acta orthopaedica belgica, 2025, 91, 15-22

doi.org/10.52628/91.1.8614

Comparing femoral bone remodeling after total hip arthroplasty using collarless POLARSTEM◊ for different Dorr types

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Using bone-cemented stems is recommended for femurs with severe osteoporosis and a large medullary cavity. This study aimed to evaluate postoperative bone changes around a collarless POLARSTEM◊ using simple X-ray images and the bone mineral density and compare them according to the medullary cavity geometry. The data used in this study consisted of 50 patients (54 joints in total) who underwent total hip arthroplasty with POLARSTEM◊ (Dorr type A: 19 joints, Dorr type B: 19 joints, and Dorr type C: 16 joints) between January 2018 and December 2021. Clinical evaluations included Harris' hip score, blood loss, radiological evaluation, and bone mineral density changes. The postoperative Harris hip score was better than that preoperatively in Dorr types A, B, and C. Radiolucent lines were observed in two joints, but there was no evidence of subsidence greater than 3 mm or cortical hypertrophy. Stress shielding was found proximally in zones 1 and 7, while cancellous condensation was found distally in zones 3, 4, and 5. The postoperative bone mineral density of the femoral condyle was greater than that preoperatively in all zones, with the highest and lowest bone mineral density in zones 5 and 1, respectively, in all medullary configurations. In Dorr type C, there was no postoperative femoral pain or stem subsidence. Good bone remodeling also occurred, suggesting that POLARSTEM◊ may be a valuable option for hip arthroplasty in older adults.

Keywords: Hydroxyapatite coating, POLARSTEM◊, Dorr type classification, bone mineral density, radiographic images.

INTRODUCTION

In the near future, cases of osteoporosis-based hip disorders, such as femoral neck fractures and subchondral insufficiency fractures of the femoral head, are expected to increase due to declining birth rates and an aging population in many developed countries[1]. Problems with hip replacement using cementless stems for elderly patients include difficulty in ensuring sufficient strength for the initial fixation of the stem,[2] fractures occurring frequently,[3] and three stress shielding (SS) likely to occur after biological fixation[4]. Therefore, the use of bone-cemented stems is recommended for femurs with severe osteoporosis and large medullary cavities[5]. Total hip arthroplasty (THA) for Dorr type C remains controversial regarding the surgical technique and implant selection.

The full hydroxyapatite (HA) compaction stem, in which the entire stem is coated with HA, was introduced and has become widely used with good postoperative survival rates[6,7]. The unique feature of full HA-coated compaction stems is that instead of shaving the cancellous bone in the medullary cavity of the femur as a preliminary step for the placement of the cementless stem, the stem is placed by compressing the cancellous bone. This method can provide good fixation of the femur of older adults whose cortical bone may have become thin and fragile, with fewer complications, such as fractures. The CORAIL® stem (DePuy International Ltd, Leeds, UK), a typical full HA compaction stem, is considered a silent stem regarding radiological evaluation and clinical symptoms because it causes less SS and less postoperative thigh pain[8]. Meanwhile, some cases of stem subsidence have been reported,[9] and collared stems have been recommended. Subsequently, many full HA compaction stems with different HA thicknesses, stem lengths, and other characteristics were introduced, such as CORAIL®, which are thus far the most common. Another stem is the POLARSTEM◊ (Smith & Nephew Manufacturing AG, Aarau, Switzerland), which has a 180 µm open porous titanium plasma coating and a 50 µm HA coating treatment on the stem surface. Although the stem length is shorter than that of the CORAIL®, it has a larger proximal medial side for initial fixation. It is allowed to contact partially proximal cortical bone and is triple-tapered for good rotational stability. It also has a stronger taper angle to avoid distal fixation and does not necessarily require the use of a collar. This study aimed to evaluate the clinical outcomes, postoperative radiographic findings, and changes in bone mineral density (BMD) due to the femoral medullary morphology to identify the potential of this collarless stem for femurs with Dorr type C medullary morphology.

