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HIP ARTHROPLASTY

Fully hydroxyapatite-coated compaction broached and triple-tapered stem may reduce the risk of stress shielding after primary total hip arthroplasty

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Abstract

Purpose Changes in bone mineral density (BMD) around the fully hydroxyapatite (HA)-coated compaction broached and triple-tapered stem, namely, Polarstem, after total hip arthroplasty (THA) are currently unknown. Therefore, the aims of this study were to investigate clinical outcomes of Polarstem, mainly postoperative temporal changes in BMD around the stem for 2 years, and to compare them with those of HA-coated and non-HA-coated tapered-wedge stems.

Methods This retrospective cohort study enrolled 100 consecutive patients who underwent THA using Polarstem ($n = 38$), HA-coated Anthology ($n = 31$), and non-HA-coated Anthology ($n = 31$). BMD was evaluated using dual-energy X-ray absorptiometry in seven regions according to the Gruen zones. Postoperatively, BMD around the stem was assessed within 2 months (baseline BMD) and at 6, 12, and 24 months. A change in BMD was defined as the value calculated by dividing each postoperative BMD value at 6, 12, and 24 months by the baseline BMD value. Changes in BMD and radiographic parameters such as stress shielding and spot welds were compared among the three stems.

Results The incidence rate of stress shielding in the Polarstem group was significantly lower than those in the other two groups ($p = 0.007$). The change in BMD in Zone 7 of Polarstem was significantly more than that of the other two groups at 12 and 24 months postoperatively ($p = 0.030$ and $p = 0.009$, respectively).

Conclusion Polarstem, a fully HA-coated compaction broached and triple-tapered stem, maintained BMD around the femoral calcar until 2 years postoperatively and could reduce the risk of stress shielding compared with tapered-wedge stems.

Keywords Total hip arthroplasty · Compaction broached stem · Triple-tapered stem · Bone mineral density

Introduction

Functional outcomes and implant longevity of primary total hip arthroplasty (THA) have significantly improved due to innovations in prosthesis technology and the introduction of new surgical techniques [1]. Although cemented THA is associated with satisfactory outcomes [2, 3], uncemented femoral components are being used more frequently as these components preserve the femoral bone stock and achieve long-term osseointegration [4]. To gain the long-term osseointegration of uncemented implants, either ingrowth or ongrowth of the bone on the surface of the implant is necessary [5].

A fully hydroxyapatite (HA)-coated compaction broached stem is expected to be able to maintain the cancellous bone around the stem and acquire good bone growth [6–9]. Cidambi et al. reported that the revision rate for femoral loosening was significantly lower in a fully HA-coated compaction broached stem than in tapered-wedge stem [6]. Polarstem (Smith & Nephew, Memphis, TN) is one of the fully HA-coated compaction broached stems, which has broaches with compaction teeth anterior/posterior and bone cutting teeth medial/lateral. Furthermore, Polarstem also has a triple-tapered structure, which is expected to enhance fixation, reduce risk of subsidence, and improve loading of the

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proximal femoral neck [10]. This stem has been reported to have excellent long-term postoperative survivorship and satisfactory functional outcomes [10]. It may be due to the achievement of good bone growth around the stem.

Dual-energy X-ray absorptiometry (DEXA) has been reported as an established method of monitoring the bone quality around an implant following THA, which can evaluate bone growth by detecting even small changes in bone mineral density (BMD) around the stem [11]. Thus, DEXA is considered the most reliable method to evaluate femoral remodeling related to implant fixation after THA [12]. Several studies have used this method to assess the postoperative BMD around a tapered-wedge stem following THA [13]. However, to date, very few studies had evaluated postoperative changes in BMD around the fully HA-coated compaction broached and triple-tapered stem, namely, Polarstem, using DEXA; thus, it is currently unclear whether BMD around a triple-tapered stem is higher than that around a tapered-wedge stem.

Therefore, the aims of this study were to investigate clinical outcomes of Polarstem, especially postoperative temporal changes in BMD around the stem within 2 years after THA, and to compare the outcomes with those of the HA-coated and non-HA-coated tapered-wedge stems. It was hypothesized that the fully HA-coated compaction broached and triple-tapered stem would maintain a more periprosthetic BMD compared with the tapered-wedge stem.

