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Rectangular tapered short stem excellently preserves proximal bone mineral density preservation than tapered wedge short stem

K. ANJIKI[1,2], S. HAYASHI[1], T. FUJISHIRO[2], T. HIRANAKA[2], R. KURODA[1], T. MATSUMOTO[1]

[1]*Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, Kobe, Japan;* [2]*Department of Orthopaedic Surgery and Joint Surgery Centre, Takatsuki General Hospital, Osaka, Japan.*

Correspondence at: Shinya Hayashi, Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, Kobe, Japan, 7-5-1 Kusunoki-cho, Chuo-ku, Kobe, 650-0017, Japan, Tel.: 81-78-382-5985, Fax: 81-78-351-6944, E-mail: shayashi@med.kobe-u.ac.jp

Fitmore stem is a rectangular, tapered, short, cementless stem. A characteristic feature of this stem is that it provides rotational stability due to the high medullary occupancy achieved by its rectangular cross-section and thick antero-posterior width. We aimed to investigate the differences in periprosthetic bone remodelling between a rectangular-tapered short stem and a short tapered-wedge stem. Eighty patients who underwent primary total hip arthroplasty using a rectangular-tapered short stem (Fitmore) or a short tapered-wedge stem (Tri-Lock BPS) were enrolled in this study. Bone mineral densities (BMDs) in the seven Gruen zones were evaluated using dual-energy X-ray absorptiometry at baseline, and at 6 and 24 months postoperatively. Peri-prosthetic BMD and clinical factors were assessed and compared. In addition, correlations between periprosthetic BMD changes and stem anteversion error were analyzed using Pearson's correlation coefficient in the two groups. A significantly better postoperative periprosthetic BMD change was found in zones 1 and 7 in the rectangular-tapered group. Additionally, no significant correlation was observed between stem anteversion error and periprosthetic BMD changes in the rectangular-tapered groups. However, in the tapered-wedge group, there were significant negative correlations between the stem anteversion error and BMD changes at 6 months and 24 months in zones 1 and 7. In the rectangular-tapered group, a significantly better postoperative periprosthetic BMD change was found particularly in the region proximal to the stem. Rectangular-tapered short stem can be more resistant to rotation due to higher medullary occupancy and may lead to better periprosthetic BMD than the tapered-wedge short stem, especially in the proximal region of the stem.

Key words: total hip arthroplasty, cementless tha, fitmore, bone mineral density.

INTRODUCTION

Total hip arthroplasty (THA) is an effective surgical procedure for treatment of end-stage hip osteoarthritis, osteonecrosis, and rheumatoid arthritis and can effectively improve function and reduce pain[1]. Cementless fixation is a standard fixation method and has been reported to have excellent midterm results[2,3]. Furthermore, cementless short-stem total hip arthroplasty can preserve femoral bone stock, address stress shielding effects, and provide a greater physiological load transfer than traditional THA, and its use has been on the rise in recent years[4,5].

Proper load transfer of implants is also important for long-term results, as irregular load patterns cause abnormal stress shields and bone remodeling, leading to decreased periprosthetic bone mineral density (BMD)[6]. Periprosthetic BMD reduction causes aseptic loosening, migration of prosthesis, and periprosthetic fractures[7,8]. Another report demonstrated that periprosthetic BMD may lead to loosening of the implants and poor clinical outcomes[9], therefore, implants must aim to reproduce physiological stress distribution[10]. The dual-energy X-ray absorption assay (DEXA) is a well-established method for monitoring patients after THA[11]. DEXA can detect small changes in BMD around a stem[12,13], therefore, it is considered as the most reliable method of assessing periprosthetic bone stress shielding and proximal femur remodeling after THA[14].

In recent years, various types of cementless short stems have been introduced; however, little is known about bone remodeling and periprosthetic BMD associated with them. Several studies have reported that cementless short stems might reduce periprosthetic bone loss in the proximal femur compared with that associated with traditional THA[15,16]. Furthermore, concerning the effect of cementless stem alignment to periprosthetic BMD, several studies have reported

(a) (b)