MATERIALS AND METHODS

Among the THAs performed at our hospital between January 2018 and December 2021, POLARSTEM◊ was used in 92 joints. This retrospective study included 50 patients (54 joints, three males and 47 females, mean age 68.4±10.1 years, mean height 154.2±9.4 cm, mean weight 57.0±8.6 kg, and mean body mass index 24.0±3.2 kg/m2) who were postoperatively evaluated for at least 24 months. A narrow medullary cavity with a Canal Flare Index (CFI) ≥4.7 was classified as Dorr type A, an intermediate cavity of 4.7 >CFI ≥3.0 was Dorr type B, and a wide medullary cavity of 3.0 >CFI was Dorr type C.10,11 The groups were as follows: 1) Dorr type A: 19 joints (1 male and 17 females), 2) Dorr type B: 19 joints (2 males and 16 females), and 3) Dorr type C: 16 joints (1 male and 14 females) (Table I). Thirty-six patients (38 joints, four males and 32 females) could not be assessed because they could not be followed up in the stipulated time period. The diagnostic distribution was as follows: osteoarthritis in 48 joints, osteonecrosis of the femoral head in 5, and rapidly destructive coxarthrosis in 1. All patients with osteoarthritis underwent preoperative planning using a 3D template of the Zed Hip 11.5.3 (LEXI Co., Ltd., Tokyo, Japan) and were operated on by the same hip surgeon using CT-based navigation (Stryker Navigation Cart System, Stryker Leibinger GmbH & Co. KG, Freiberg, Germany). All patients began rehabilitation for ambulation with full load-bearing a day after surgery.

The cups used were either G7 Osseo-Ti Shell (Zimmer-Biomet, Warsaw, Indiana, USA) or SQRUM (Kyocera, Kyoto, Japan). Polyethylene liners E1 (Biomet) and Aquala (Kyocera, Kyoto, Japan) were used, and Oxinium (Smith & Nephew, Inc., Tennessee, USA) ball heads were used in all cases.

Clinical outcomes were evaluated by the preoperative and 1-year postoperative Harris hip score (HHS). Preoperative, 6-month, 12-month, and 24-month postoperative frontal X-ray images of all hip joints were obtained. The following parameters were assessed: stem alignment, cortical hypertrophy, radiolucent line, subsidence (≥3 mm), SS (Engh's classification),[12] cancellous condensation (CC), and endosteal bone formation (EBF). Radiolucent lines, SS, and CC, were evaluated by Gruen's zone classification. BMD was measured by dual-energy X-ray absorptiometry (DEXA) using Hologic QDR-Discovery A (Hologic Inc., MA, USA) preoperatively and during the specific postoperative periods. Preoperatively, the femoral neck and trochanteric femur were measured, and postoperatively, the femur was divided into seven zones according to Gruen's zone classification[13]. Pre- and postoperative Harris hip scores (HHS), radiographs, and BMD were assessed by the same non-treatment doctor investigator.

This study was performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. This study was approved by the Ethics Committee of Oita University (approval number 1414, May 2018).

Continuous variables are expressed as mean±standard deviation. The Mann-Whitney and Kruskal-Wallis tests were used for comparisons between groups. SPSS Statistics Version 25 was used for statistical analysis, with $p < 0.05$ considered significant.

Table I. — Demographic data.

	Dorr type A	Dorr type B	Dorr type C
Number	19 (35.2%)	19 (35.2%)	16 (29.6%)
Age (years)	65.8±9.1	68.4±11.4	71.2±7.9
Sex (male/female)	1/17	2/16	1/14
Height (cm)	153.6±7.9	156.0±11.7	153.0±6.5
Body weight (kg)	57.4±7.9	57.8±7.6	54.4±11.2
BMI (kg/m^2)	24.3±3.2	23.9±3.1	23.6±2.9
CFI	4.86±0.27	3.87±0.37	2.84±0.17

BMI: Body Mass Index; CFI: Canal Flair Index.

RESULTS

Clinical Results

The blood loss averaged 250.2±106.4 ml, 276.3±102.3 ml, and 204.4±85.7 ml for Dorr types A, B, and C, respectively. One intraoperative complication, a fissure fracture of the calcar, occurred in Dorr type C. We performed cable fastening of the fissure fracture. Following the surgery, the patient commenced walking without load restrictions. The patient is progressing well, and no stem subsidence has been observed. There were no complications such as infection, dislocation, or deep vein thrombosis, and no patient had postoperative thigh pain. Postoperative hip pain relief and improved hip function were observed, and HHS was improved in all medullary forms compared to preoperative levels, as shown in Table II, with no significant differences.