Patients and methods

This study retrospectively analyzed consecutive patients who underwent THA with a fully HA-coated compaction broached stem (POLARSTEM; Smith & Nephew, Memphis, TN) between March 2017 and September 2018 (43 hips; Polarstem group). As a comparison group, consecutive patients who underwent THA with a proximally HA-coated tapered-wedge stem (Anthology; Smith & Nephew, Memphis, TN) between May 2015 and May 2016 (33 hips; HA Anthology group) and non-HA-coated tapered-wedge stem (Anthology; Smith & Nephew, Memphis, TN) between July 2013 and March 2015 (34 hips; non-HA Anthology group) were included in the study. In all three groups, the indication for THA was the last stage of osteoarthritis or idiopathic osteonecrosis of the femoral head, which was resistant to conservative treatment.

For patients who underwent bilateral THA (two in the Polarstem group, two in the HA Anthology group, and one in the non-HA Anthology group), data concerning only the first unilateral THA were assessed. When the exclusion criteria were set to anatomical distortion of the proximal femur, osteoporosis (lumbar spine BMD < 0.8), a history of metabolic bone disease or use of related medications, or failure to follow up for 2 years after surgery, a total of 10 hips were excluded, and 100 hips (38 hips, Polarstem group; 31 hips, HA Anthology group; 31 hips, non-HA Anthology group) were finally included in the study. All THA procedures were performed consecutively at the authors' affiliated institutions by a single highly experienced surgeon using the above three stems with a mini-anterolateral supine approach. All patients were allowed full weight-bearing immediately after the surgery. Age at surgery, body mass index (BMI), and gender of the patients were recorded as background data. Further details regarding the implant, other than the stems used in the three groups, are shown in Table 1.

Radiographic and clinical evaluations

Radiographic findings were assessed preoperatively and at 2 years postoperatively. Preoperatively, the proximal femoral shape was classified based on Dorr classification [14]. Postoperatively, the incidence of femoral osteopenia due to

Table 1 Implants used in the three stem groups

	Polarstem	HA Anthology	non-HA Anthology
Acetabular component			
Implant	R3 (Smith and Nephew): all cases	R3 (Smith and Nephew): all cases	R3 (Smith and Nephew): all cases
Size	48 mm:10 cases	48 mm:10 cases	48 mm:11 cases
	50 mm:17 cases	50 mm:12 cases	50 mm:14 cases
	52 mm:8 cases	52 mm:6 cases	52 mm:4 cases
	54 mm:2 cases	54 mm:3 cases	54 mm:1 cases
	56 mm:1 case		56 mm:1 case
Liner and femoral head			
Size	32 mm:25 cases	32 mm:20 cases	32 mm:18 cases
	36 mm:13 cases	36 mm:11 cases	36 mm:13 cases
Combination of materials (liner and femoral head)	XLPE and Oxinium: all cases	XLPE and Oxinium: all cases	XLPE and Oxinium: all cases

stress shielding was assessed based on the system described by Engh et al. [15]. Incidence rates of cortical hypertrophy, reactive line, and spot welds [16] were also evaluated. The angle between a line which was drawn along the major axis of the stem and a line passing through the middle points of the distance between the surfaces of the endo-cortex of two different points was measured as the stem alignment angle. Varus and valgus were distinguished by the deviation of the stem axis with respect to the femoral axis, and valgus alignments were defined as positive. Harris hip score (HSS) [17] was investigated preoperatively and 2 years after THA. The presence or absence of complications such as dislocation and infection and the need for revision surgery were evaluated.

The above radiographic and clinical outcomes were compared among the three groups, including the Polarstem group, HA Anthology group, and non-HA Anthology group.

DEXA measurements

In all cases, the DEXA measurements were performed in accordance with previous reports [18].

DEXA was performed using a DPX-L scanner (GE Lunar Corporation, Madison, WI, USA). The whole-body scans were performed using software version 1.35, and the appropriate transverse speed was set to 16, 8, or 4 cm/s depending on the subject's height. Patients were positioned supine, at the neutral positions of the legs with knees and feet supported, to facilitate scanning of the anterior–posterior projection of the proximal femur, including the distal part of the stem using an edge-detection technique.