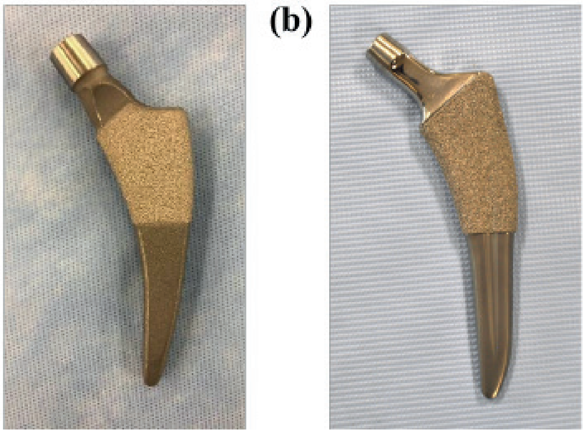

Fig. 1 — Photographs of (a) the rectangular-tapered short stem (Fitmore) and (b) the short tapered-wedge stem (Tri-Lock BPS).

that cementless stem alignment affects periprosthetic BMD[17,18]. Among them, a few have reported that stem anteversion error affects the periprosthetic BMD change proximal to the tapered-wedge stem[18,19].

Fitmore stem (Zimmer Biomet Inc., Warsaw, IN, USA) (Fig. 1a) is a curved, short, triple-tapered, cementless stem prosthesis with a rectangular cross-section and metaphyseal anchoring, whose diaphyseal fixation and load transfer simulate the physiological conditions and enable metaphyseal fitting. The rotational stability due to the high medullary occupancy achieved by the rectangular cross-section and thick antero-posterior width is one of the major features of this stem. Several studies have reported good short- and mid-term results using Fitmore stem[20-22] and better periprosthetic BMD than that associated with other short stems in patients who underwent THA with Fitmore stem[23,24]. However, there are no reports concerning the effect of stem alignment on BMD around the prosthesis when using Fitmore stem.

In this study, we compared the periprosthetic BMD between patients who underwent THA with rectangular-tapered stem and those who underwent THA with tapered-wedge stem (Tri-Lock BPS; DePuy Orthopaedics, Warsaw, IN, USA) (Fig. 1b), with small shoulder shape and small anterior-posterior width, and the effect of stem anteversion error on the periprosthetic BMDs. We hypothesized that periprosthetic BMD is well preserved and less susceptible to stem anteversion error in patients with rectangular tapered stem.

MATERIALS AND METHODS

This present study was approved by the institutional review board, and patients provided informed consent for participation in this study. This retrospective cohort study enrolled 80 consecutive patients with osteoarthritis or osteonecrosis of the hip who underwent primary THA using the rectangular-tapered short stem (Fitmore: 40 joints; rectangular-tapered group) or the short tapered-wedge stem (Tri-Lock: 40 joints; tapered-wedge group) at two institutions from 2013 to 2016. Patients with a distorted anatomy of the proximal femur, osteoporosis (lumbar spine BMD <0.8), metabolic bone disease, rheumatoid arthritis, Dorr classification type C, and bilateral THA were excluded. A senior surgeon (T.F.) performed all surgeries using the anterolateral supine approach. Patient background data including mean age, body mass index, and the Harris hip score (HHS) were collected (**Table** I). Postoperative radiographic findings and clinical factors, including HHS, were assessed 24 months postoperatively.

According to previous studies[18,19] the DEXA scan was performed using the DPX-L scanner (GE Lunar, Madison, WI). Periprosthetic BMD was measured using the same equipment and settings in the two institutions. Patients were placed in supine position with patella in the front. This allowed the edge detection algorithm to scan the anterior-posterior projection of the proximal femur, including the distal region of the prosthesis. The scanner was equipped with a software for bone

Table I. — Patient characteristics

Characteristic	Rectangular curved	Tapered wedge	P-value
Number of cases	40	40	
Sex, female/male	35/5	34/6	1
Diagnosis, OA/ON	38/2	36/4	0.675
Age, years	64.7±9.1	65.1±10.8	0.875
Height, cm	154.1±6.3	155.4±8.8	0.42
Weight, kg	56.7±9.2	57.4±11.7	0.832
Body mass index, kg/m^2	23.9±3.5	23.7±4.0	0.783
HHS, points	58.0±13.5	59.2±14.3	0.678

OA, osteoarthritis; ON, osteonecrosis; HHS, Harris hip score. Data are given as mean ± standard deviation.