Radiographic Evaluation

The neutral stem alignment was defined within ±2° in the frontal view and ±3° in the lateral view, and no alignment deviations were noted. The stem size groupings were 0–1: 5 joints (26.3%); 2–3: 11 joints (57.9%); 4–5: 3 joints (15.8%); and ≥6: 0 joints (0%) for Dorr type A. For Dorr type B, the groupings were 0–1: 5 joints (26.3%); 2–3: 7 joints (36.8%); 4–5: 3 joints (15.8%); and ≥6: 4 joints (21.1%). For Dorr type C, the groupings were 0–1: 2 joints (12.5%); 2–3: 7 joints (43.8%); 4–5: 6 joints (37.5%); and ≥6: 1 joint (6.3%).

There was one case each of subsidence in Dorr types B and C (1.7 mm and 1.5 mm) but no subsidence greater than 3 mm in either of the medullary forms (Table III). SS was Grades 1, 2, and 3 in 9 (16.7%), 12 (22.2%), and 8 (14.8%) cases, respectively, at 24 months postoperatively (Figure 1). SS with Grade 3 at 24 months postoperatively was observed in Dorr type A in 3 (15.8%) cases, Dorr type B in 2 (10.5%) cases, and Dorr type C in 3 (18.8%) cases. In distal zones 3 to 5, there was no SS in any of the medullary forms, and CC was more common (Figure 2). EBF was observed in 25 (46.3%), 34 (63.0%), and 43 (79.6%) patients at 6, 12, and 24 months, respectively. Regardless of the medullary form, cases with partial EBF at 6 and 12 months postoperatively tended to spread circumferentially at 24 months. A longitudinal radiograph of a Dorr type C case is presented in Figure 3.

Table II. — Clinical results.

		Dorr type A	Dorr type B	Dorr type C	p-value
Thigh pain		-	-	-	
	Preoperative	45.8±13.6	49.8±15.0	46.9±11.1	0.572
HHS (points)	12 months postoperative	94.6±5.1	93.3±11.2	96.5±0.41	0.890

HHS: Harris hip score.

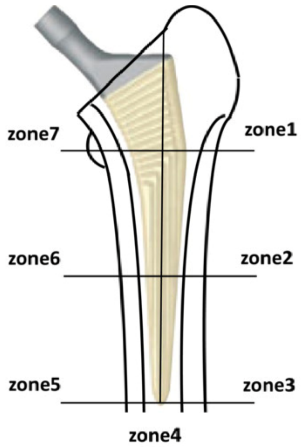
Table III. — Radiographic evaluation.

	Postoperative period	Dorr type A	Dorr type B	Dorr type C	P-value
Subsidence (≥3mm)		0	0	0	
Cortical hypertrophy		0	0	0	
Radiolucent line	6 months	0	0	0	
	12 months	0	1	1	
	24 months	0	1	1	
Stress shielding	6 months	63.2 (12/19)	57.9 (11/19)	56.3 (9/16)	
% (joint)	12 months	73.7 (14/19)	63.2 (12/19)	68.8 (11/16)	
	24 months	78.9 (15/19)	68.4 (13/19)	75.0 (12/16)	0.110
Cancellous condensation	6 months	47.4 (9/19)	42.1 (8/19)	43.8 (7/16)	
%(joint)	12 months	52.6 (10/19)	57.9 (11/19)	62.5 (10/16)	
	24 months	52.6 (10/19)	63.2 (12/19)	75.0 (12/16)	0.942

zone 7	6 months	12 months	24 months
Dorr type A	31.6%	47.4%	57.9%
Dorr type B	31.6%	37.8%	48.4%
Dorr type C	43.8%	62.5%	56.3%

zone 6	6 months	12 months	24 months
Dorr type A	5.3%	5.3%	10.5%
Dorr type B	5.3%	10.5%	10.5%
Dorr type C	6.3%	18.8%	6.3%