BMD was determined perioperatively in seven regions according to the Gruen zones [19]. The values were expressed as a real BMD in g/cm^2. Postoperatively, BMD around the stem was assessed within 2 months (baseline BMD) and at 6, 12, and 24 months. A change in BMD was defined as the value calculated by dividing each BMD value at 6, 12, and 24 months postoperatively by the baseline BMD value, and these changes were compared among the three groups.

Statistical analysis

All values are reported as mean ± standard deviation. Results were analyzed using EZR (Saitama Medical Center, Jichi Medical University), a graphical user interface for R (R Foundation for Statistical Computing) [20].

Intra-observer and inter-observer reliabilities were calculated to examine the reproducibility of all radiographic measurements using Cohen's kappa coefficient test and an intraclass correlation coefficient (ICC) test using a subset of 30 cases. For the assessment of intra-observer reliability, the measurements were performed twice at 6-week intervals by one author (Y.K.). For the assessment of inter-observer reliability, the measurements were assigned to two surgeons (Y.K. and N.N.). All measurements were carried out by orthopedic surgeons with over 10 years of experience. The kappa coefficients and ICC for intra- and inter-observer reliabilities were all > 0.8 (range, 0.83–0.94) for all measurements (Table 2). Due to the high reliability observed, the measurements obtained by the initial observer (Y.K.) were used for all analyses. The examiners that conducted the analysis were blinded to all information on clinical outcomes.

One-way analysis of variance (ANOVA), followed by the Bonferroni post hoc test, was performed to compare changes in BMD over time in the Polarstem group. Comparisons among the three groups were performed using the one-way ANOVA, followed by the Tukey–Kramer post hoc test, to identify the greater differences among the mean values. Fisher's exact test was adopted in the intergroup comparisons of count data.

Post hoc power analysis was performed using G*Power 3 version 3.121 [21]. With a sample size of 100 and a type-I error (α) of 0.05 (one-way ANOVA), the study provided a power ($1-\beta$) of 0.95 for detecting large effect sizes (0.4). A probability value (p) less than 0.05 was considered statistically significant.

Results

There was no significant difference in background characteristics of the patients, including age, gender, and BMI among the three groups (Table 3). No significant difference in operative time was observed among the three groups: 77.3 ± 12.0 (55–118) min in the Polarstem group; 81.2 ± 12.4 (60–112) min in the HA Anthology group; and 81.7 ± 13.4 (59–109) min in the non-HA Anthology group ($p=0.279$). In the radiographic evaluation, no significant difference in the distribution of Dorr types among the three groups was observed. The incidence rate of stress shielding in the Polarstem group was significantly lower than those in the other two groups ($p=0.007$) (Table 4). The other radiographic parameters and HHS were not significantly different among the three groups. There were no complications during follow-up in all groups.

Table 2 Kappa coefficients for intra- and inter-observer reliabilities of measurements

Variable	Intra-observer	Inter-observer
Dorr classification	0.94	0.83
Stress shielding	0.93	0.85
Cortical hypertrophy	0.87	0.89
Reactive line	0.92	0.84
Spot welds	0.86	0.86
Stem alignment angle	0.94	0.90

Regarding the temporal change in BMD around Polarstem, the change in BMD in Zone 1 at 24 months postoperatively was significantly less than those at 6 and 12 months ($p < 0.001$ and $p = 0.008$, respectively). On the contrary, the change in BMD in Zone 4 at 24 months postoperatively was significantly more than those at 6 and 12 months ($p < 0.001$ and $p = 0.013$, respectively) (Fig. 1).