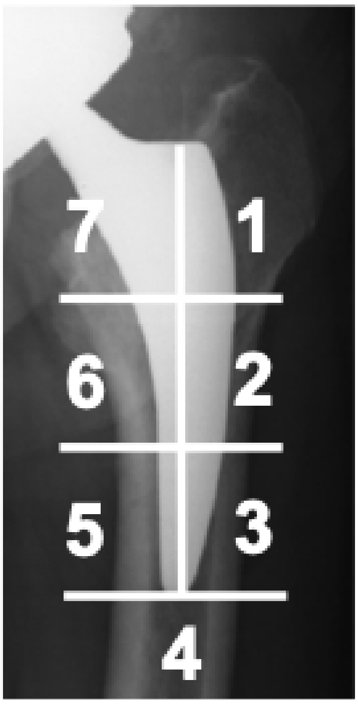

Fig. 2 — Scheme of the seven Gruen zones.

mineral measurement around the femoral prostheses. The software detected the interface between the bone part and the stem as the density change. BMD was measured in seven areas of interest based on the Gruen zones[25] at 2 months (baseline) and at 6 and 24 months postoperatively (Fig. 2). BMD changes were calculated by dividing each BMD value at 6 and 24 months postoperatively by the baseline value. The values were expressed as area BMD in g/cm^2.

Preoperative and postoperative computed tomography (CT) from the pelvis to the knee joint was performed and images were transferred to a three-dimensional template software (Zed Hip; Lexi, Tokyo, Japan). Computer-aided design models of the implants were manually adjusted for postoperative multiplanar reconstruction in CT images. Stem anteversion and anatomical canal anteversion angles were measured with respect to the posterior condylar axis of the femur[26]. The anatomical canal anteversion and postoperative stem anteversion were compared, and the anteversion error was defined as the difference between the two values[19].

To determine the intra- and inter-observer reliabilities of the radiographic measurements, all measurements were performed twice by one surgeon (K.A.) and once by another surgeon (S.H.). The correlation coefficients for the intra- and inter-observer reliability were >0.80 (range, 0.82-0.96) for all measurements.

All values are presented as the mean ± standard deviation (SD). A statistical software package (EZR, Saitama Medical Center, Jichi Medical University, Saitama, Japan) was employed to analyze the results[27] .

Unpaired t-test was performed to compare parameters between the two groups, and qualitative variables were compared using Fisher's exact test. Sequential changes in BMDs at each area were analyzed with repeated measures analysis of variance. The correlations between periprosthetic BMD changes and stem anteversion

Table II. — Periprosthetic BMD changes in each Gruen zone at each follow-up point in the two groups

		Rectangular tapered	Tapered wedge	P-value	Hedges'g	95%CI
Zone 1	6 months	1.00±0.07	0.93±0.09	<0.001*	0.86	0.41, 1.32
	24 months	0.98±0.11	0.91±0.12	0.015*	0.60	0.16, 1.05
Zone 2	6 months	1.07±0.10	0.97±0.08	<0.001*	1.09	0.63, 1.57
	24 months	1.04±0.14	0.99±0.08	0.118	0.43	-0.01, 0.88
Zone 3	6 months	1.04±0.06	1.01±0.07	0.013*	0.46	0.01, 0.90
	24 months	1.06±0.08	1.03±0.08	0.218	0.37	-0.07, 0.82
Zone 4	6 months	1.01±0.05	0.99±0.05	0.11	0.40	-0.04, 0.84
	24 months	1.03±0.07	1.00±0.05	0.149	0.49	0.05, 0.94
Zone 5	6 months	1.03±0.09	1.00±0.07	0.051	0.37	-0.07, 0.81
	24 months	1.09±0.11	1.05±0.12	0.233	0.34	-0.10, 0.79
Zone 6	6 months	1.01±0.13	0.97±0.09	0.066	0.35	-0.09, 0.80
	24 months	1.05±0.18	0.99±0.13	0.225	0.38	-0.06, 0.82
Zone 7	6 months	1.02±0.11	0.86±0.16	<0.001*	1.15	0.69, 1.64
	24 months	0.97±0.17	0.84±0.17	0.003*	0.76	0.31, 1.22

Data are given as mean ± standard deviation. * Statistically signifcant diference between rectangular tapered and tapered wedge groups (p<0.05).

Table III. — Results of anatomical canal anteversion and postoperative stem anteversion

	Rectangular tapered	Tapered wedge	P-value
Stem Anteversion, °	25.7 ±13.5	26.7 ±13.4	0.757
Anatomical canal anteversion, °	27.0 ±13.5	27.1 ±13.2	0.972
Absolute anteversion error, °	6.1 ±5.1	6.8 ±5.2	0.533
Data are given as mean ± standard deviation.			