zone 5	6 months	12 months	24 months
Dorr type A	0%	0%	0%
Dorr type B	0%	0%	0%
Dorr type C	0%	0%	0%



zone 1	6 months	12 months	24 months
Dorr type A	42.1%	57.9%	63.2%
Dorr type B	42.1%	47.4%	52.6%
Dorr type C	43.8%	50%	62.50%

zone 2	6 months	12 months	24 months
Dorr type A	0.0%	0.0%	10.5%
Dorr type B	5.3%	5.3%	5.3%
Dorr type C	0.0%	6.3%	12.5%

zone 3	6 months	12 months	24 months
Dorr type A	0%	0%	0%
Dorr type B	0%	0%	0%
Dorr type C	0%	0%	0%

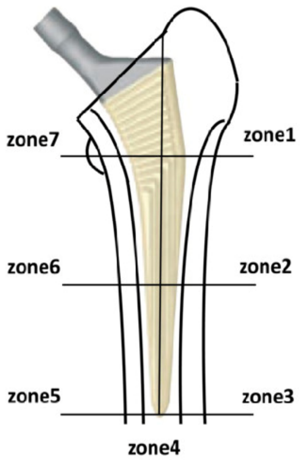
zone 4	6 months	12 months	24 months
Dorr type A	0%	0%	0%
Dorr type B	0%	0%	0%
Dorr type C	0%	0%	0%

Fig. 1 — Radiographic evaluation of stress shielding: It is more common proximally in zones 1 and 7 than distally in zones 3, 4, and 5.

zone 7	6 months	12 months	24 months
Dorr type A	0%	0%	0%
Dorr type B	0%	0%	0%
Dorr type C	0%	0%	0%

zone 6	6 months	12 months	24 months
Dorr type A	5.3%	5.3%	5.3%
Dorr type B	5.3%	5.3%	10.5%
Dorr type C	6.3%	18.8%	18.8%

zone 5	6 months	12 months	24 months
Dorr type A	31.6%	36.8%	52.6%
Dorr type B	26.3%	42.1%	52.6%
Dorr type C	31.3%	50.0%	62.5%



zone 1	6 months	12 months	24 months
Dorr type A	0%	5.3%	5.3%
Dorr type B	5.3%	5.3%	0%
Dorr type C	0%	0%	0%

zone 2	6 months	12 months	24 months
Dorr type A	10.5%	15.80%	15.8%
Dorr type B	10.5%	10.5%	15.8%
Dorr type C	6.3%	6.3%	12.5%

zone 3	6 months	12 months	24 months
Dorr type A	36.8%	42.1%	52.6%
Dorr type B	31.6%	47.4%	63.2%
Dorr type C	18.8%	43.8%	56.3%

zone 4	6 months	12 months	24 months
Dorr type A	10.5%	21.1%	36.8%
Dorr type B	10.5%	36.8%	42.1%
Dorr type C	25.0%	31.3%	25.0%

Fig. 2 — Radiographic evaluation of cancellous condensation: It occurs distally in zones 3, 4, and 5 and not proximally in zones 1 and 7.

BMD

BMD was low proximally in zones 1 and 7 and high in zones 3 to 5 (Table IV). It increased over time in zones 3, 4, and 5 and decreased in zone 1 and 7. In all zones, the bone BMD at 6, 12, and 24 months postoperatively was greater than that of the preoperative trochanteric femur (Figure 4). In zone 4, all medullary spaces showed an increasing trend in BMD at 24 months postoperatively compared to 6 months postoperatively, whereas in zone 7, they showed a decreasing trend (Figure 5a-c).

DISCUSSION

In this study, the short-term POLARSTEM◊ results indicated no postoperative thigh pain and improved HHS. SS was observed proximally in zones 1 and 7, while CC was observed distally in zones 3 to 5. In zone 4, EBF, in which stiffened bone covers the entire distal periphery of the stem, increased over time. In all zones, BMD was greater postoperatively than in the preoperative trochanteric femur. Dorr type C was nearly equal to Dorr types A and B in clinical

Fig. 3 — Representative case of an 81-year-old female with Dorr type C: Postoperatively, there is no stem subsidence. There is wide cancellous condensation and an increased cortical bone width in the middle distal region around the stem.