Table 3 Comparison of patient background characteristics among the three stems

	Polarstem	HA Anthology	non-HA Anthology	*p* value
Number of patients	38	31	31	
Age	67.8 ± 12.5	63.4 ± 10.9	68.5 ± 11.3	0.169
Gender: female ratio	33/38 (86.8%)	27/31 (77.4%)	29/31(93.5%)	0.722
BMI	22.7 ± 2.8	23.2 ± 3.6	24.4 ± 4.1	0.124

The data are expressed as mean ± SD values

BMI body mass index

Table 4 Comparison of radiographic and clinical outcomes among the three stems

	Polarstem	HA Anthology	non-HA Anthology	*p* value
Dorr classification	A:8 B:23 C:7	A:3 B:25 C:3	A:4 B:20 C:7	0.393
Stress shielding	10/38 (26.3%)	17/31 (54.8%)	19/31 (61.3%)	0.007*
Cortical hypertrophy	3/38 (7.9%)	5/31 (16.1%)	4/31 (12.9%)	0.635
Reactive line	2/38 (5.3%)	5/31 (16.1%)	6/31 (19.4%)	0.164
Spot welds	10/38 (26.3%)	5/31 (16.1%)	6/31 (19.4%)	0.614
Stem alignment angle	0.9 ± 1.4	0.8 ± 1.3	0.8 ± 1.7	0.974
Preoperative HHS	47.9 ± 12.4	50.5 ± 12.6	51.5 ± 11.8	0.689
Postoperative HHS	92.5 ± 7.6	91.3 ± 9.2	89.6 ± 9.7	0.404

HHS Harris hip score

*$p < 0.05$, by Fisher's exact test for count data

The data are expressed as mean ± SD values

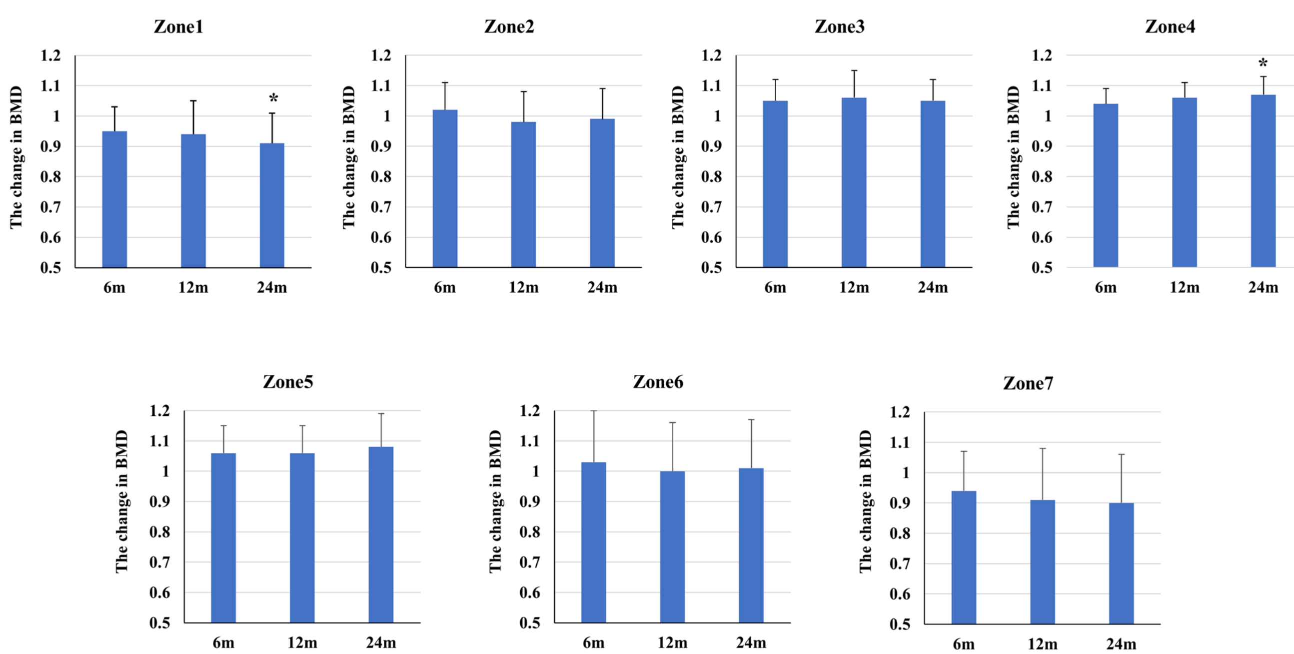

Fig. 1 Change in bone mineral density (%) at 6, 12, and 24 months in comparison with less 2 months postoperatively based on seven Gruen's zones. Columns represent mean ± S.D values. *$p < 0.05$, compared with 6 and 12 months postoperatively by Bonferroni post hoc test

In a comparison between the three stems, the change in BMD in Zone 7 in the Polarstem group was significantly more than those in the other two groups at 12 and 24 months after surgery ($p = 0.030$ and $p = 0.009$, respectively) (Table 5).