Table IV. — Correlation between stem anteversion error and periprosthetic BMD changes in the two groups

		Rectangular curved			Tapered wedge		
		R	95%CI	P-value	R	95%CI	P-value
Zone 1	6 months	0.111	-0.208, 0.409	0.495	-0.486	-0.695, -0.201	0.002*
	24 months	-0.161	-0.45, 0.159	0.322	-0.431	-0.665, -0.119	0.009*
Zone 7	6 months	0.105	-0.214, 0.403	0.52	-0.352	-0.601, -0.041	0.028*
	24 months	-0.004	-0.315, 0.308	0.983	-0.463	-0.687, -0.158	0.005*

Data are given as mean ± standard deviation. CI, confidence interval. * Statistically significant negative correlations were found between the stem anteversion error and the BMD changes at 6 and 24 months of zones 1 and 7, in the tapered-wedge group ($p<0.05$).

were analyzed using Pearson's correlation coefficient. In all cases, p values <0.05 were considered significant.

With a sample of 70 patients (35 patients per group), the study would have a power (1-β) of 0.95 to detect an effect size of 0.8, with a type I error (α) of 0.05 (unpaired t-test) with respect to the endpoint of BMD changes, respectively. For the unpaired t-test, we calculated the effect size by means and SDs based on Hedges' g for each parameter and the 95% confidence interval (CI) for effect sizes *(28)*.

RESULTS

No significant differences were found between patient background data including, sex, diagnosis, mean age, height, weight, body mass index, and the HHS (Table I).

Table II presents BMD changes in each Gruen zone at each postoperative follow-up time point in the two groups. In the proximal part of the stem, in zones 1 and 7, the BMD changes at 6 and 24 months in the rectangular-tapered group were significantly superior to those in the tapered-wedge group (zone 1: 6 months, p<0.001; 24 months, p=0.015; zone 7: 6 months, p<0.001; 24 months, p=0.003). Furthermore, in zones 2 and 3, the BMD changes at 6 months were significantly superior in the rectangular-tapered group (zone 2: 6 months, p<0.001, zone 3: 6 months, p=0.013). In other Gruen zones, no significant difference was found in the BMD changes between the two groups. We compared the periprosthetic BMD between the two institutions to avoid bias of institutional difference. There was no significant difference in periprosthetic BMD in the Fitmore and Tri-Lock stems at the two institutions (Supplemental Data).

Table III presents a summary of the stem anteversion in the two groups. The postoperative stem anteversion, a canal anteversion, and the absolute anteversion error were not significantly different between the two groups.

Table IV presents the correlation between the stem anteversion error and the periprosthetic BMD changes in the two groups. No significant correlation was observed between the stem anteversion error and periprosthetic BMD changes in the rectangular-tapered group. However, in the tapered-wedge group, significantly negative correlations were found between the stem anteversion error and the BMD changes at 6 and 24 months in zones 1 and 7, proximal to the stem (zone 1: 6 months, R=-0.486, 95% CI: -0.695, -0.201; p=0.002; zone 7: 6 months, R=-0.352, 95% CI: -0.601, -0.041; p=0.028; zone 1: 24 months, R=-0.431; 95% CI: -0.665, -0.119; p=0.009; zone 7: 24 months, R=-0.463; 95% CI: -0.687, -0.158; p=0.005) (Figs. 3 and 4).

No revision surgeries were performed as of the latest follow-up visit in both the groups. Neither group had postoperative complications, such as infection, periprosthetic fracture, or nerve and vascular injury. The HHS at 24 months postoperatively was not significantly different between the two groups (rectangular-tapered group, 90.3±9.4 points; tapered-wedge group, 88.8±9.3 points; p=0.484).