Table IV. — Progress of postoperative bone density at each zone according to the Dorr type.

		Dorr type A	Dorr type B	Dorr type C	P-value
Preoperative	Femoral neck	0.70	0.70	0.65	
	Trochanteric femur	0.57	0.55	0.50	
6 months postoperative (g/cm^2)	zone1	0.63±0.14	0.61±0.14	0.55±0.09	0.231
	zone2	1.23±0.24	1.20±0.22	1.05±0.18	0.054
	zone3	1.52±0.19	1.50±0.17	1.34±0.20	0.017
	zone4	1.54±0.20	1.49±0.22	1.26±0.20	0.001
	zone5	1.54±0.18	1.59±0.17	1.44±0.19	0.089
	zone6	1.23±0.17	1.23±0.21	1.05±0.23	0.024
	zone7	0.84±0.24	0.90±0.33	0.73±0.23	0.277
12 months postoperative (g/cm^2)	zone1	0.59±0.09	0.62±0.13	0.56±0.09	0.377
	zone2	1.21±0.25	1.23±0.19	1.13±0.19	0.404
	zone3	1.51±0.21	1.54±0.17	1.36±0.18	0.025
	zone4	1.56±0.20	1.51±0.22	1.28±0.19	0.001
	zone5	1.57±0.20	1.58±0.20	1.49±0.19	0.424
	zone6	1.23±0.23	1.20±0.25	1.02±0.28	0.050
	zone7	0.78±0.25	0.85±0.32	0.72±0.28	0.454
24 months postoperative (g/cm^2)	zone1	0.60±0.08	0.60±0.11	0.56±0.07	0.340
	zone2	1.1 9±0.25	1.19±0.15	1.05±0.19	0.109
	zone3	1.51±0.19	1.53±0.13	1.39±0.22	0.087
	zone4	1.56±0.21	1.50±0.22	1.28±0.19	0.001
	zone5	1.59±0.17	1.63±0.28	1.48±0.31	0.239
	zone6	1.27±0.19	1.20±0.20	1.05±0.19	0.041
	zone7	0.76±0.23	0.84±0.29	0.66±0.20	0.136

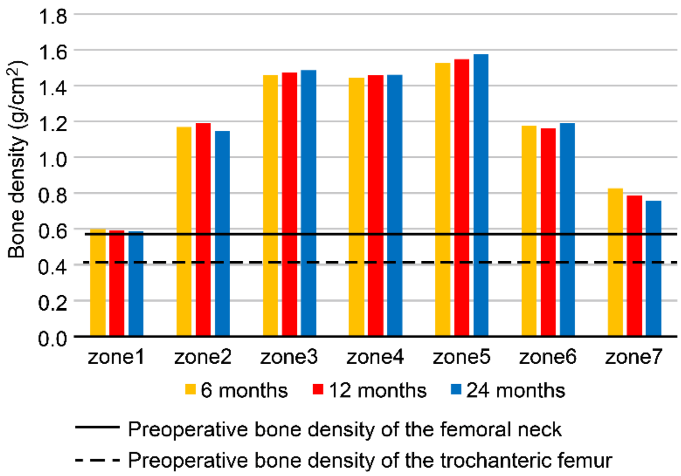


Fig. 4 — Bone density changes in each zone at 6, 12, and 24 months postoperatively in all patients: Bone mineral density increases over time in zones 4 and 5 and decreases over time in zone 7. All zones show an increase in bone density over the preoperative trochanteric femur.

outcomes and radiological findings, but BMD in zones 1 and 7 decreased, while that in Dorr types A and C increased distal to the stem over time.

Vidalain et al. reported that HHS improved from an average preoperative score of 41.3 to 85.1 during a 20-year follow-up with the CORAIL® stem as a 'silent' hip, with no unexplained thigh or groin pain[14]. In the present study, there was no postoperative thigh pain, and HHS improved compared to preoperatively in all medullary forms.

A high probability of postoperative stem subsidence was reported in patients with CORAIL® collarless stems[9,15]. Demey et al. reported that collared stems are more resistant to subsidence and fractures and safer in cases of poor bone quality owing to a better initial fixation.16 In collarless POLARSTEM◊, no stem subsidence greater than 3 mm or loss of significant leg length were observed in this study. The effectiveness of collars, including that for revision surgery, remains controversial,[16,17] and the results of no subsidence in the collarless POLARSTEM◊ could be a valuable discovery in the development of the full HA compaction stem.