Discussion

The most important finding of the present study was that Polarstem had significantly more changes in BMD in Zone 7 compared with tapered-wedge stems with and without HA-coating at 12 and 24 months after THA. This suggests that Polarstem may prevent stress shielding and is consistent with the results of radiographic evaluations, which showed that the incidence of stress shielding was significantly lower with the Polarstem than with the other two stems at 24 months after surgery.

For Zone 1, all three stems showed a decrease in BMD over time, consistent with the results of previous studies on tapered-wedge stem and compaction broached stem [22–24]. However, in the present study, the change in BMD in Zone 1 of Polarstem tended to be more than that of the tapered-wedge stem at 24 months postoperatively, suggesting that BMD was relatively well-maintained by Polarstem. Furthermore, Polarstem showed an increase in BMD distal to the stem, mainly in Zone 4. This trend was also observed with the tapered-wedge stem, consistent with the results of previous studies [13, 23].

A recent randomized controlled trial reported that the Corail stem, a representative compaction broached stem, showed less loss in BMD compared with a tapered-wedge stem over a 24-month period. This effect was most prominent in the regions of the femoral calcar and greater trochanter [24]. Similarly, in the present study, Polarstem revealed significantly higher BMD around femoral calcar (Zone 7) compared with tapered-wedge stems. However, in the greater trochanter area (Zone 1), BMD decreased significantly at 24 months postoperatively. The broach of Polarstem is a hybrid broach of compaction with anterior–posterior (AP) aspect and cutting with medial–lateral (ML) aspect. The ML-cutting broach may cause the loss of BMD in Zone 1 during femoral canal preparation.

Furthermore, Polarstem is a triple-tapered stem, which contains a third taper from the wide lateral to the narrow medial plane in addition to the tapers in the AP and ML planes. The third taper is designed to improve loading at the proximal femoral neck, thus preserving bone quality and avoiding stress shielding [13, 25]. Hayashi et al. reported that triple-tapered stem showed a high maintenance rate of BMD around the stem. Conversely, they also reported relatively low maintenance of BMD in Zone 7 [13]. In the present study, Zone 7 around Polarstem maintained BMD significantly better than tapered-wedge stems, suggesting that the preservation of cancellous bone by compaction broaching in addition to the triple-tapered structure might have contributed to the prevention of further stress shielding.

The effect of HA-coating on the fixation of a cementless femoral stem is controversial. Delaunay et al. demonstrated that HA-coating significantly improved the radiographic results of the proximal bone–implant interface consisting of Zone 1 and Zone 7 [26]. On the contrary, in a meta-analysis including 792 hips, Li et al. showed that the use of HA-coated femoral stems in primary THA had no significant beneficial effects on radiographical parameters such as spot welds and radioactive line [27]. In the present study,

Table 5 Comparison of changes in BMD among the three stems at 6, 12, and 24 months postoperatively