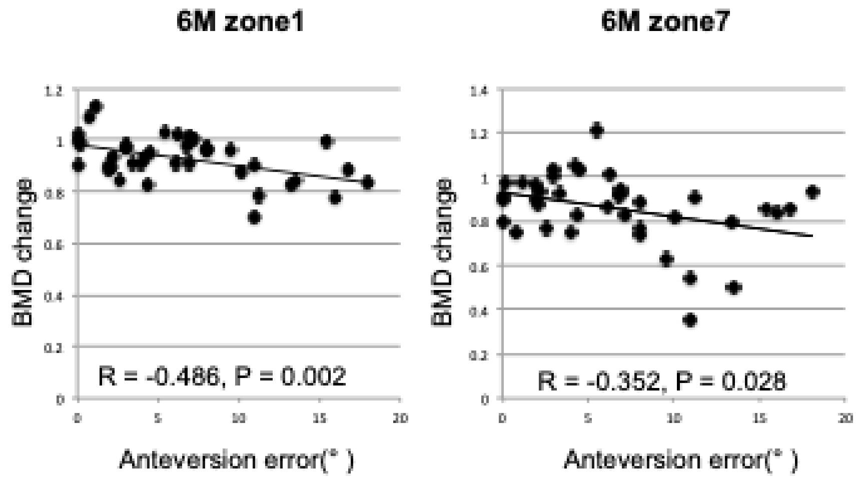

Fig. 3 — Correlation between the stem anteversion error and periprosthetic BMD changes at 6 months postoperatively in the tapered-wedge group. A significant negative correlation was observed between stem anteversion error and periprosthetic BMD changes (zone 1: R = -0.486; 95% CI: -0.695, -0.201; p = 0.002; zone 7: R = -0.352; 95% CI: -0.601, -0.041; p = 0.028).
BMD, bone mineral density; CI, confidence interval; p < 0.05 = statistical significance.

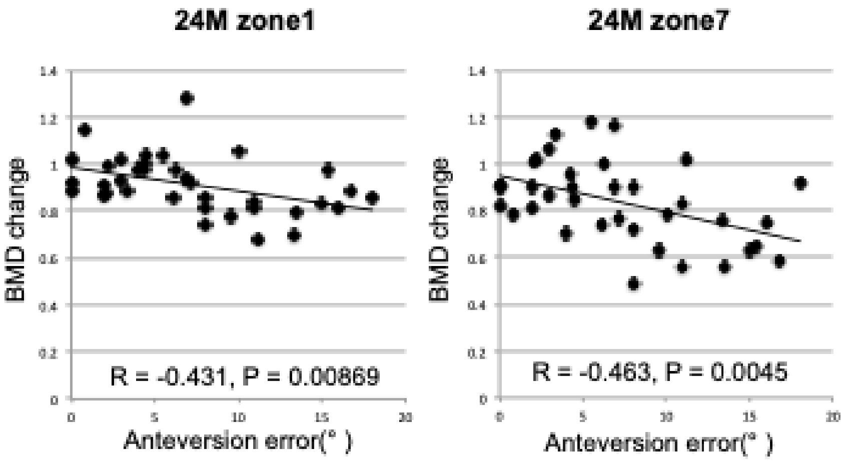

Fig. 4 — Correlation between the stem anteversion error and periprosthetic BMD changes at 24 months postoperatively in the tapered-wedge group. A significant negative correlation was observed between the stem anteversion error and periprosthetic BMD changes (zone 1: R = -0.431; 95% CI: -0.665, -0.119; p = 0.009; zone 7: R = -0.463; 95% CI: -0.687, -0.158; p = 0.005).
BMD, bone mineral density; CI, confidence interval; p < 0.05 = statistical significance.

DISCUSSION

The most important finding in this study was that a significantly better postoperative periprosthetic BMD change, particularly in the proximal region of the stem, was found in the rectangular-tapered group than in the tapered-wedge group. In addition, no significant negative effects pertaining to stem malalignment were observed in the periprosthetic BMD after THA with the rectangular-tapered stem. This indicates that the stem design of a rectangular-tapered stem with its inherent rotational resistance is beneficial for the preservation of periprosthetic BMD. To the best of our knowledge, this is the first study to report the effect of stem alignment on periprosthetic BMD after THA using rectangular-tapered stem.

Fitmore prostheses allowed for reduced stress shielding and comparable primary stability when compared with established short stems and traditional shaft-designed stems in a human cadaver study[29]. Regarding the periprosthetic BMD, Freitag et al.[21] reported that the periprosthetic BMD increased in zone 3 one year after THA, based on DEXA measurements 1 week after surgery, when Fitmore stem was used