SS is femoral atrophy, likely due to the load transfer distal to the stem[12]. A study using the CORAIL® stem reported that 83% showed a radiographic silent hip with no bone changes due to contact with the preserved cancellous bone around the entire stem surface, which eventually led to extensive fixation[14]. The POLARSTEM◊ showed Grade 2 SS in zones 1 and 7, while CC was more common distally in zones 3 to 5. Since BMD in zones 1 and 7 was comparable to the preoperative BMD, the proportion of SS in the proximal region was possibly relatively higher due to the contrast with the distal region. Unlike fit-and-fill or tapered-wedge stems[18,19] the EBF was fixed over a wide area, from mid-distal to distal to the stem. EBF has been reported to cause bone union in the HA coating area. A radiological examination of CORAIL® stems also showed endosteal remodeling in 100% at one year postoperatively[20]. EBF found distal to the stem is considered a good osteogenic reaction involved in the stem's stability. EBF distal to the POLARSTEM◊ increased over time, with medial EBF present at six months and circumferential EBF present at 12 and 24 months postoperatively.

Karachalios et al. investigated the change in BMD of the calcar at 12–24 months postoperatively with four cementless stems, including CORAIL®. They reported that while the other three types of BMD decreased significantly at two years postoperatively, the CORAIL® stem showed the lowest BMD of 8%, with no significant difference[21]. Vidalain reported a decrease in calcar BMD in 15% of the 20-year postoperative results for the CORAIL® stem[14]. In the present study with POLARSTEM◊, all zones, regardless of the medullary form, had increased postoperative BMD compared to the preoperative BMD in the trochanteric femur. In those cases that were followed up 24 months postoperatively, BMD increased in distal zones 3, 4, and 5 and decreased in proximal zones 1 and 7.

A comparison by Dorr classification showed a similar trend, with a nearly flat or increasing trend in zone 4 and a decreasing trend in zone 7. In all medullary geometries, sclerotized bone on the distal side of the stem increased over time, increasing BMD and contributing to stem stabilization. This was thought to