	Polarstem	HA Anthology	Non-HA Anthology	*p* value
Zone 1				
6 m	0.95 ± 0.08	0.92 ± 0.24	0.92 ± 0.07	0.612
12 m	0.94 ± 0.11	0.89 ± 0.28	0.91 ± 0.07	0.545
24 m	0.91 ± 0.10	0.84 ± 0.15	0.90 ± 0.08	0.07
Zone 2				
6 m	1.02 ± 0.09	1.04 ± 0.26	1.00 ± 0.09	0.627
12 m	0.98 ± 0.09	1.01 ± 0.29	0.98 ± 0.12	0.827
24 m	0.99 ± 0.11	1.03 ± 0.31	0.98 ± 0.14	0.588
Zone 3				
6 m	1.05 ± 0.07	1.02 ± 0.06	1.03 ± 0.08	0.134
12 m	1.06 ± 0.09	1.02 ± 0.09	1.04 ± 0.09	0.379
24 m	1.05 ± 0.07	1.03 ± 0.09	1.06 ± 0.10	0.519
Zone 4				
6 m	1.04 ± 0.05	1.03 ± 0.04	1.01 ± 0.06[a]	0.049*
12 m	1.06 ± 0.05	1.05 ± 0.06	1.04 ± 0.08	0.558
24 m	1.07 ± 0.06	1.06 ± 0.07	1.04 ± 0.09	0.293
Zone 5				
6 m	1.06 ± 0.09	1.01 ± 0.13	1.02 ± 0.05	0.080
12 m	1.06 ± 0.09	1.06 ± 0.10	1.03 ± 0.09	0.288
24 m	1.08 ± 0.11	1.08 ± 0.10	1.05 ± 0.09	0.477
Zone 6				
6 m	1.03 ± 0.17	1.02 ± 0.11	1.01 ± 0.10	0.824
12 m	1.00 ± 0.16	1.01 ± 0.09	0.99 ± 0.15	0.933
24 m	1.01 ± 0.16	0.98 ± 0.12	1.00 ± 0.12	0.764
Zone 7				
6 m	0.94 ± 0.13	0.88 ± 0.16	0.89 ± 0.14	0.248
12 m	0.91 ± 0.17[b]	0.82 ± 0.13	0.84 ± 0.12	0.030*
24 m	0.90 ± 0.16[b]	0.77 ± 0.20	0.78 ± 0.17	0.009*

The data are expressed as mean ± SD values

*$p < 0.05$ by one-way ANOVA test

[a] $p < 0.05$, compared with Polarstem and HA Anthology by Tukey–Kramer post hoc test

[b] $p < 0.05$, compared with HA Anthology and non-HA Anthology by Tukey–Kramer post hoc test

HA-coated tapered-wedge stems did not show a significant difference in changes in BMD compared with non-HA-coated tapered-wedge stems, indicating that HA-coating on tapered-wedge stem alone did not enhance bone ingrowth into the prosthesis. In contrast, fully HA-coated compaction broached stems have an abundant cancellous bone, which may enhance the effects of HA-coating and contribute to the maintenance of BMD.

For Polarstem, the proximal diameter is slightly wider and the stem length is shorter than those of the other common tapered designs. These design features are expected to further enhance the proximal loading and reduce distal mechanical load bearing [28]. Willburger et al. reported a survival rate of 99.6% in the mid-term at 5 years [28], and Cypres et al. reported a survival rate of 99.1% in the long term at 10 years [10], thus showing high tolerability of Polarstem. The reduction in stress shielding, which was demonstrated in the present study, might be one of the reasons for this excellent survival rate.

There are several limitations to this study. First, since the follow-up period of this study was only 2 years, long-term changes in BMD could not be evaluated. Second, the number of subjects in the present study was relatively small. Therefore, further study with a longer follow-up period and larger sample size should be performed. Third, this was a retrospective study, which included a comparison of consecutive patients at different times and was not a randomized controlled trial. A randomized controlled trial is preferable to reduce the patient selection bias. However, we had changed the use of uncemented stem type over time, and the surgical indication and patient selection criteria for the use of all three stems were almost the same. Fourth, the learning curve of the surgeons between 2013 and 2018 may have been affected. However, the surgeons already had more than 10 years of experience in THA as at 2013, and there was no significant difference in the aforementioned operative time. Therefore, we believe that there was little difference in surgical skills between the three groups. Finally, the placement of the acetabular component, pelvic tilt, and leg length discrepancy may have also affected the BMD around the stem. Thus, it is necessary to evaluate how these factors relate to the BMD in the future.

Conclusions

Polarstem, a fully HA-coated compaction broached and triple-tapered stem, maintained BMD around the femoral calcar until 2 years postoperatively and could reduce the risk of stress shielding compared with tapered-wedge stems. Regarding clinical relevance, the findings of this study may play a role in supporting the favorable survival rates with the use of Polarstem.

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Declarations

Conflict of interest The authors have no competing interests to declare.

Ethical approval Our hospital's ethics committee approved the protocol of this study.

Informed consent All subjects in this study were informed of the study protocol and written informed consent to participate and publish was obtained.

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