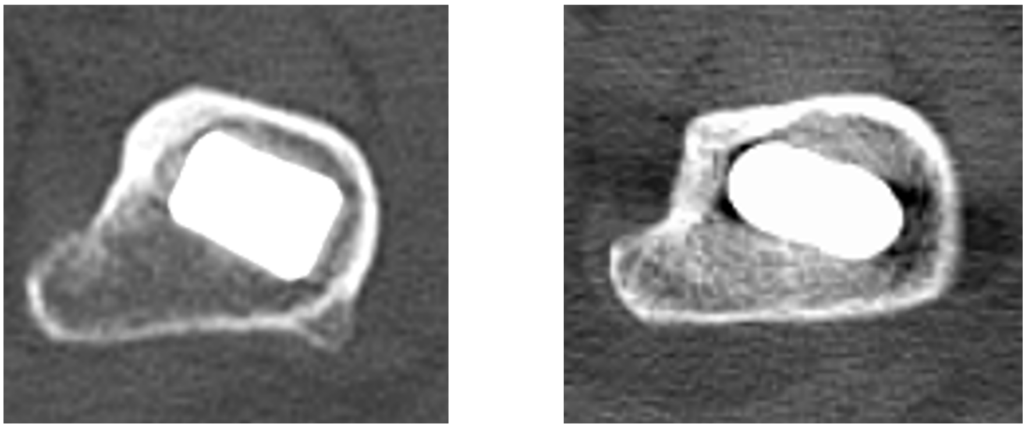

Fig. 5. — Computer tomography axial plane of (a) the rectangular-tapered short stem (Fitmore) and (b) the short tapered-wedge stem (Tri-Lock BPS). The rectangular-tapered short stem is fixed at the metaphysis given its rectangular structure and thick anterior–posterior width.

in 57 cases, and decreased in the other zones, with the largest decrease rate in zone 7. Gasbarra et al.[20] compared the Fitmore stem with the Trabecular Metal Primary Stem (Zimmer, Inc; Warsaw, IN) and reported that periprosthetic BMD was significantly preserved in zones 1, 3, and 7 in patients with Fitmore stem. In addition, Yan et al.[23], in a review of cementless THA, reported that periprosthetic BMD in zones 1 and 7 decreased slightly in cases with Fitmore stem compared with those with other short stems. They also reported that the BMDs in other Gruen zones tended to increase. Similarly, we observed a slight decrease in periprosthetic BMD in Gruen zones 1 and 7; however, the other zones revealed increased periprosthetic BMD at 2 years after surgery. Our study confirmed that the rectangular-tapered stem preserved better periprosthetic BMD than tapered-wedge stem did, especially in the proximal region of the stem, 6 months postoperatively, and was maintained up to 2 years after the operation.

Previous studies on short-tapered-wedge stem have demonstrated that a mismatch between stem anteversion and anatomical canal anteversion causes stem point contact with the cortical bone in the distal portion and affects proximal periprosthetic BMD loss[18,19] Similarly in this study, the tapered-wedge group showed a significant decrease in proximal bone density with increasing anteversion error. Conversely, in the rectangular-tapered group, there was no significant stem anteversion and, hence, no significant effect on the periprosthetic BMD. This is probably due to the difference in the stem design. Fitmore stem is a curved short stem that has a rectangular structure and thick antero-posterior width of a metaphyseal filling stem, such as the Zwey Muller type, and can be expected to be fixed in the proximal femoral cavity and provide rotational stability (Fig. 5). Effenberger et al.[30] compared a metaphyseal filling stem (Zwey Muller SL) and another cementless stem (Schenker SK). They concluded that the metaphyseal filling stem was proximally broader and therefore proved to have better rotational stability; furthermore, metaphyseal filling stem had significantly superior 10-year survival rate. Furthermore, Kim et al.[31] reported that metaphyseal fitting stem, which was particularly characterized by metaphyseal fixation, was associated with predominantly proximal load transfer and excellent periprosthetic BMD preservation in the proximal region of the stem. These reports indicated that the Fitmore stem, which is a metaphyseal filling stem, has high rotational stability due to its higher medullary occupancy proximal to the stem and can be expected to be associated with proximal mechanical loading; thus they preserve periprosthetic BMD better than tapered-wedge short stems.

This study has some limitations. First, this study lacked direct evidence of periprosthetic bone stress distribution after THA. Therefore, we must analyze the simulation of stress distribution in the periprosthetic bone. Second, the clinical outcomes and postoperative complications were assessed only till 2 years postoperatively. Therefore, a long-term follow-up should be performed to determine clinical outcomes such as implant survival. Third, this study is a single surgeon series leading to surgeon bias. Therefore, we need to confirm the results through studies involving procedures performed by multiple surgeons in the future.

CONCLUSION

A significantly better postoperative periprosthetic BMD change was found, particularly in zones 1 and 7, which are proximal to the stem, in the rectangular-tapered group. Fitmore stem can be expected to be more resistant to rotation than a tapered-wedge short stem. Further, this resistance might lead to better periprosthetic BMD especially in the proximal region of the stem.

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