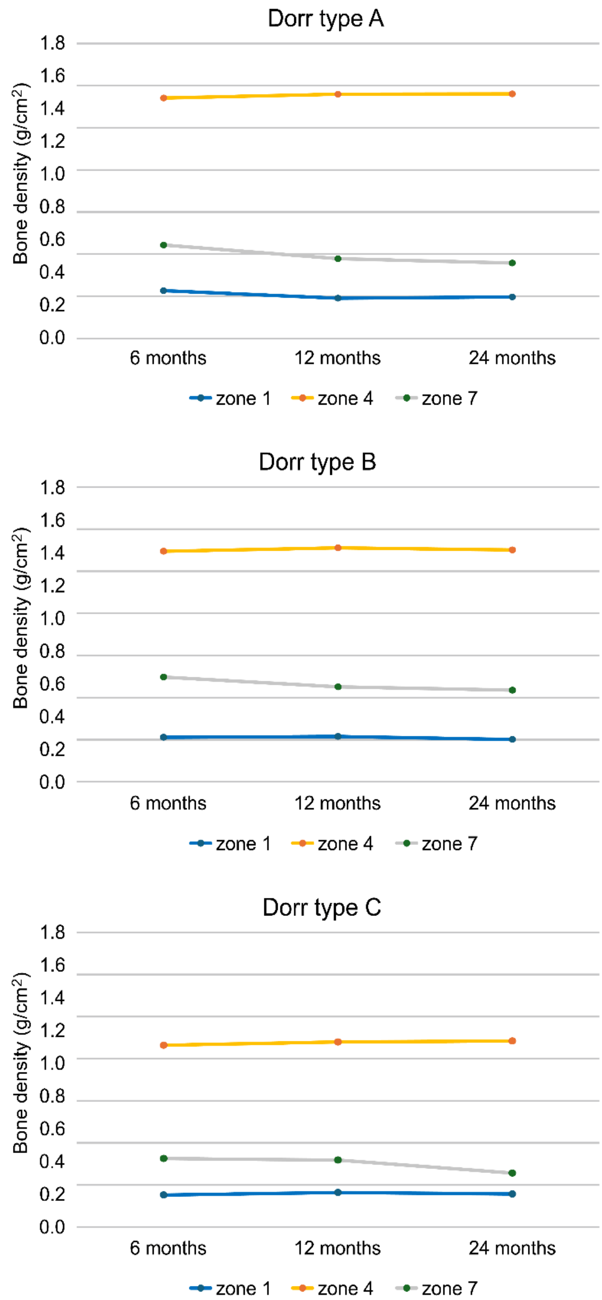


Fig. 5 — Bone density changes by the medullary form in zones 1, 4, and 7 in patients followed up 24 months postoperatively: In zone 4, all medullary spaces showed an increasing trend in BMD at 24 months postoperatively compared to 6 months postoperatively, whereas those in zone 7 showed a decreasing trend.

have caused progressive SS proximally and decreased BMD.

Usually, a large femoral medullary cavity forces the selection of a larger-sized stem[22]. In the present study, a relatively larger size was also selected for Dorr type C compared to that of Dorr types A and B. In Dorr type C, the preoperative BMD at the femoral neck and trochanter area was lower than that in Dorr types A and B. Postoperatively, BMD in zone 7 decreased for up to 24 months. However, clinical results, including symptoms, stem subsidence, postoperative radiographic changes around the stem, and increased BMD around the distal midline of the stem, were almost the same as in Dorr type B. This indicates that this stem, which compresses and fixes the cancellous bone, can provide good initial fixation and short-term postoperative results even in Dorr type C, where osteoporosis is present.

This study's limitations included no comparison with other stems, no systematic evaluation of bone metabolism, a small number of cases, and insufficient long-term observation, particularly clinical evaluations at 6 and 24 months. In addition, postoperative radiographic evaluation was limited to frontal views, and BMD measurements were two-dimensional, with no accurate three-dimensional bone strength assessment. At our institution, only frontal views were used to evaluate femoral radiographs because postoperative BMD changes around the stem can only be measured on frontal views. It may be useful to evaluate lateral images to more accurately validate bone changes around the femoral stem.

The collarless POLARSTEM◊ that allowed contact with the femoral cortical bone proximal to the stem showed no postoperative thigh pain or stem subsidence, no significant SS, and extensive osseointegration in the middle and distal areas. Meanwhile, SS was observed markedly in zones 1 and 7. These trends did not differ according to the medullary form, and the POLARSTEM◊ is also expected to be an effective option for Dorr type C. Further studies with a larger number of patients and a longer follow-up period are needed to better understand this stem's characteristics.

Acknowledgments: We would like to thank Editage (www.editage.com) for the English language editing. No external funding was received for the study.

Funding: None.

