parameters in each group are shown in Table 1; they were not significantly different between the groups except the occurrence of thigh pain.

Table 2 demonstrates the characteristics of femoral bone shape according to the Dorr classification. There was no significant difference in the characteristics of femoral bone shape between the groups.

Complications

Overall, stem related complications were seen in three cases in this study. In the full HA compaction group, intraoperative greater trochanter chip fracture involving the small body occurred in one patient and healed without requiring any further treatment. In the tapered-wedge stem group, subsidence of the stem occurred in two patients; this was within 2 mm and stopped around 2 months after surgery. Other complications such as dislocation, loosening, and infection were not noted, and no revision surgery was performed in either group during the follow-up period.

Peri-prosthetic BMD changes were similar between the groups

Minimal BMD changes were found in the distal femur (Gruen zones 3, 4, and 5) and zone 6 of both types of stems (Table 3). However, a significant BMD loss was observed in zones 1 and 7 at each timepoint in both groups compared with the BMD value obtained within 1-month postoperatively (full HA compaction: zone 1, 24 months, \( p < 0.001 \); zone 7, 24 months, \( p < 0.001 \)). Additionally, BMD loss was observed in zone 2 at 12, 18, and 24 months postoperatively in the full HA compaction group (12 months, \( p = 0.003 \); 18 months, \( p < 0.001 \); and 24 months, \( p < 0.001 \)). On comparing the BMD changes between the groups, we found that the changes in the BMD of the tapered wedge stem group were significantly higher in zone 2 at each time point. The changes in the BMD of the full HA compaction group were significantly higher in zones 4 and 5 (Table 3).

Correlations between peri-prosthetic BMD changes and clinical factors

There were no significant correlations between the BMD changes and age, BMI at surgery, or the UCLA score 24 months postoperatively in the full HA compaction group and the tapered-wedge stem group (Table 4).

Correlation between femoral bone shape and peri-prosthetic BMD changes in the two groups

We compared the peri-prosthetic BMD changes at 24 months postoperatively between the two groups according to the Dorr classification for femoral bone shape. Table 5 shows that significant peri-prosthetic BMD changes were found in zones 4 and 6 of the tapered-wedge stem group among Dorr types A, B, and C. A post hoc analysis demonstrated that significant peri-prosthetic BMD changes were found among Dorr types B and C in zones 4 (\( p = 0.001 \)) and 6 (\( p = 0.038 \)). However, no significant peri-prosthetic BMD changes were found in any Gruen zone in the full HA compaction group among Dorr types A, B, and C (Table 5).

Relationship between the stem collar and peri-prosthetic BMD changes

There were no differences in any of the Gruen zones between the stem collar-calcar contact and non-contact groups (Table 6).

Full HA compaction stem represents bone remodelling in the calcar region

Evidence of bone remodelling in the calcar region was observed in 27.6% (8/29 cases) of cases in which the stem collar did not contact with the femoral calcar region. Figure 2 demonstrates two representative cases. Bone remodelling in the calcar region was observed 12 months postoperatively in both cases.
Relationship between the occurrence of thigh pain and peri-prosthetic BMD changes

Table 7 demonstrates that significant differences in peri-prosthetic BMD changes at 24 months postoperatively in Gruen zone 2 were found between patients with or without thigh pain.

Discussion

In this study, similar peri-prosthetic BMD changes were observed between the full HA compaction short stem and tapered-wedge stem; patients’ characteristics, including the femoral bone shape, affected the post-THA peri-prosthetic BMD in the tapered-wedge stem group but not in the full HA compaction group. We further demonstrated that unique bone remodelling in the calcar region was observed in the full HA compaction stem group, and subsidence of implant occurred in two cases of tapered-wedge stem group but was not found in the full HA compaction stem because of the stem’s medial collar.

As previously reported, minimal BMD changes after THA were observed in the distal femur with the short-tapered stem, that is, in Gruen zones 3, 4, and 5. However, significant BMD loss was observed in zones 1 and 7 at 24 months postoperatively [16]. In this study, the peri-prosthetic BMD loss observed with the full HA compaction short stem was almost maintained in the middle and distal femur, that is, in Gruen zones 3, 4, 5, and 6, but significant BMD loss was found in Gruen zones 1, 2, and 7 at 24 months postoperatively, and the change in BMD was comparable to that seen with the short-tapered stem, except in Gruen zone 2. We also demonstrated that the change in the BMD of the HA compaction stem was significantly higher in Gruen zones 4 and 5; however, the differences in the changes between the two types of stems in Gruen zones 4 and 5 were obviously very small in comparison with the changes in Gruen zone 2. Recently, Slullitel et al. conducted a randomized controlled trial demonstrating that BMD reduction in the calcar and proximal lateral regions after THA was smaller with the conventional full HA compaction stem than with the short tapered-wedge stem [17]. This result is inconsistent with our results, which revealed that regarding BMD preservation in the proximal femoral region, the results with the newly full HA compaction short stem are similar to those seen with short tapered-wedge stem. One of the reasons for BMD loss in the newly full HA compaction short stem may be dependent on broaching during femoral canal preparation. The broach of newly full HA compaction short stem is hybrid broach of compaction with antero-posterior aspect and cutting with medial–lateral (ML) aspect, and the ML cutting broaching may cause proximal BMD loss in the newly full HA compaction short stem.

We demonstrated that no correlation was found between BMD changes and age, BMI, or the UCLA scores in both the full HA compaction and short-stem groups. These results suggest that none of the clinical factors affected femoral stem fixation in the full HA compaction short stem and short tapered-wedge stem. However, previous study
has demonstrated a significant correlation between BMD changes in the proximal femur and the activity levels in the short tapered-wedge stem, and this result is inconsistent with previous results [12]. This discrepancy may be explained by the difference in the size of the sample population and the statistical methods used. A previous study used parametric tests for analysis of the BMD changes and clinical factors; however, the present study used non-parametric tests.

The occurrence of thigh pain impairs the restoration of hip function, occasionally resulting in revision surgery; however, this is a common complication following THA [18, 19]. Thigh pain was previously reported in 16.7% of 222 patients after THA using the short tapered-wedge stem [20], and thigh pain was reported by 18.9% of 95 patients with the short tapered-wedge stem in this study. In contrast, thigh pain did not occur in 133 patients with the conventional full HA compaction stem at the 11.5-year follow-up [21], and 83% of the patients were completely symptom-free at the 20-year follow-up [8]. This study revealed that thigh pain did not occur with the full HA compaction short stem at the 2-year follow-up, and the result was similar to that seen with the conventional full HA compaction stem. We also demonstrated that the BMD change in Gruen zone 2 was significantly higher in patients with thigh pain than in patients without thigh pain. A previous study has showed that the average peri-prosthetic BMD of the short tapered-wedge stem did not change among patients with or without thigh pain in Gruen zones 1 and 7 [20]. These results were in line with our result. Moreover, we identified that the BMD change was higher in patients with thigh pain at Gruen zone 2.

Several studies have focused on the peri-prosthetic BMD changes and femoral bone shape [12, 22]. Nakamura et al. investigated the influence of the proximal femoral canal shape on post-operative BMD changes in the femur around a Zweymüller-type stem and showed that the pre-operative morphology of the femoral canal did not affect the change in BMD 2 years postoperatively [22]. A previous study also demonstrated that the proximal femoral canal shape did not affect the post-operative BMD change in 65 patients using the short tapered-wedge stem 2 years postoperatively [12]. However, our study demonstrated that the femoral canal shape of Dorr type C contributed to peri-prosthetic BMD loss in 95 patients with the short tapered-wedge stem. This result is inconsistent with previous results [12]. This discrepancy may be attributed to the statistical power. Previous study may not have been sufficiently powered to analyse BMD differences between Dorr types B and C. In contrast, the proximal femoral canal shape did not affect post-operative BMD changes in the full HA compaction short stem group.

Previous studies have reported unique calcar bone remodelling with the conventional full HA compaction stem [8, 23]. Bone remodelling in the calcar region was observed in 15% of cases, and only two cases of grade 3 stress shielding were noted [8]; multivariate analysis revealed that femoral remodelling was not influenced to any significant extent by either patient-related or prosthesis-related factors (such as the collar, positioning, and size) [8]. Another study reported bone remodelling in the calcar region in 26.9% cases but calcar lysis in only 7% cases [23]. This study found that calcar bone remodelling was observed in 29% of all patients using the new full HA compaction short stem. These results indicate that HA may induce osteoinduction in the calcar region of the HA-coated stem.

The limitations of this study were as follows: first, this was not a randomized study but a retrospective cohort study. To evaluate the clinical and radiographical outcomes, an analysis of randomly selected patients is preferable. The backgrounds of the patients were also similar in our study. Second, the sample size, with respect to the evaluation of outcomes, was small. Third, ROI analysis was not performed for BMD evaluation. Fourth, the pre-operative peri-prosthetic BMD was not measured. We did not compare the BMD values pre- and postoperatively. The BMD around the stem was assessed within 1-month postoperatively (baseline BMD) and compared to 6, 12, 18, and 24 months postoperatively.

Conclusions

This study investigated the differences in peri-prosthetic bone remodelling between the full HA-collared compaction short stem and short tapered-wedge stem. Peri-prosthetic BMD changes after THA were similar between the two groups. The change in BMD was affected by daily activity levels and Dorr type C femoral shape in the short tapered-wedge stem group but was not affected by any factor in the full HA-collared compaction short stem group. Further, the full HA compaction short stem revealed unique bone remodelling in the calcar region. These findings suggest that the new full HA-collared compaction short stem may be useful in a variety of cases such as the patients with Dorr type C.

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Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical approval This research was approved by the institutional review board of the authors’ institution, and the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki.
Informed consent

Informed consent for participation in the study was obtained from all participants.