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

REFERENCES

1. Orimo H, Yaegashi Y, Hosoi T, Fukushima Y, Onoda T, Hashimoto T, et al. Hip fracture incidence in Japan: Estimates of new patients in 2012 and 25-year trends. Osteoporos Int. 2016 May;27(5):1777-1784.
2. Aro HT, Alm JJ, Moritz N, Mäkinen TJ, Lankinen P. Low BMD affects initial stability and delays stem osseointegration in cementless total hip arthroplasty in women: a 2-year RSA study of 39 patients. Acta Orthop. 2012 Apr;83(2):107-114.
3. Tsubosaka M, Hayashi S, Hashimoto S, Takayama K, Kuroda R, Matsumoto T. Patients with a Dorr type C femoral bone require attention for using a Summit cementless stem: Results of total hip arthroplasty after a minimum follow-up period of 5 years after insertion of a Summit cementless stem. J Orthop Sci. 2018 Jul;23(4):671-675.
4. Rodriguez-Buitrago A, Attum B, Cereijo C, Yusi K, Jahangir AA, Obremskey WT. Hemiarthroplasty for Femoral Neck Fracture. JBJS Essent Surg Tech. 2019 Apr;9(2):e13.
5. Ahmad A, Mirza Y, Evans AR, Teoh KH. A Comparative Study Between Uncemented and Hybrid Total Hip Arthroplasty in Octogenarians. J Arthroplasty. 2018 Dec;33(12):3719-3723.
6. Froimson MI, Garino J, Machenaud A, Vidalain JP. Minimum 10-year results of a tapered, titanium, hydroxyapatite-coated hip stem: an independent review. J Arthroplasty. 2007 Jan;22(1):1-7.
7. Hallan G, Lie SA, Furnes O, Engesaeter LB, Vollset SE, Havelin LI. Medium- and long-term performance of 11,516 uncemented primary femoral stems from the Norwegian arthroplasty register. J Bone Joint Surg Br. 2007 Dec;89(12):1574-1580.
8. Varnum C. Outcomes of different bearings in total hip arthroplasty - implant survival, revision causes, and patient-reported outcome. Dan Med J. 2017 Mar;64(3):B5350.
9. Selvaratnam V, Shetty V, Sahni V. Subsidence in Collarless Corail Hip Replacement. Open Orthop J. 2015 May;9:194-197
10. Noble PC, Alexander JW, Lindahl LJ, Yew DT, Granberry WM, Tullos HS. The anatomic basis of femoral component design. Clin Orthop Relat Res. 1988 Oct;235:148-165.
11. Dorr LD, Absatz M, Gruen TA, Saberi MT, Doerzbacher JF. Anatomic Porous Replacement hip arthroplasty: first 100 consecutive cases. Semin Arthroplasty. 1990 Jul;1(1):77-86.
12. Engh CA, Bobyn JD, Glassman AH. Porous-coated hip replacement. The factors governing bone ingrowth, stress shielding, and clinical results. J Bone Joint Surg Br. 1987 Jan;69(1):45-55.
13. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res. 1979 Jun;141:17-27.
14. Vidalain JP. Twenty-year results of the cementless Corail stem. Int Orthop. 2011 Feb;35(2):189-194
15. Al-Najjim M, Khattak U, Sim J, Chambers I. Differences in subsidence rate between alternative designs of a commonly used uncemented femoral stem. J Orthop. 2016 Jul;13(4):322-326.
16. Demey G, Fary C, Lustig S, Neyret P, si Selmi T. Does a collar improve the immediate stability of uncemented femoral hip stems in total hip arthroplasty? A bilateral comparative cadaver study. J Arthroplasty. 2011 Dec;26(8):1549-1555.
17. Lamb JN, Baetz J, Messer-Hannemann P, Adekanmbi I, van Duren BH, Redmond A, et al. A calcar collar is protective against early periprosthetic femoral fracture around cementless femoral components in primary total hip arthroplasty: a registry study with biomechanical validation. Bone Joint J. 2019 Jul;101-B(7):779-786.
18. Hu H, Liu Z, Liu B, Ding X, Liu S, Wu T, et al. Comparison of Clinical Outcomes, Radiological Outcomes and Bone Remodeling Outcomes Between Proximal Coated Single-Wedge New Stem and Full Coated Dual-Wedge Classic Stem in 1-Stage Bilateral Total Hip Arthroplasty. Med Sci Monit. 2020 Jan;26:e921847.
19. Hirata Y, Inaba Y, Kobayashi N, Ike H, Fujimaki H, Saito T. Comparison of mechanical stress and change in bone mineral density between two types of femoral implant using finite element analysis. J Arthroplasty. 2013 Dec;28(10):1731-1735.
20. Bakkai A, Ryan P, Goga IE. Tapered uncemented HA-coated femoral stems: a radiological study. SA Orthop J. 2017 Sep;16(3):27-30.
21. Karachalios T, Tsatsaronis C, Efraimis G, Papadelis P, Lyritis G, Diakoumopoulos G. The long-term clinical relevance of calcar atrophy caused by stress shielding in total hip arthroplasty: a 10-year, prospective, randomized study. J Arthroplasty. 2004 Jun;19(4):469-475
22. Takigami I, Ito Y, Matsumoto K, Terabayashi N, Miyagawa T, Akiyama H. Mid-Term Results of the SL-PLUS Femoral Prosthesis The Influence of Femoral Bone Type. Bull Hosp Jt Dis (2013). 2017 Apr;75(2):128-133