References

1. Mulholland SJ, Wyss UP (2001) Activities of daily living in non-Western cultures: range of motion requirements for hip and knee joint implants. Int J Rehabil Res 24(3):191
2. Huiskes R (1990) The various stress patterns of press-fit, ingrown, and cemented femoral stems. Clin Orthop Relat Res (261): 27
3. Kroger H, Venesmaa P, Jurvelin J, Miettinen H, Suomalainen O, Allhava E (1998) Bone density at the proximal femur after total hip arthroplasty. Clin Orthop Relat Res (352): 66
4. Engli CA, McGovern TF, Bobyn JD, Harris WH (1992) A quantitative evaluation of periprosthetic bone-remodeling after cementless total hip arthroplasty. J Bone Jt Surg 74(7):1009
5. Furnes O, Lie SA, Espehaug B, Vollset SE, Engesaeter LB, Havelin LI (2001) Hip disease and the prognosis of total hip replacements. A review of 53,698 primary total hip replacements reported to the Norwegian Arthroplasty Register 1987–99. J Bone Jt Surg Br 83(4):579
6. Pettersen SH, Wik TS, Skallerud B (2009) Subject specific finite element analysis of stress shielding around a cementless femoral stem. Clin Biomech 24(2):196
7. Chen Y-L, Lin T, Liu A, Shi M-M, Hu B, Shi Z-L, Yan S-G (2015) Does hydroxyapatite coating have no advantage over porous coating in primary total hip arthroplasty? A meta-analysis. J Orthop Surg Res 10:21
8. Vidalain JP (2011) Twenty-year results of the cementless Corail stem. Int Orthop 35(2):189
9. Huiskes R, Weinsans H, van Rietbergen B (1992) The relationship between stress shielding and bone resorption around total hip stems and the effects of flexible materials. Clin Orthop Relat Res (274):124
10. Molli RG, Lombardi AV Jr, Berend KR, Adams JB, Sneller MA (2012) A short tapered stem reduces intraoperative complications in primary total hip arthroplasty. Clin Orthop Relat Res 470(2):450
11. Patel RM, Smith MC, Woodward CC, Stulberg SD (2012) Stable fixation of short-stem femoral implants in patients 70 years and older. Clin Orthop Relat Res 470(2):442
12. Hayashi S, Hashimoto S, Kanzaki N, Kuroda R, Kurosaka M (2016) Daily activity and initial bone mineral density are associated with periprosthetic bone mineral density after total hip arthroplasty. Hip Int 26(2):169
13. Hasegawa Y, Iwata H, Mizuno M, Genda E, Sato S, Miura T (1992) The natural course of osteoarthritis of the hip due to subluxation or acetabular dysplasia. Arch Orthop Trauma Surg 111(4):187
14. Gruen TA, McNeilie GM, Amstutz HC (1979) “Modes of failure” of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 141:17
15. Faul F, Erdfelder E, Buchner A, Lang AG (2009) Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods 41(4):1149
16. Hayashi S, Hashimoto S, Kanzaki N, Kuroda R, Kurosaka M (2016) Stem anteversion affects periprosthetic bone mineral density after total hip arthroplasty. Hip Int J Clin Exp Res Hip Pathol Ther 26(3):260
17. Slullitel PA, Mahatma MM, Farzi S, Grammatopoulos G, Wilkins JM, Beaule PE (2020) Influence of femoral component design on proximal femoral bone mass after total hip replacement: a randomized controlled trial. J Bone Jt Surg 103:74
18. Domb B, Hostin E, Mont MA, Hungerford DS (2000) Cortical strut grafting for enigmatic thigh pain following total hip arthroplasty. Orthopedics 23(1):21
19. Lavernia C, D’Apuzzo M, Hernandez VH, Lee DJ (2005) Patient-perceived outcomes in thigh pain after primary arthroplasty of the hip. Clin Orthop Relat Res 441:268
20. Hayashi S, Hashimoto S, Matsumoto T, Takayama K, Niikura T, Kuroda R (2020) Risk factors of thigh pain following total hip arthroplasty with short, tapered-wedge stem. Int Orthop 44(12):2553
21. Froimson MI, Garino J, Machenaud A, Vidalain JP (2007) Minimum 10-year results of a tapered, titanium, hydroxyapatite-coated hip stem: an independent review. J Arthroplasty 22(1):1
22. Nakamura S, Minoda Y, Ohta Y, Sugama R, Yamamura K, Ueyama A, Nakamura H (2019) Preoperative morphology of the proximal femoral canal did not affect the postoperative bone mineral density change around the zweymuller-type stem. Orthopedics 42(5):e449
23. Jacquot L, Bonnin MP, Machenaud A, Chouteau J, Saffarini M, Vidalain J-P (2018) Clinical and radiographic outcomes at 25–30 years of a hip stem fully coated with hydroxylapatite. J Arthroplasty 33(2):482

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